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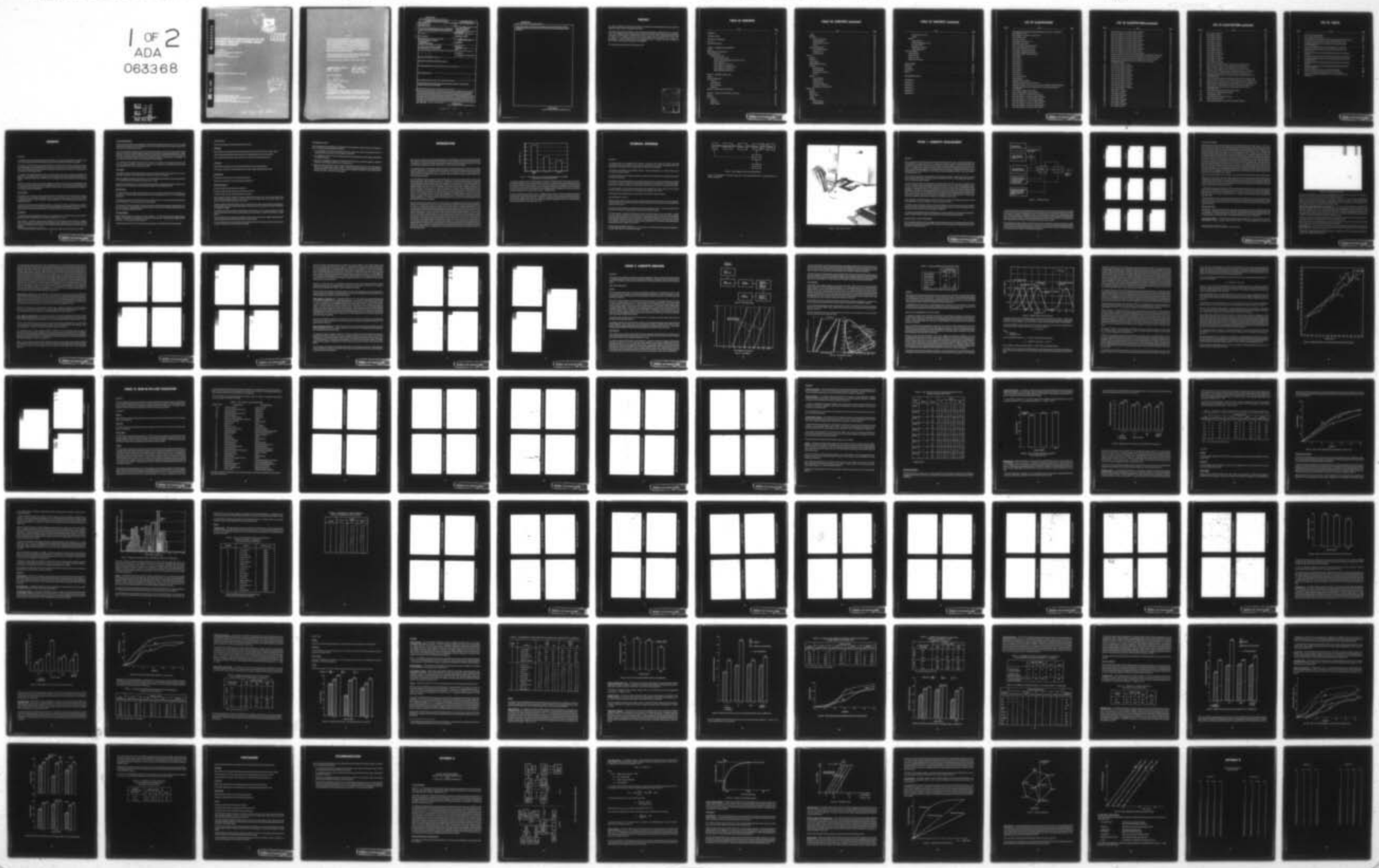

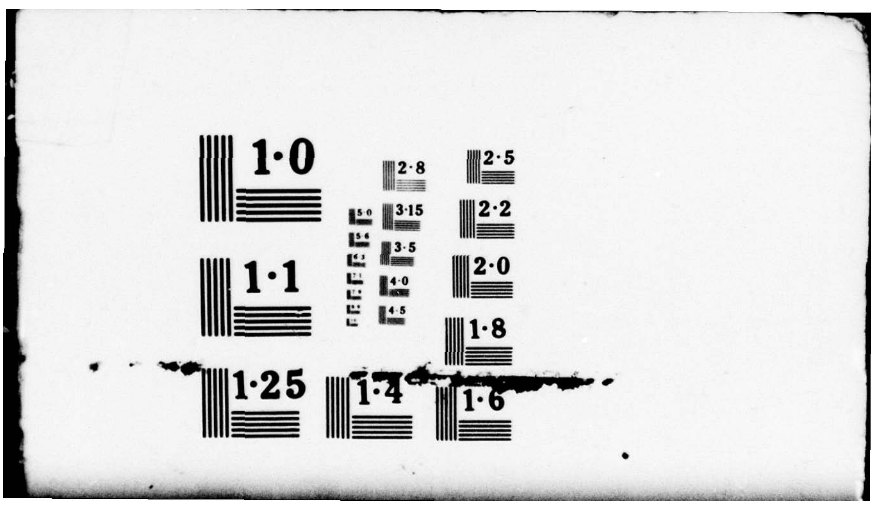
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THE EFFECTS OF PSEUDO-COLOR ON THE APPARENT DISPLAYED DYNAMIC RANGE OF RADAR IMAGERY

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30 DECEMBER 1977

Final Report for Period 1 November 1975 - 30 July 1977

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Synthetic aperture radar (SAR) has a dynamic range much greater than displays used to present the radar ground map video to human observers. This study program was undertaken to explore pseudo-color encoding of radar/display transfer functions by which the information contained within the large SAR dynamic range could be presented to human observers. The codes developed were evaluated by measuring operator performance improvement compared with a monochromatic code for a strategic, tactical, and reconnaissance mission task. The pseudo-color codes offered no improvement in the strategic mission task; however, the tests indicated that the developed pseudo-color codes may improve

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operator performance in the tactical and reconnaissance tasks. These codes appear particularly promising when used with radar resolutions where the target returns are clearly above the clutter background.

PREFACE

The research reported in this document focuses on the effects of color coding radar imagery to extend the apparent dynamic range of the displayed radar scene.

The research program was initiated by the Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio. The investigations were conducted between November 1975 and August 1977 at Goodyear Aerospace Corporation, Arizona Division, Litchfield Park, Arizona, under Contract No. F33615-76-C-1242, Project No. 7622. Mr. G.L. LaMonica served as the Principal Investigator and was assisted by Mr. J.D. Greer. The responsibility of USAF Project Engineer was undertaken by Mr. F.P. Johnson and later transferred to Mr. E. Zelnio of the Avionics Laboratory (AFAL/RWM-5).

This final report was submitted on 30 December 1977.

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SUMMARY

GENERAL

A research program was undertaken to determine whether or not color coding results in an apparent extension in dynamic range of the CRT displayed radar scene over the standard monochromatic display.

The program was divided into three separate phases. The objective of Phase I was to develop a number of pseudo-color codes, *i.e.*, step wedges, which had potential for improving radar operator performance in SAC, TAC, and RECCE tasks. Primary emphasis in generating codes focused on matching the characteristics of the radar, visual, and display systems.

An analysis of the codes developed in Phase I was conducted during Phase II to assess their feasibility with regard to cost, complexity, ease of implementation, and potential for enhancing operator performance. In addition, a Goodyear-USAF team reviewed all of the developed codes and selected those to be empirically tested.

Phase III was a series of man-in-the-loop tests designed to compare the utility of the two selected color codes (C1 and C2) versus standard black and white (BW) imagery in SAC, TAC, and RECCE task situations. The procedures and results of these tests are individually summarized in the following paragraphs, followed by the conclusions and recommendations.

SAC Procedure

For the SAC test, 27 targets or offset aimpoints (OAPs) were identified on nine separate 40-foot-resolution FLAMR radar scenes. Individual target/OAP folders were provided each subject and contained a vertical photograph with target or OAP annotated, a photo enlargement of the immediate target area, and a list of target location cues.

The subject reviewed the briefing materials and when he was ready, the 2-NMI by 2-NMI radar scene was displayed in one of the three codes. When he reported and designated the target/OAP, his accuracy and time were recorded. This procedure was followed for 27 targets for each of the nine subject/observers.

SAC Results

The subjects correctly detected 80.2 percent of the target/OAPs with C1; 86.4 percent with C2; and 87.7 percent with BW. The differences are not statistically significant ($p > 0.19$*).

Color code No. 1 produced a median correct response time of 12.8 seconds; color code No. 2 a response time of 11.8 seconds, and the black and white standard a median response time of 11.0 seconds. The rates at which the target/OAPs were detected with the various codes were compared and found to be nearly identical.

*$p > 0.19$ is the probability of being incorrect in stating that a difference exists between 87.7 and 80.2.

TAC/RECCE Procedure

Twelve tactical-type targets were embedded in twelve 20-foot FLAMR radar scenes. Each of the 12 subjects was tested on six targets in the TAC evaluation and six in the RECCE situation. Each subject observed a different set of six targets under each task.

In the TAC evaluation the subject was informed of the exact target, *e.g.,* convoy, and a target folder included sketches of the varieties of target signatures expected. He also was given the general background, *e.g.,* urban/industrial, of the target. When the subject was ready, the radar scene was displayed and he attempted to find the target of interest and counted the number of vehicles, weapons, or active positions in the target. The accuracy of his response, detection time, and target count was recorded.

In the RECCE test the subject was instructed to find one of the targets on the target list, classify it, and count the vehicles, weapons, or positions. The accuracy of the detection and classification, the detection plus classification time, and the count was recorded.

TAC Results

The subjects correctly detected 79.2 percent, 75 percent, and 66.7 percent of the targets with C1, C2, and BW codes, respectively, with median detection times of 5.9, 10.1, and 8.1 seconds.

While no statistical difference was found, the rate at which targets were detected was nominally highest for C1, with BW producing a rate slightly higher than C2 ($p > 0.28$).

Subjects counted 78.9 percent of the C1 coded individual vehicles, weapons, and positions without error, 50 percent of the C2 coded targets, and 68.8 percent coded with the standard BW code.

RECCE Results

The subject observers accurately detected 75 percent of the C1 targets, 70.8 percent of the C2 targets, and 54.2 percent of the BW targets. Median detection times for these codes were 14.1, 17.5, and 17.9 seconds, respectively.

Acquisition rates were very similar through the first 10 seconds, with the C1 code achieving a slightly higher rate of detection than the other codes from 15 to 30 seconds.

The accuracy with which the subjects counted the weapons, vehicles, and positions of targets varied. Subjects counted the C1 targets without error 55.6 percent of the time. Code C2 produced 70.6-percent count accuracy, and BW produced 46.2 percent.

TAC versus RECCE

Subjects detected about five percent more TAC targets than RECCE targets when the image was color coded, *i.e.,* 78 percent versus 73 percent, and about 12.5 percent more TAC than RECCE targets in black and white, *i.e.,* 67.7 percent versus 54.2 percent.

Target detection rates in the TAC test were clearly above those in the RECCE test for all codes tested.

CONCLUSIONS

From the test results the following conclusions were drawn:

SAC Study

Color does not improve target/OAP recognition performance with 40-foot resolution radar imagery

Color and achromatic display codes produce rates of target detection which are very similar

Color-coded 40-foot resolution radar images do not enhance SAC operator performance.

TAC Study

Pseudo-color has potential for increasing target detection over achromatic displays

Color codes constructed to facilitate detection can produce higher target acquisition rates.

RECCE Study

Pseudo-color has potential for enhancing target detection

Pseudo-color has potential for enhancing target classification.

General Conclusions

Knowing a target's identity facilitates its detection

Knowing a target's identity reduces the time required to find it

Knowing a target's identity facilitates target count accuracy

Color coding has a higher potential for enhancing operator performance with radar imagery having better than the 20-foot resolution utilized in this study since there is a higher signal-to-clutter ratio where a more definite threshold between targets and clutter exists

Using low color/low brightness contrast colors for coding the lower intensity terrain features, and high color/high brightness contrast for coding targets appears to present the best color/brightness contrast combination for coding radar images

It is better to use colors to which the visual system is less sensitive, *e.g.*, blues, reds, and browns, for terrain feature coding and colors to which the visual system is most sensitive, *e.g.*, greens and yellows, for target coding

Pure saturated colors have maximum potential use when they are used at levels slightly above high clutter values to facilitate discrimination among medium-to-strong targets.

A system designed to use color should provide a radar gain control at the display to permit the operator to maximize the potential of the color code(s) employed.

RECOMMENDATIONS

From the aforementioned results and conclusions and from observations made throughout the research program, the following recommendations are offered:

1. This investigation has identified a potential for pseudo-colored radar imagery which deserves further investigation before operational recommendations can be made.
2. An investigation similar to the one reported here should be conducted with radar imagery having better than 20-foot resolution.
3. Pseudo-color investigations should be considered that employ radar resolutions capable of producing individual vehicle/weapon classification-type image quality.
4. Observing radar images with some of the color codes tested indicates that color may reduce operator fatigue. The colored imagery appears "easier" to view. Adding the dimensions of hue and saturation may add information which can result in less strain than ordinarily produced in a visual system searching black and white. This should be investigated.

INTRODUCTION

The past several years have seen major advancements in the development of high-resolution synthetic array radar systems. The ability to obtain sufficient resolution for the recognition of a variety of military targets, the capability for long stand-off range, the all-weather capability, and the increased survivability of the radar is ample reason for greater utilization of SAR sensors in future strike aircraft systems.

A considerable amount of laboratory operator performance research dealing with synthetic array mapping radars for application to reconnaissance image interpretation and real-time airborne strike systems has been conducted during the past several years. For the most part, this research has been oriented towards parametric studies of most cost-sensitive system variables, types of briefing and reference material aids, or general performance estimation.

From the beginning, the key questions have centered about radar front-end requirements, the radar processing requirements, and the display necessary for presentation of radar ground map data to the operator to assure successful target acquisition and mission success. The requirements for an all-weather sensor are mission-dependent, and span from strategic deep interdiction to tactical close air support missions. In the strategic mission, there is an "a priori" knowledge of the target's exact location, enabling a contextual recognition on behalf of the operator. In the event the target is a "no-show," various offset aimpoints can be used for targeting in lieu of the actual target. Obviously, this mode of operation is contingent upon a very accurate and calculated relationship of the target with respect to its background. In the case of the tactical mission, it is very likely that only a rough area knowledge of the target's location exists. This forces the operator to depend more heavily on actual target signal-to-clutter or equivalently, immediate area contrast yielding conspicuity. All of these efforts have concentrated on the sensor and mission parameters, giving little attention to display techniques.

Synthetic array ground mapping radars have a large dynamic range. Measurements made from existing SAR systems show this dynamic range to be in excess of 60 dB from shadow (no signal) to peak signal returns, see Figure 1. Existing display systems, whether they be light tables for viewing processed radar film or monochromatic cathode-ray tubes for displaying real-time processed radar data, are limited in dynamic range to about 30 dB at best. Past and present SAR system designs and flight test systems have typically: (1) compressed radar dynamic range at the high end such that the high radar signal intensities, *i.e.*, the intervals from 30 to 60 dB are not discriminable from other targets which fall within this intensity range; (2) clipped radar dynamic range at the high and/or low ends such that these intensities are either not displayed or are displayed at a level wherein discriminance between specific radar returns and many other radar returns is not possible; or (3) displayed the full radar dynamic range in such a way so as to limit the possibility of extracting contextual detail needed in acquiring many targets, *e.g.*, allotting 3 dB per gray shade and compressing 60 dB of information onto a 20 dB display, thus losing the fine granularity needed for contextual recognition of many targets. It is expected that any of the above three approaches could substantially reduce operator performance from that achievable with a display technique portraying the full dynamic range in a finely granulated form.

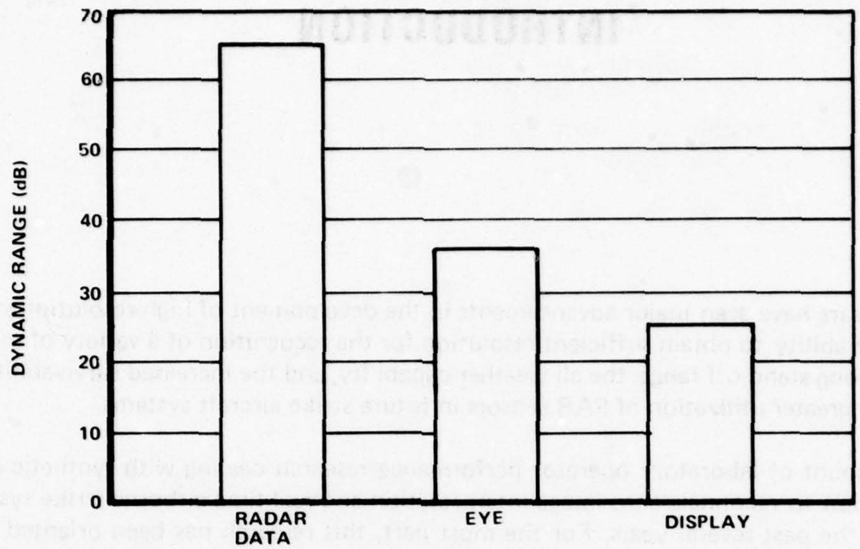


Figure 1 – Relationship of the Dynamic Range Capabilities of the Radar, Visual System, and Cathode-Ray Tube

It is generally accepted that the instantaneous monochromatic dynamic range of the human visual system, under ideal conditions, is about 35 dB, as shown in Figure 1. This capability is rarely achieved, except in a very well-controlled ambient environment. It certainly is not achievable in an operational environment where the operator must view several different scenes or displays and does not have sufficient time to dark-adapt to any one. The result is that the eye adapts to the average brightness of the objects he is monitoring, making the useful display dynamic range less than the ideal – possibly 25 dB.

The primary purpose of this research was to investigate the use of color to present the radar information and determine if enhanced radar operator performance could be achieved over the standard achromatic or monochromatic display. Since color has, in addition to brightness, the extra dimensions of hue and saturation, it was hypothesized that more radar information could be displayed in color than in black and white and improved operator performance would result.

TECHNICAL APPROACH

GENERAL

The research plan for this program was to develop a number of color codes* from which a few codes demonstrating maximum potential for increasing the apparent dynamic range of the displayed radar could be selected for comparison with the standard black and white CRT presentation.

The program was divided into three separate phases: I. Concepts Development, II. Concepts Analysis, and III. Man-in-the-Loop Evaluation.

The purpose of Phase I was to generate strategies, philosophies, and rationales for color codes and to formulate some of these codes.

During Phase II the codes generated during concepts development were analyzed and evaluated with respect to cost and complexity, feasibility of operational implementation, and potential for improving operator performance. This phase was used as a filtering process to assist in selecting codes for the laboratory evaluation.

The codes selected in the concepts analysis phase were subjected to a human factors, man-in-the-loop evaluation (Phase III) to determine if color coding enhances operator performance.

These phases, briefly described above, are discussed in more detail in sections following.

COLOR DISPLAY FACILITY

Figure 2 is a block diagram of the color display facility designed to accept 8-bit data from a 7-track, computer-compatible tape unit. Amplitude weighting is available through the use of read-only memories (ROMs) that reduce the data to 6 bits.

The scan converter consists of the necessary buffers and shift registers to store an image of 512 by 512 pixels, 6 bits deep. This step can be displayed as a 6-bit black and white CRT image.

The color encoder is capable of generating any color (hue and saturation) to any input level. It accepts 5-bit input data and provides 5-bit output data to each of the guns in the color monitor. The color encoder is capable of being programmed by a minicomputer or digi-switches located on the front panel. The encoder is also capable of generating a color bar pattern for monitoring the programmed color code. Also included in the encoder is a display linearization function that will compensate for the nonlinear display characteristics (brightness versus grid voltage) of the monitor.

*A color code is defined as a discrete set of hue, saturation, and brightness values selected and assigned to the 4-bit (16-level) or 5-bit (32-level) step wedge.

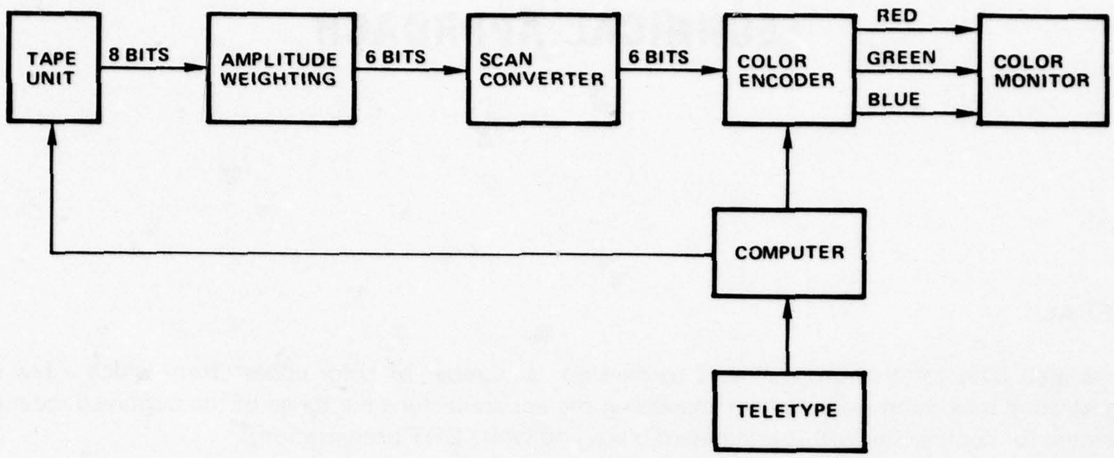


Figure 2 – Block Diagram of the Color Display System

Figure 3 is a photograph of the display equipment. A more detailed description of the equipment is contained in Appendix A.

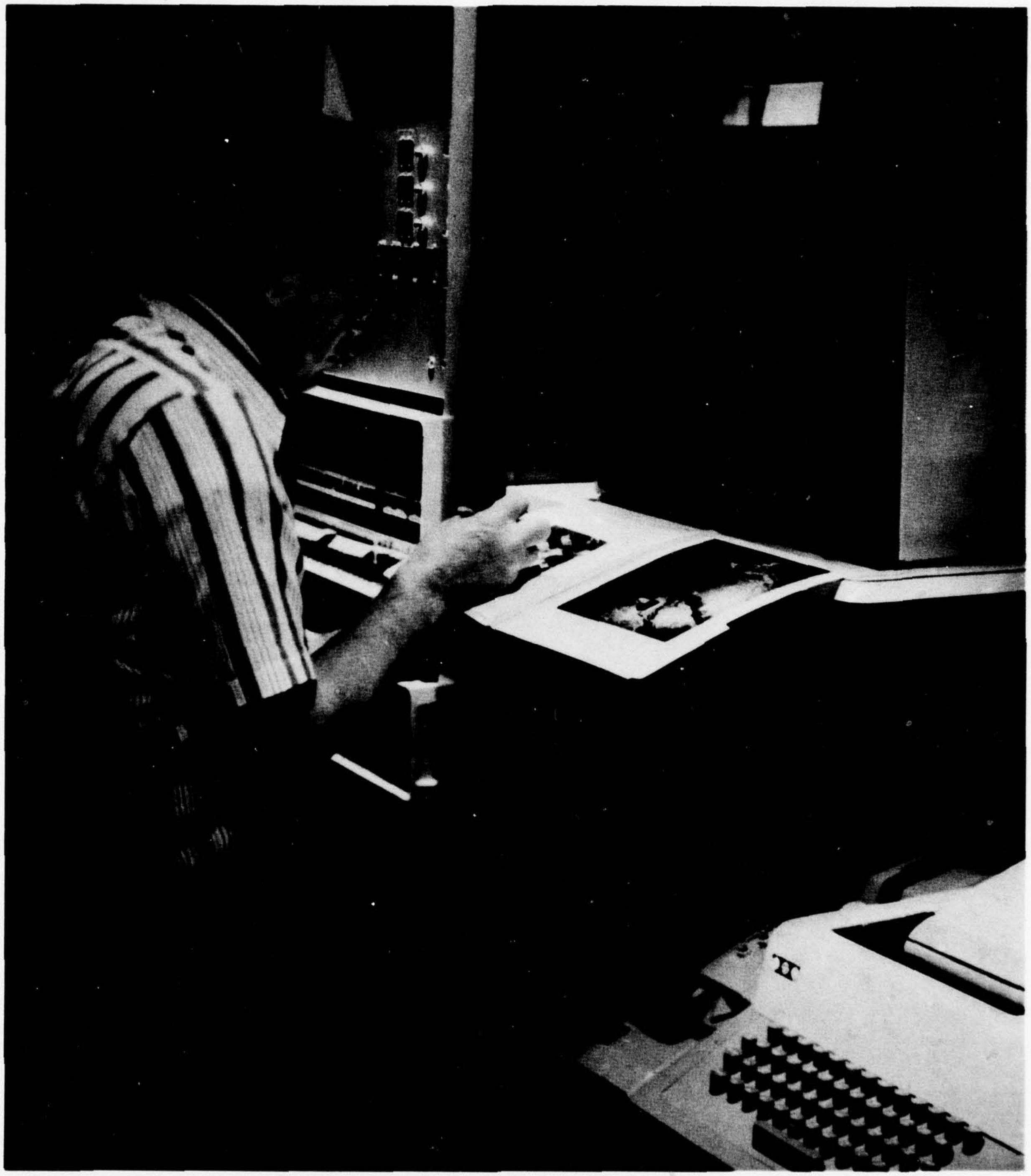


Figure 3 – Color Display Facility

PHASE I: CONCEPTS DEVELOPMENT

GENERAL

While the objective of this program was to optimize the interface of visual, radar, and display characteristics, the development of codes which did not fit within this framework were not immediately discarded. The philosophy adopted during this phase was to brainstorm as much as possible in order to minimize the possibility of a narrow research approach. Another reason for taking this modified shotgun approach is that several varying ideas and suggestions were offered by consulting Goodyear Aerospace personnel not directly associated with the project. Most of them had color-coding hypotheses centered in some logic based in physics, perception, etc.

These ideas and codes were included because if they had been omitted, a reader might think of a similar code or strategy and wonder why it had not been considered. Therefore, any code offered that appeared to have some logical basis was considered.

For the most part however, code development considered and emphasized visual, radar, and display characteristics. In addition, codes were generated keeping the Phase III test in mind. Since the laboratory evaluation was to include quantitative operator performance measures in SAC-, TAC-, and RECCE-type tasks, appropriate consideration was given to strategies that would be optimized under these conditions. Codes developed for the SAC scenario emphasized ground painting since this task is primarily a map-matching effort by the operator. TAC and RECCE codes were developed that emphasize detection of mobile targets. Some codes were generated which combined the advantages of both ground painting and strong target detection to produce an overall apparent expansion of displayed dynamic range.

Since radar data is distributed along an intensity continuum, an attempt was made to generate color codes which appeared to increase in brightness in order to minimize confusion.

The Phase I process is depicted in Figure 4. Concepts, strategies, or codes were generated using the mission-scenario definitions, radar cross-section estimates, amplitude and frequency distributions, display brightness and color limitations, and human visual perception limitations.

The codes are discussed later under code development in order to describe the techniques and rationales employed in constructing color codes and their potential for enhancing operator performance.

RADAR SIGNAL LEVEL DETERMINER

Prior to generating specific color step wedges or codes for displaying radar, a software program was written that permits the experimenter to determine the relative level of any image feature in dBs for signal-to-clutter and dynamic range measurements.

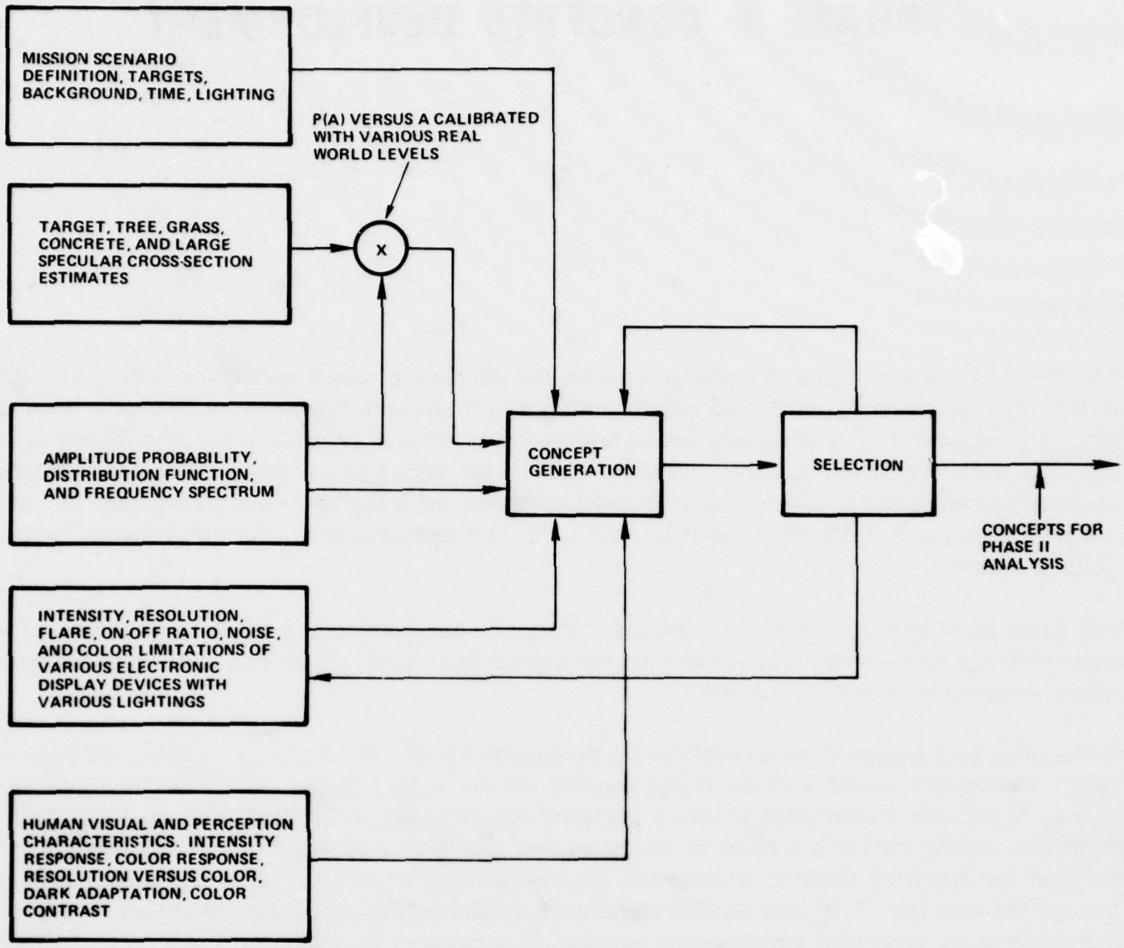


Figure 4 — The Phase I Process

In this mode, any input level can be displayed as saturated red. This input level can be varied from 0 through level 31 so that the input amplitude of any pixel can be determined by sequencing through the input levels until the pixel in question is represented by red. Input levels above or below can be represented by other colors. Since the input levels correspond to equal steps in the radar signal, relative cross-section measurements easily can be made. Of course, if a known cross-section return such as a corner reflector is in the image (and can be identified by pixel position), then absolute measurements can be made.

An example of this mode is shown in Figure 5. As the red bar is advanced, the levels accumulated are coded in green. Therefore, looking at Figure 5 it can be seen that at level 15, for example, everything at level 15 is red; levels 0 to 14 are green and levels 16 to 31 are grey shades. Variations of this mode include blanking out all levels below the red bar for thresholding experiments.

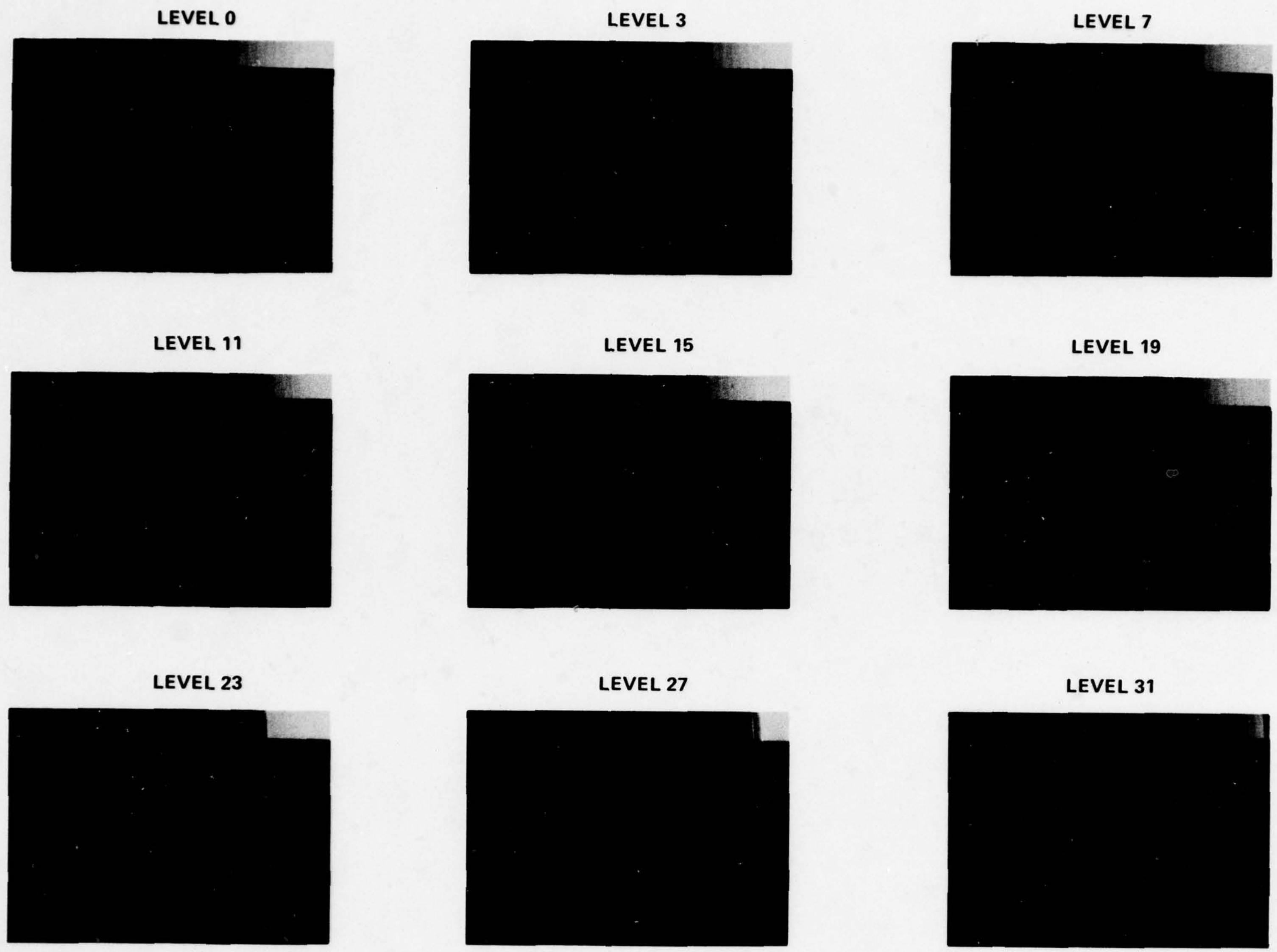


Figure 5 – Radar Signal Level Determiner

CODE DEVELOPMENT

Developing color codes involves assigning one of the 32,768 possible color encoder values, *i.e.,* 32 x 32, to each of the 32 input levels. To aid in code development, the color computer is used to display color choices on the lower part of the screen while viewing the developing color step wedge on the top of the screen. The color choices are arranged in 15 groups of 32 (maximum) equal brightness colors with a 1-dB brightness difference between groups. One group of the 15 is displayed at a time. In general, the color codes used increase continuously in brightness with increasing step numbers. Thus, the operator generating a code may, for example, begin with step zero and set red, green, and blue (RGB) values to zero, thereby inserting black into step zero. He then would display on the lower part of the display the set of equal brightness colors in group No. 1 and select a hue to be placed into step No. 1 of the developing color code. Using the keyboard, he would command the computer to print out the RGB values of the selected color. Once this occurs he plugs the listed RGB values of the desired color into step No. 1 of the wedge. The operator can select another color from this equal-brightness color grouping or call up the next equal-brightness color group to the display and select from it. This is repeated until all 32 levels are assigned RGB values. Since there are many more than 32 possible colors at most equal-brightness levels, thinning was necessary to select the maximum of 32 that could be displayed. The 32 colors displayed are representative of the available colors and the operator can use intermediate values if desired.

Once the code is developed, it may be stored in the computer and the RGB code listed using the teletype.

Figure 6 is an example of a color code under construction. Fifteen steps have been assigned RGB values as indicated by the step wedge, and the resulting image also is shown. In general, the signal level determiner mode explained above is used to locate the mode of the signal distribution and the levels where targets and clutter overlap. By doing this, colors and brightness values can be assigned which are thought to be appropriate for the features at these particular levels.

In attempting to generate various color codes, a general philosophy emerged. Since a major portion of most radar scenes is composed of large areas of terrain and relatively few small cultural features, *e.g.,* targets, it became apparent that using low brightness/low color contrast to display the terrain and high brightness/high color contrast for targets produced codes that, in general, had the most potential for enhancing the displayed image.

It also was decided during the concepts development phase that codes which do not have brightness reversals transfer the information more accurately than those that do. The operator who is accustomed to viewing radar imagery along a brightness continuum can be confused if the data are presented nonmonotonically in apparent brightness.

Specific Color Codes

During Phase I: Concepts Development, 14 color codes were developed with various strategies, philosophies, and rationales. These codes are individually described in the following paragraphs and include physical and/or psychophysical rationales and reasons. For each code discussed there is a corresponding printout that lists the RGB values for the 32 levels of each code. These printouts are contained in Appendix B.

Monochromatic Codes – The baseline standard black and white code (No. 1*) against which the two color codes selected in Phase II would be tested is shown in Figure 7. The code was generated by turning off the

*The codes will be arbitrarily numbered for ease in reference.

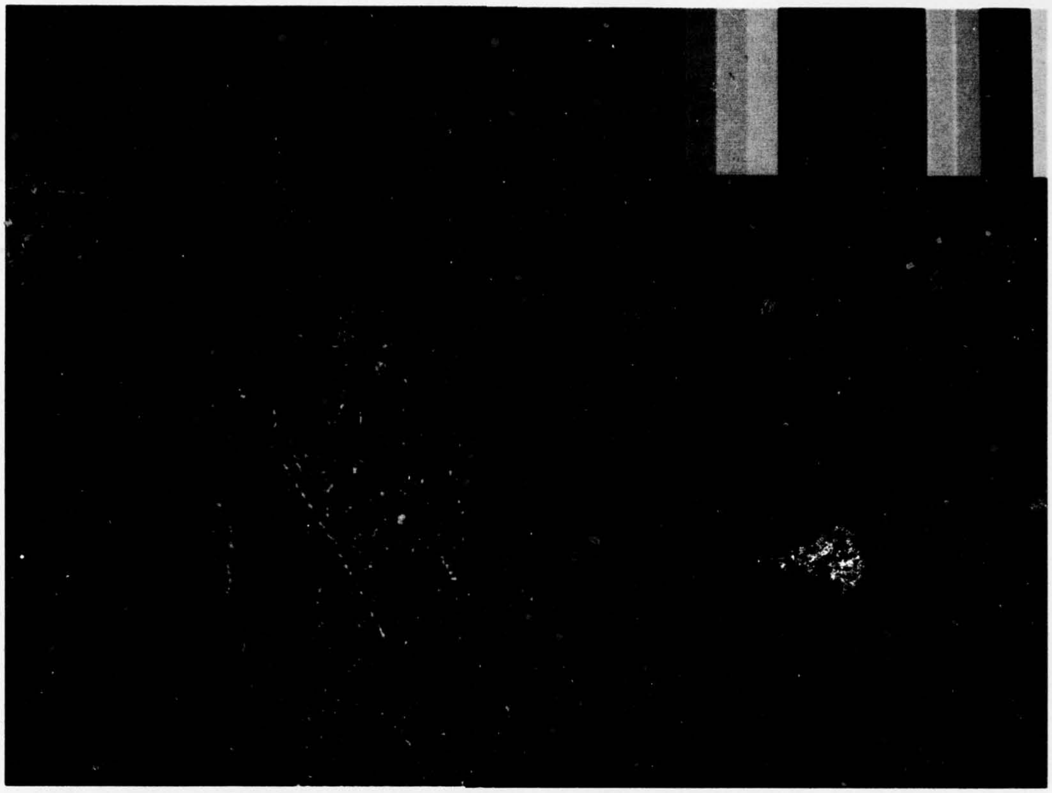


Figure 6 – Developing a Color Code

red, green and blue-guns for step zero and increasing each gun one level for each step, one through 31. Hence, a grey step wedge is created with equal brightness increments.

Figure 8, red (No. 2), Figure 9, blue (No. 3), and Figure 10, green (No. 4) are the other monochromatic codes that were developed. These codes were generated by increasing a single gun in 32 equal steps from 0 to 31 with two guns off. These concepts are applicable to single-gun, single-phosphor, CRTs and also represent a logical starting point in constructing other color codes.

Wide Dynamic Range (WDR) Red-Yellow Code (No. 5) – A previous in-house experiment was conducted at Goodyear Aerospace to determine if the apparent dynamic range of radar data could be enhanced if the data were recorded on color film. A recording laser wavelength of 6000Å produced a continuous color shift from red through orange, yellow, and white. This color film was judged by interpreters to contain more information than a black and white image of the same area.* As a result, the WDR red-yellow code shown in Figure 11 was built to resemble the color shift obtained on film.

This code is primarily a two-color code using the red and green guns throughout most of the steps, employing the blue gun only at the high end of the continuum to produce white.

Unlike most of the color codes developed on the following pages, this code and the monochromatic codes can be implemented into display systems without color encoders.

Color Code No. 6 – One of the very first complex color codes developed is shown as No. 6 in Figure 12. Several things were realized during and after constructing this code. This code was built with the intention

*GERA-2180: *Image Quality and the Radar Operator.* Litchfield Park, Arizona, Goodyear Aerospace Corporation, June 1976 (CONFIDENTIAL).

of providing good ground painting and high target detection. One thing that became evident with this particular code was the selection of hue and low brightness and color contrast worked very satisfactorily in presenting the terrain features. Most of the ground and clutter features are distributed below the rust and yellowish colors shown in the step wedge. Although the wedge appears to have rather irregular steps, it provided a good basis from which to make smoother transitions in later codes. Another characteristic of the code that was found to be desirable was the use of saturated, *i.e.*, pure, colors and white for that part of the continuum containing strong targets which are principally above the clutter distribution. Using pure and high contrasting colors at these levels also facilitates discriminability among relatively small targets that are spatially separated over the black and white linear standard. And because of the low percentage of targets distributed above the red bar of this code in the FLAMR imagery, the last six steps were set to maximum brightness, *i.e.*, white. While this results in displaying 7.5 dB less dynamic range or 42.5 dB (since six 1.5-dB steps are compressed into one) it does not affect significantly the tasks considered in this investigation. Only very large reflecting targets, *e.g.*, buildings, exist in this region of the FLAMR data with smaller cross sections corresponding to vehicles existing below the white. And for the SAC scenario, targets selected in this white region also would be highly detectable by the operator.

Color Codes No. 7 and No. 8 – Color codes No. 7 and No. 8 shown in Figures 13 and 14 are modifications of No. 6. First, they are essentially 4-bit (versus 5-bit) codes with color/brightness assignments made in 3-dB steps with the last six steps coded in white. Code No. 7 was generated by selecting the RGB values assigned to the even-numbered steps in code No. 6 and making the odd-numbered steps immediately succeeding them the same (up to red). The main reason for doing this was to get some feel for how 4-bit and 5-bit quantization color codes compare in the amount of information displayed (or lost).

Code No. 8 is similar to No. 7 and basically is lower in gain. Inspection of Figures 13 and 14 reveals this shift in gain. Actually Code 8 (except for two slight changes) is composed of Code 6 steps 0, 2, 5, 7, 8, 11, 13, 15, 18, 19, 21, 23, 25, 27, 29, and 31. The two deviations occur at steps 15 and 21.

Color Codes No. 9 through 12 – Color codes 9, 10, and 11 are shown as Figures 15, 16, and 17. These three codes emphasize the use of blues, greens, and browns for ground painting and exhibit a rather smooth shift in hue and brightness through this range. In fact, the three codes are identical through the first 17 steps.

Code No. 9 was developed first and demonstrates good ground painting and high detection. The small targets are concentrated in the peach-colored levels, however, and little brightness/color discriminability exists among these levels. In addition, a brightness shift also is apparent in this area.

One modification due to these drawbacks resulted in Code No. 10. The brightness shift from steps 19 through 21 were smoothed and increased in apparent brightness and the upper levels coded in shades of grey to white. While these upper levels provide for excellent target detection, discrimination among spatially separated strong targets is difficult. As a consequence, the code was modified to include the wide red, green, and yellow bands shown in Figure 17 as Code No. 11.

While it may be argued by some that the underlying strategy of coding stronger targets to appear brighter than weaker ones does not hold in some of the codes in the region of saturated colors it also can be argued that it is easy to learn that yellow targets return more energy than green which return more energy than red ones.

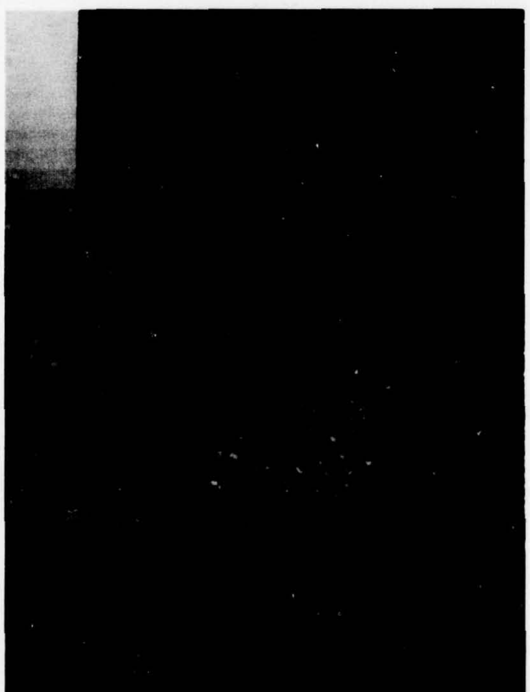


Figure 7 – Code 1, the Black and White Standard

Figure 8 – Color Code 2, Monochromatic Red

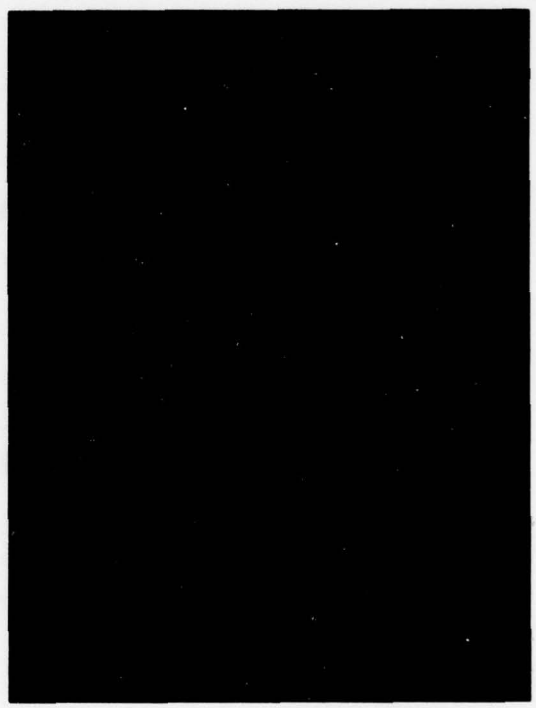


Figure 9 – Color Code 3, Monochromatic Blue

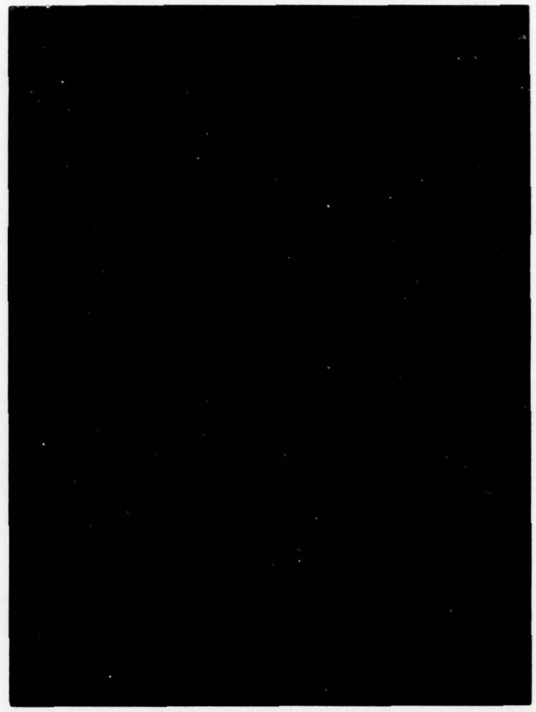


Figure 10 – Color Code 4, Monochromatic Green

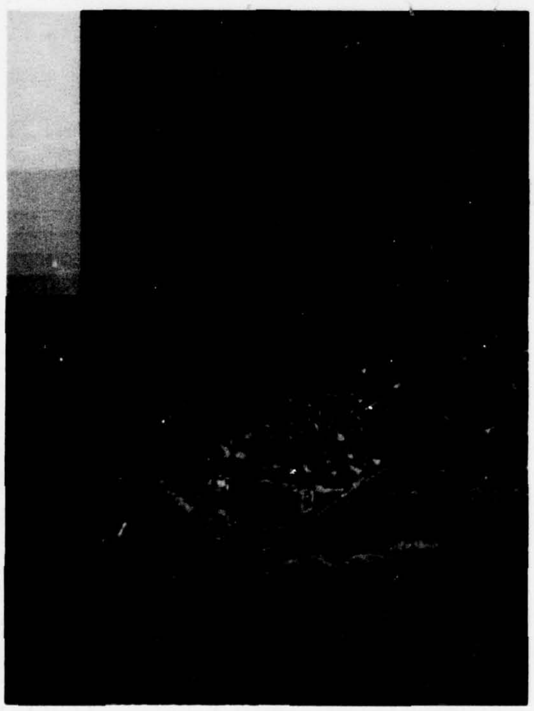


Figure 11 – Color Code 5, WDR, Red-Yellow-White

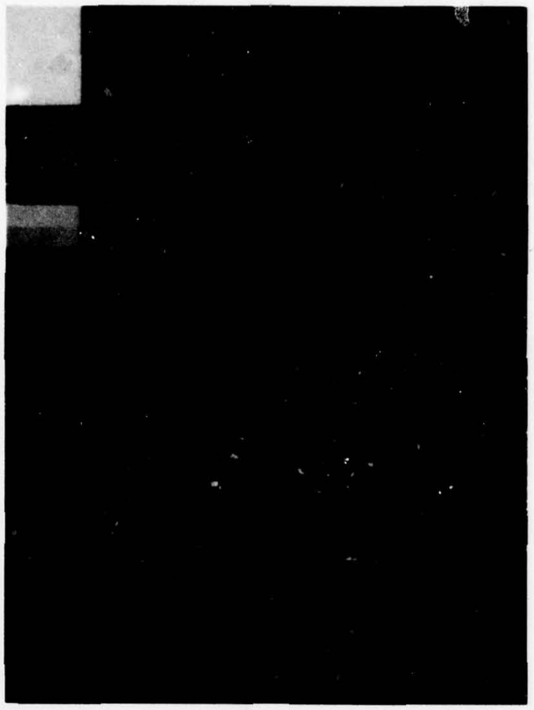


Figure 12 – Color Code 6

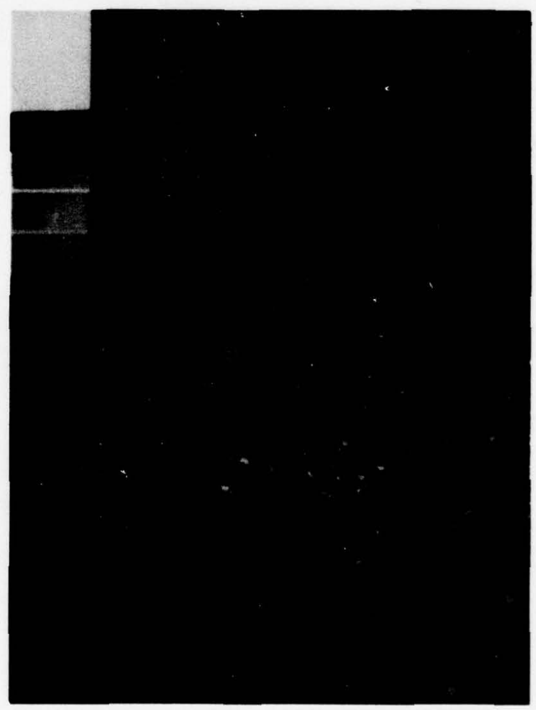


Figure 13 – Color Code 7

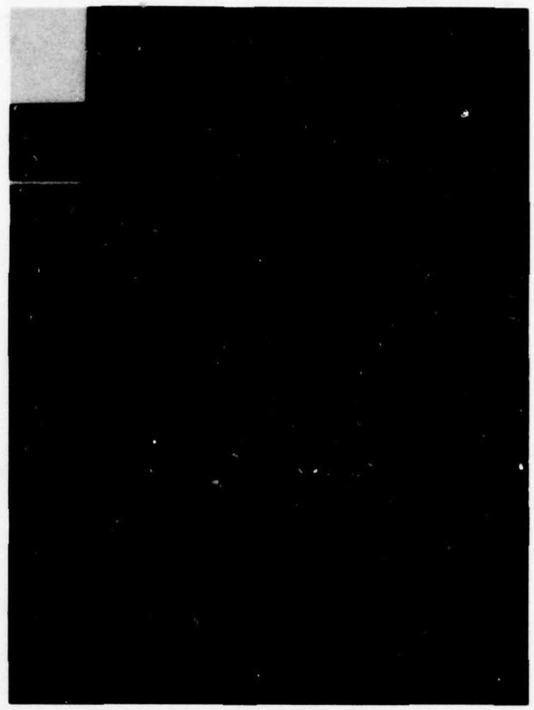


Figure 14 – Color Code 8

Another innovation was attempted with this code. Since the small targets in the FLAMR imagery would occur near the lower edge of the red bar, Figure 17, it was decided to use neutral grey shades just below the red. It was predicted that this would accomplish two things. If a few targets in a cluster were presented as red, the subject/operator would detect them and search the immediate area for grey point returns. Finding them, he could better determine whether they were targets or clutter false alarms. Since small targets and clutter appear at nearly the same levels with the radar imagery employed in this study, it is advantageous to have a code that facilitates detection of a few targets to cause inspection of the surrounding area. An operator using Code 11 may classify some grey spots as targets when they are in the presence of red ones and others as clutter when they are not.

Code No. 12, Figure 18, also is a modification of Code No. 9 and is characterized with slightly brighter ground painting and with red, magenta, green, and white at the upper levels. Like Code No. 11, Code No. employs the grey shades at the levels of maximum target/clutter overlap.

Codes 6 through 12 represent an empirical evolution of color code development. Hues were identified for ground painting, various codes for strong targets were examined, and brightness levels were adjusted for predicted increased discriminability among terrain features.

Color Codes No. 13 and No. 14 – In developing Code No. 13, a new strategy was implemented departing from most of the discoveries in the codes described above. It was the intent in generating this code shown in Figure 19 to present a color stepwedge that appeared to have a continuous shift in hue transition, a gradual shift in brightness up to the estimated target/clutter overlap levels, and then produce a more rapid increase in the rate of brightness change at the upper levels. A continuous shift in hue means that adjacent colors do not cause a drastic color contrast with one another. Code 13 begins with black and shifts gradually through blues, greens, oranges, and yellows, and culminates in white at the upper levels. In order to generate a stepwedge which appears to present a logical hue and brightness continuum, it is necessary to have gradual shifts that result in a number of levels having similar hue and brightness values. This results in reduced discrimination among those levels.

Code No. 14 is identical to Code No. 13 through the lower 21 levels and is modified to include 3-dB steps of red, magenta, green, yellow and white at the upper end to increase strong target discrimination. This code is shown in Figure 20.

Beam Penetration Code No. 15 – A beam penetration tube utilizes a variable accelerating voltage to produce different phosphor hues. As the voltage is varied from 8 KV to 16 KV, the phosphorescence changes from red, through orange and yellow to green.

An attempt was made to generate a code (No. 15, shown in Figure 21) that would simulate the maximum potential of the tube for producing a continuously increasing brightness continuum. Because of the physical characteristics of the beam penetration tube, the code is composed of combinations of red and green only. In the RGB simulation, the lowest value is produced by turning off both guns to achieve black. The highest brightness value possible is produced by turning both guns on at maximum intensity, which yields a bright yellow.

The end product of Code No. 15 produces results similar to the continuous code (No. 13) discussed previously. Broad bands of adjacent levels which have similarly programmed values reduce the discriminability among features within those bands.

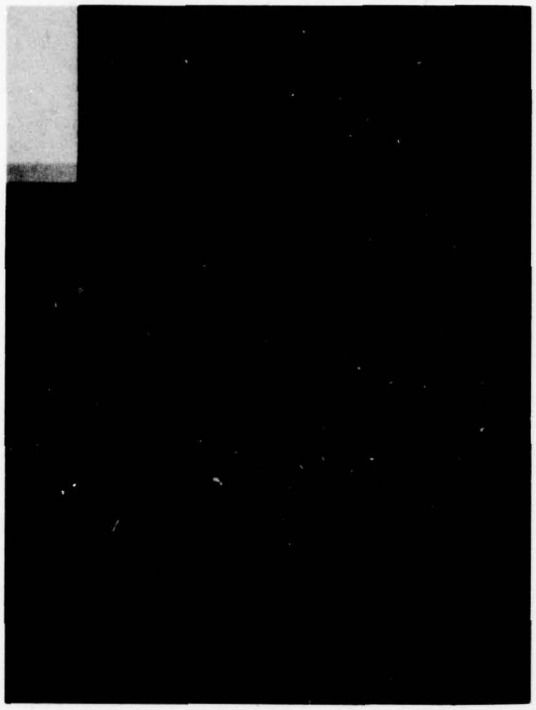


Figure 16 – Color Code 10

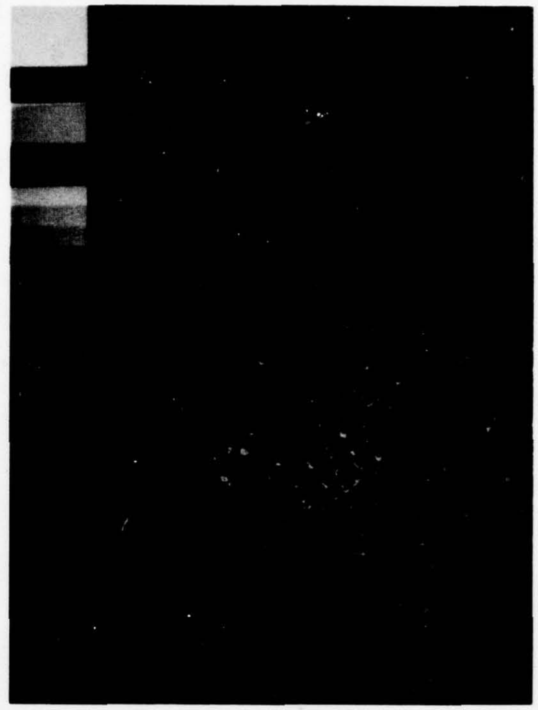


Figure 18 – Color Code 12

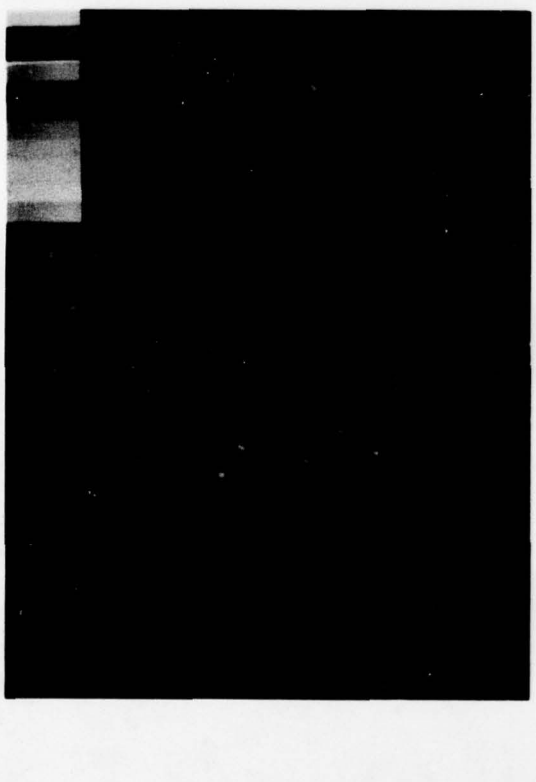


Figure 15 – Color Code 9

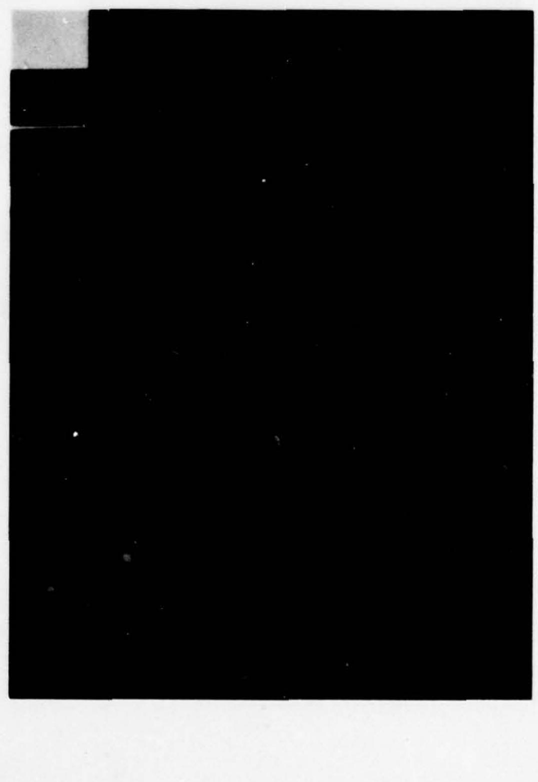


Figure 17 – Color Code 11

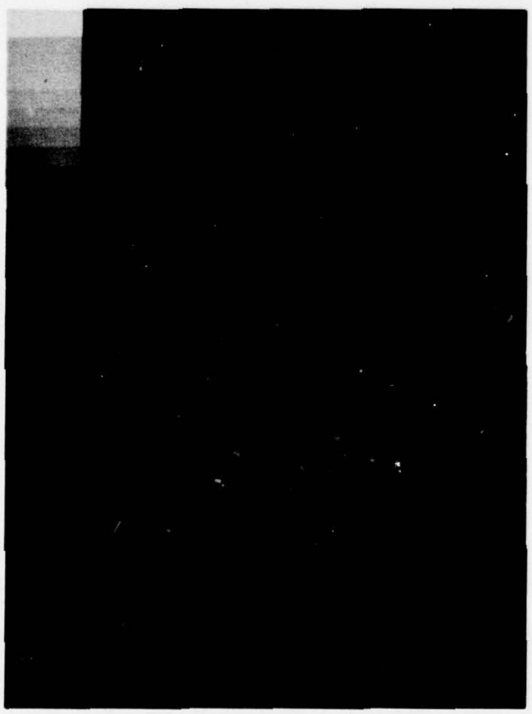


Figure 19 – Color Code 13

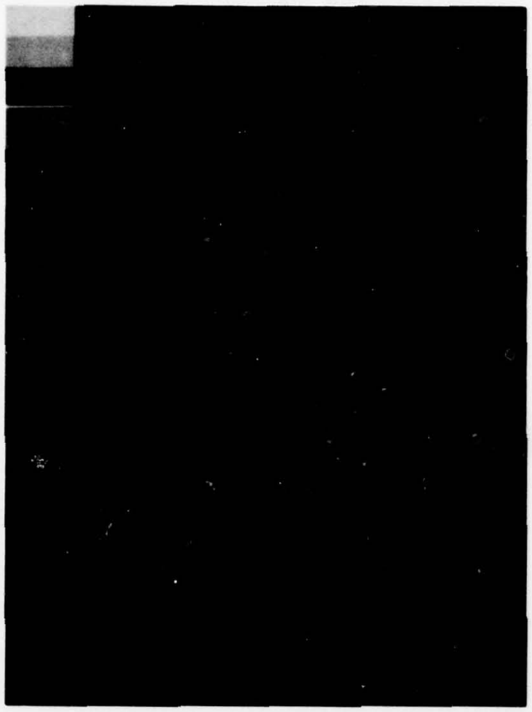


Figure 20 – Color Code 14

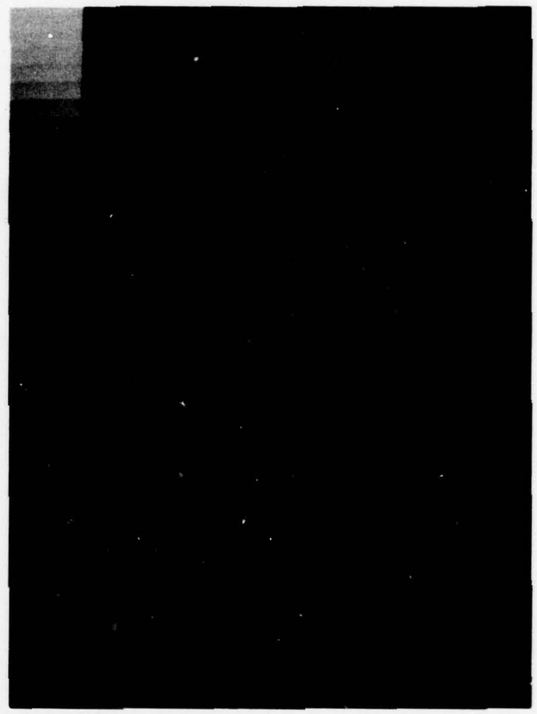


Figure 21 – Color Code 15

PHASE II: CONCEPTS ANALYSIS

GENERAL

The purpose of this phase was to evaluate the concepts developed in Phase I and select at least two concepts to be evaluated further through man-in-the-loop tests during Phase III. Evaluation criteria for this analysis included cost, complexity, and a qualitative assessment of the concepts potential from a human visual standpoint.

COST AND COMPLEXITY

General

The experimental system used in this study and described in Appendix A is necessarily complex in order to have the flexibility required for experimentation and the selection of an optimum color code. An operational system could be much less complex since weighting functions and the number of available codes could be held to a minimum.

Figure 22 is a block diagram of an operational color display system. The data-weighting function is shown as part of the display system; however, it could be part of the SAR data processor. This function selects the input dynamic range, shapes it, *e.g.,* linear to logarithmic, and reduces the quantization level to match that of the scan converter. This function could be implemented with a read-only memory (ROM) device. A separate ROM would be required for each weighting function provided. Figure 23 shows three data-weighting functions that can be obtained with three ROMs. A weighting function change from No. 1 to No. 2, for example, selects a different portion of the radar data for display and has the effect of reducing radar gain. The data-weighting function and the scan converter would be the same for all color coding techniques, including a monochromatic display.

The specific color encoder and the color monitor will be a function of the color codes under study and therefore will be discussed separately.

The display linearizer and contrast control provides a linear relationship between display signal level and display brightness. This function, which can be performed by a ROM, is essentially the inverse of the CRT transfer function (phosphor brightness versus grid voltage) such that equal input steps result in equal brightness steps. Separate ROMs and digital-to-analog converters are required for each monitor gun.

Color Monitors

Three types of color monitors were considered. One utilizes a beam penetration CRT, while the second utilizes a conventional three-gun (red-green-blue) color CRT. The third monitor considered employs three separate projection CRTs that are optically converged on a screen.

The beam penetration CRT provides a color change as a function of acceleration voltage. As the voltage is increased from about 8 to 16 kV, the phosphor color changes from red to green. Although the CRT is of a conventional type and can be ruggedized, the problems of high-voltage modulation, beam focus, and beam deflection are increased tremendously. One implementation approach for raster scanning utilizes a 120-Hertz field (60-Hertz frame) rate with 30 frames per second devoted to each color on alternate frames. This permits voltage, focus, and deflection parameter switching during vertical fly-back. Other implementation approaches for beam penetration CRTs utilize stroke writing, which appears impractical for a SAR display.

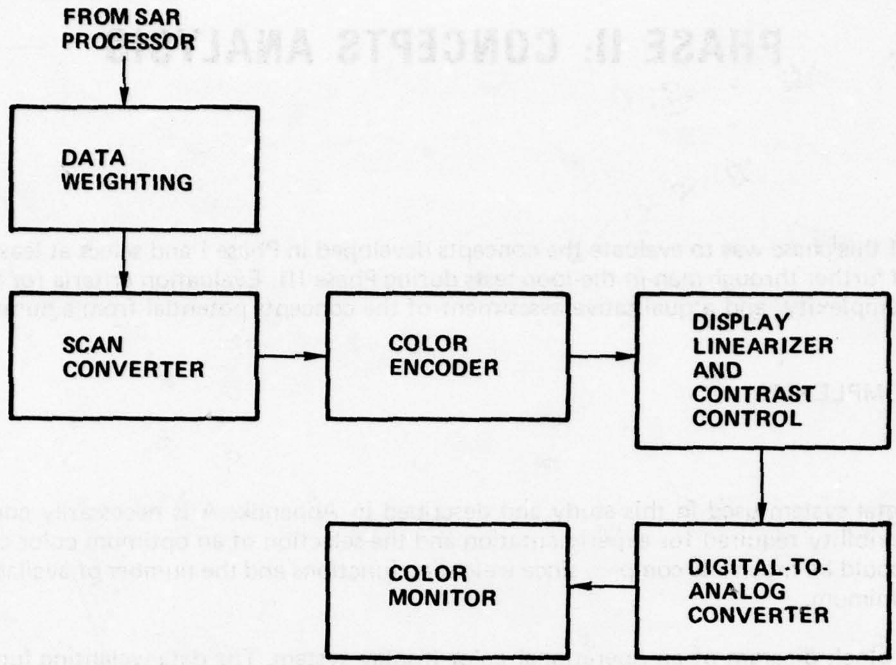


Figure 22 – Color Display System

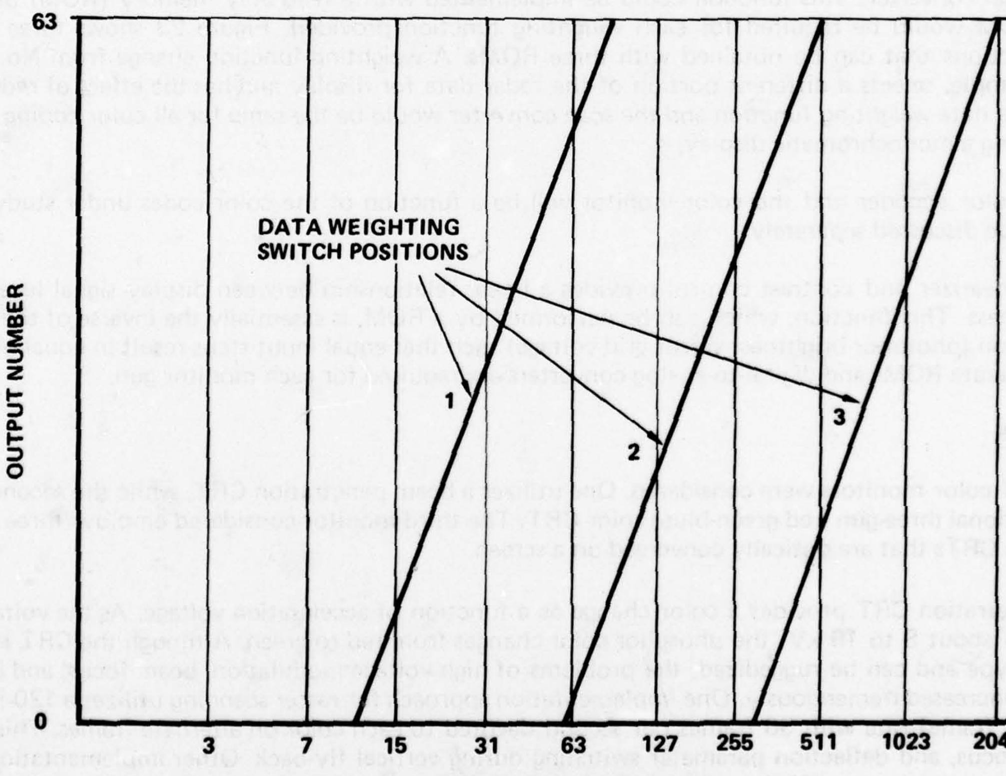


Figure 23 – Data Weighting

The conventional RGB color CRT utilizes three guns and a shadow mask located a small distance from the faceplate. This type of tube was used in the experiments described as Phase III and can produce the full spectrum of colors. To date, this type of tube has not been fully qualified for airborne use. However, one manufacturer, CONRAC, has produced a semi-militarized monitor intended for flight test application.

There are at least two color projection monitors available. Both systems utilize three separate CRTs with appropriate phosphor and filters to provide a full range of color. One system provides a conventional 525-line raster while the second has more than 1000 lines. Neither system is flight qualified. Both systems are rather bulky and are not suitable for a cockpit environment. However, they do have ground base application.

Color Encoding

The simplest color encoding technique for a three-gun color CRT is shown in Figure 24. The bias and gain (slope) of each gun can be controlled independently on an analog basis, resulting in a number of different codes. However, the color codes possible are limited; *e.g.,* in the code shown pure green and blue are not possible. The first gun (red) produces a saturated, constant hue at varying brightness. As the second gun is activated the brightness increases, however, and the hue and saturation will change, depending on the bias of the second gun and the two slopes. The depicted code produces a red to yellow to white color (Code No. 5 described previously) as the input amplitude is increased. By interchanging the biases, a different color code can be effected, *e.g.,* blue to purple to white, green to yellow to white, etc.

The described color coding technique has been implemented by Goodyear Aerospace on a number of displays including the Synthetic Aperture Precision Processor, High Reliability (SAPPHIRE) program.

A more versatile color encoder could be implemented with a set of three ROMs for each color code desired. The cost of a 5-bit/5-bit ROM is approximately $10, and therefore a color encoder of this type is not considered a costly item.

The color encoder for the beam penetration CRT would consist of two ROMs (one for each color) that would be switched alternately between frames.

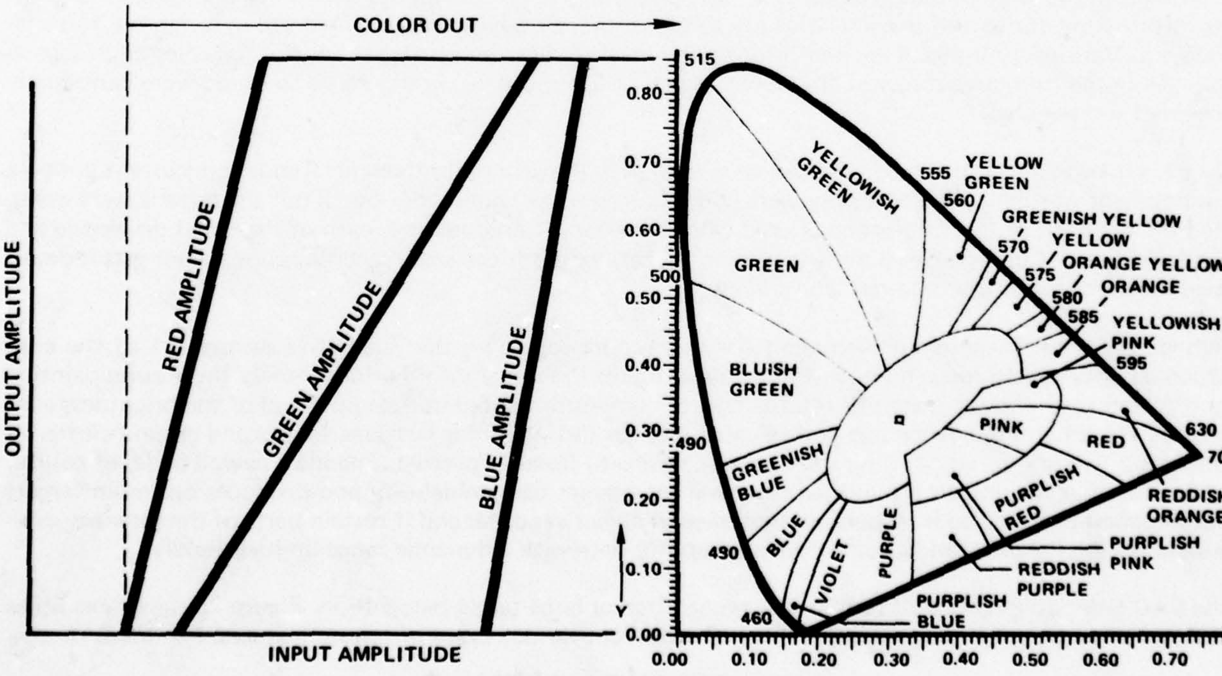


Figure 24 – Simplified Color Encoding

TABLE I – COLOR VERSUS BLACK-AND-WHITE COST

	Cost (Dollars)	
	Color	BW
Data Weighting	30	30
Scan Converter (512 x 512 x4)	6,775	6,775
Color Encoder	45	–
Display Linearizer	*	15
D/A Converter	240	80
Monitor	3,000	1,500

*This function can be included in the color encoder.

Summary

Table I shows the estimated cost of the basic elements of both a color and a black-and-white display system. The difference in cost of the basic elements is about 20 percent; however, when considering the total system (including control panel, mounting, etc.), the cost differential would be much less. The cost differential may be important when considering airborne installations; however, in a limited number of ground installations utilized primarily for RECCE, this differential should be insignificant.

The RDT&E costs for the color and monochromatic system should be very similar except for the costs of qualifying the color monitor for an airborne installation. As mentioned previously, there are no color monitors that are flight qualified and the costs of this task are difficult to project at this time.

QUALITATIVE ASSESSMENT OF COLOR CODES

In attempting to develop color codes that have potential for enhancing the qualitative and quantitative visual information content of the final displayed radar scene, Goodyear became involved in a vigorous research program. Various hypotheses existed prior to the investigation concerning rationales for color code generation. As in the formative stages of any new research area, hypotheses in this research effort were continually accepted and rejected.

Hence, the program actually experienced an evolution in the criteria for beneficial codes concurrent with the development of such codes. Not only were codes judged to be "good" or "bad," but the criteria were evaluated on the basis of test results and altered when necessary. Consequently, each of the codes developed and discussed under Concept Development was not generated with the same specific rationale nor was it developed independent of ultimate task considerations.

Perhaps the most meaningful discussion for this report regarding the qualitative assessment of the constructed codes should focus on how well a code presents the visual information, namely the ground painting represented in the lower intensity returns and the targets presented at the upper end of the brightness continuum. Of equal importance is a code's capability for distinguishing between targets and ground clutter in the region where ground painting and manmade (return) features overlap. The ideal overall code, of course, is the one that maximizes ground painting and intertarget discriminability and produces optimum target/clutter separation. It also is recognized that mission objectives differ and if certain parts of the intensity continuum need emphasis, task-specific codes are appropriate with a dynamic range-limited display.

The SAC task could consist of terrain-area recognition or large-target recognition. Figure 25 shows examples of Probability Density Functions (PDF) of returns from various types of terrain features. For the SAC area

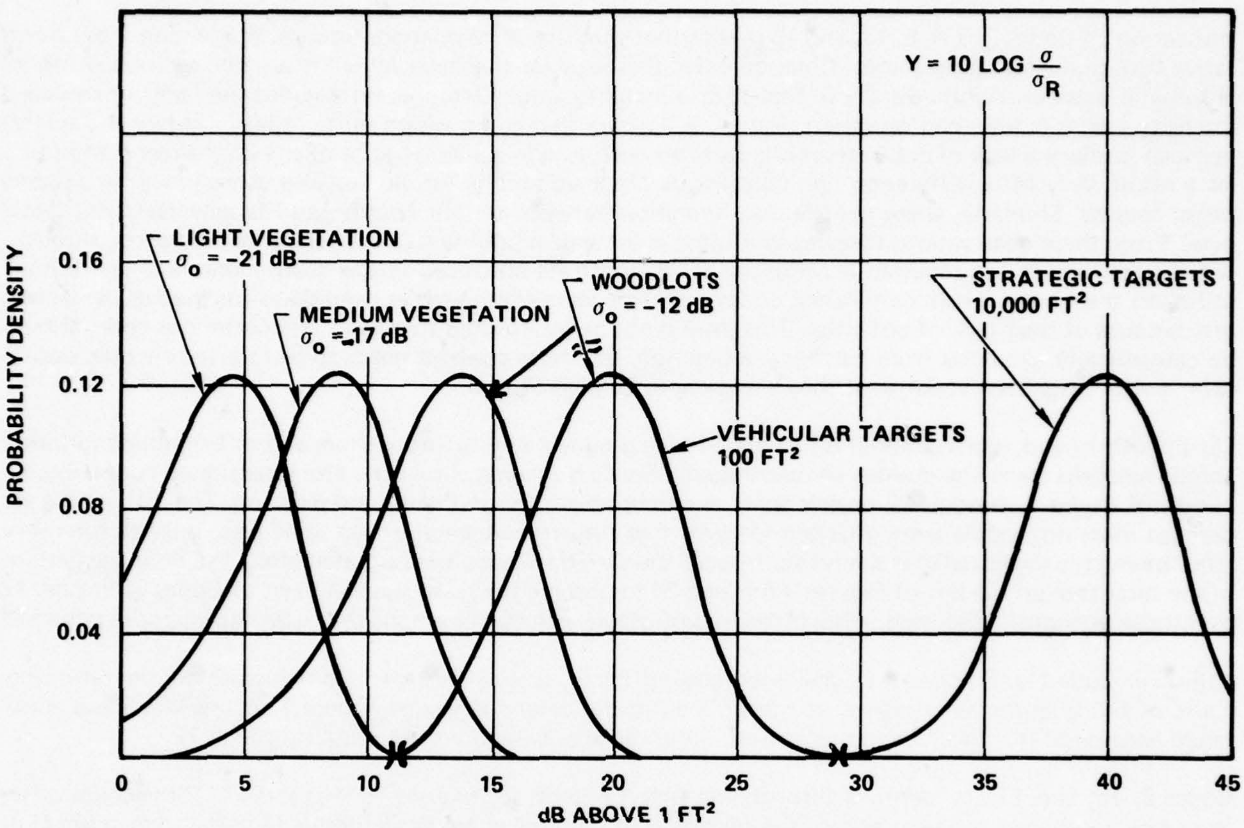


Figure 25 – Probability Density Functions of Returns

recognition task, the color code should provide easy discrimination among field patterns – areas having σ ranging from –30 dB (water) to –10 dB (woodlots). This figure also shows the ease of the large-target recognition task where the distributions of natural terrain features and large strategic targets are well separated.

The TAC and RECCE missions, particularly with a 20-foot resolution radar, are clearly a target/clutter discrimination problem. The mean return from a clutter patch is given as

$$\sigma_C = W^2 \sigma_O \sec \theta$$

where

W = resolution
θ = depression angle.

For heavy vegetation (assume a $\sigma_O = -12$ dB) and a 6-degree depression angle,

$$\sigma_C = (20)^2(10^{-1.2})(\sec 6 \text{ deg}) = 25.4 \text{ FT}^2$$

Thus the PDFs of clutter and tactical targets ($\sigma_T \cong 50$ FT²) have considerable overlap.

In summary, then, a color code for the SAC mission should provide good discrimination among field patterns, while the color code for the TAC and RECCE missions should provide good target/clutter discriminability.

Inspection of Codes 2, 3, 4, 5, 13, and 15 reveals that they are somewhat continuous, containing slight qualitative variations in adjacent hues. Consequently, they possess the same inherent weaknesses of the monochromatic black and white display in that discriminability among features throughout the range of recorded intensity values is less than optimum. Hence, it appears that codes which shift gradually in hue and brightness can produce a lack of contrast among features occurring in similar regions of the brightness continuum. As a result, very little difference, *i.e.,* contrast, is observed among terrain features as well as among strong target returns. Similarly, there is little discrimination between terrain features and targets near their crossover. From these observations it seems as if more color and/or brightness contrasts, either in part or throughout the stepwedge, are required if codes are to demonstrate enhanced image quality that is of operational utility to the viewer. These continuous codes therefore were eliminated as candidates for the human factors test because of their lack of potential. This should not be interpreted to mean that continuous codes should be categorically excluded from further examination, but more contrast needs to be inserted via hue, saturation, and/or brightness variation if they are going to be investigated.

On the other hand, when contrast is increased in the ground painting through hue and/or brightness variation among adjacent steps, the number of discriminable levels is increased over the aforementioned codes. Examination of Codes 6 through 12 reveals some apparent advantage in the ground painting. The differences are perhaps most noticeable among terrain features that return more energy than short grass but less than very large trees. It is suggested that the reader inspect the variation in features situated along the drainage pattern in the rural area on the left of Figures 7 through 21 to observe the relative advantages of Codes 6 through 12 over those previously discussed. Also, there are noticeable differences among the codes having more contrast.

Although Code No. 6 appears to give good ground detail, it was discarded from further consideration because of the brightness reversals that can be seen in the color stepwedge, Figure 12. Code No. 8 was eliminated because of its "flat," *i.e.,* low contrast, appearance as compared to Codes 9 through 12.

Codes 9, 10, and 11 are identical through the first 17 steps; see Figures 15, 16, and 17. These codes differ from one another at the high end of the stepwedge beginning where small mobile targets and medium clutter overlap. Neither Code No. 9 nor Code No. 10 separates the natural and manmade features very well. And because there are very few returns occurring in the upper six levels, it does not appear that the narrow pure color bands in Code No. 9 yield much of an advantage over the lack of discriminability among strong returns produced by Code No. 10. Code No. 14 also lacks the necessary color contrast required to separate natural clutter from targets slightly higher than clutter. There is very little shift in hue through this region of the stepwedge (see Figure 20), and discriminability is not improved over the black and white code shown in Figure 7. In fact, the two codes are nearly identical as far as apparent information content in the target/clutter region.

A comparison of Codes 11 and 12 resulted in selecting the latter for test along with Code No. 7. While Code No. 11 does not utilize maximum brightness, *i.e.,* white, at the upper steps of the wedge, its dynamic range is only about 0.7 dB less than that of Code No. 12.

Code No. 12 was judged to be the best overall code with good ground painting, good separation of clutter and target, and good intertarget discriminability. This code was developed to provide a threshold type of separation between high-return clutter such as trees and targets. However, at the 20-foot resolution of the FLAMR imagery, a clear threshold does not exist; thus, grey shades were used to encode that portion of the dynamic range where targets and high-return clutter such as trees overlap. Blues, greens, and browns were used to encode background information; and bright, pure, high-contrast colors were used to encode the portion of the dynamic range above the grey area corresponding to an area where the probability of tree false alarms is small.

In using this code, high-return targets which are portrayed in the bright colors actually "jump out" at the observer. Target returns in the grey area are portrayed with sufficient contrast for detection; however, they do not stand out unless the observer is cued to the immediate area of the returns. Since targets generally appear in clusters or recognizable patterns such as convoys or firing arrays, a single target that exceeds the bright color threshold will cue the observer to its immediate area where the adjacent targets are easily detected. The high color contrast between these regions also allows the use of a pure color which is not as bright as the grey background while still retaining good separation.

For any color display, psychoperceptual studies have shown that the absolute perceived brightness, B, is given by the relationship

$$B = 10 \log (gI_G + rI_R + bI_B)$$

where I_G, I_R, and I_B are the intensities of the primary colors green, red, and blue. If these three intensities are equal, a grey tone is produced. Otherwise, some hue will be displayed. The ratios of the constants g, r, and b vary slightly depending on the nature of the display. From equipment calibration they were determined to be 3.93, 2.06, and 1.00 in this case.

Using the brightness equation, the brightness level of any step in a color code can be determined. Also, the three equal-intensity inputs required to produce a grey tone with the same absolute brightness can be calculated. In this manner, black and white and color codes that have the same absolute brightness levels can be compared.

Figure 26 presents the brightness gradients of the two selected color codes and the black and white linear standard. (Points at output levels zero and one are missing because the three color guns are turned off.)

Code No. 7 was selected for testing because of its potential superiority over the other codes for target detection. This four-bit (16-level) code exhibits a relatively steeper slope in the brightness gradient in the region from medium clutter through levels corresponding with small tactical-type targets.

The increased target detection potential of Code No. 7 arises from the fact that this detection or TAC/RECCE code is less bright than the other two codes in the ground painting region and exhibits high brightness contrast steps that are clearly above the other codes in the critical clutter/target region. Because of this high contrast between steps, the code presents a seemingly noisy image. However, since tactical targets appear in groups and quite often in patterns, and since most groups of equivalent-sized targets are contained in a few steps that are discriminable from the others, the noisy appearance of the image is not confusing. While it was felt that this noisiness might interfere somewhat with SAC performance, the code's potential for tactical target detection was judged to be high and therefore the code was selected.

The brightness reversals in Code No. 7 at step 24 and Code No. 12 at step 22 correspond with the pure color introduction into the stepwedges and therefore the downward shift in brightness is compensated by saturation.

The code described in Phase I as Code No. 7 was selected for its target detection potential in the TAC and RECCE mission scenario. The code described as Code No. 12 was chosen because of its overall ground painting and large-target recognition potential for use in the SAC evaluation. For the sake of simplicity, the TAC/RECCE code will be referred to hereafter as Code No. 1 (C1), and the SAC code as Code No. 2 (C2).

Figure 27 shows the stepwedges of each of the color and black and white codes selected, as well as a typical radar scene utilizing the respective codes.

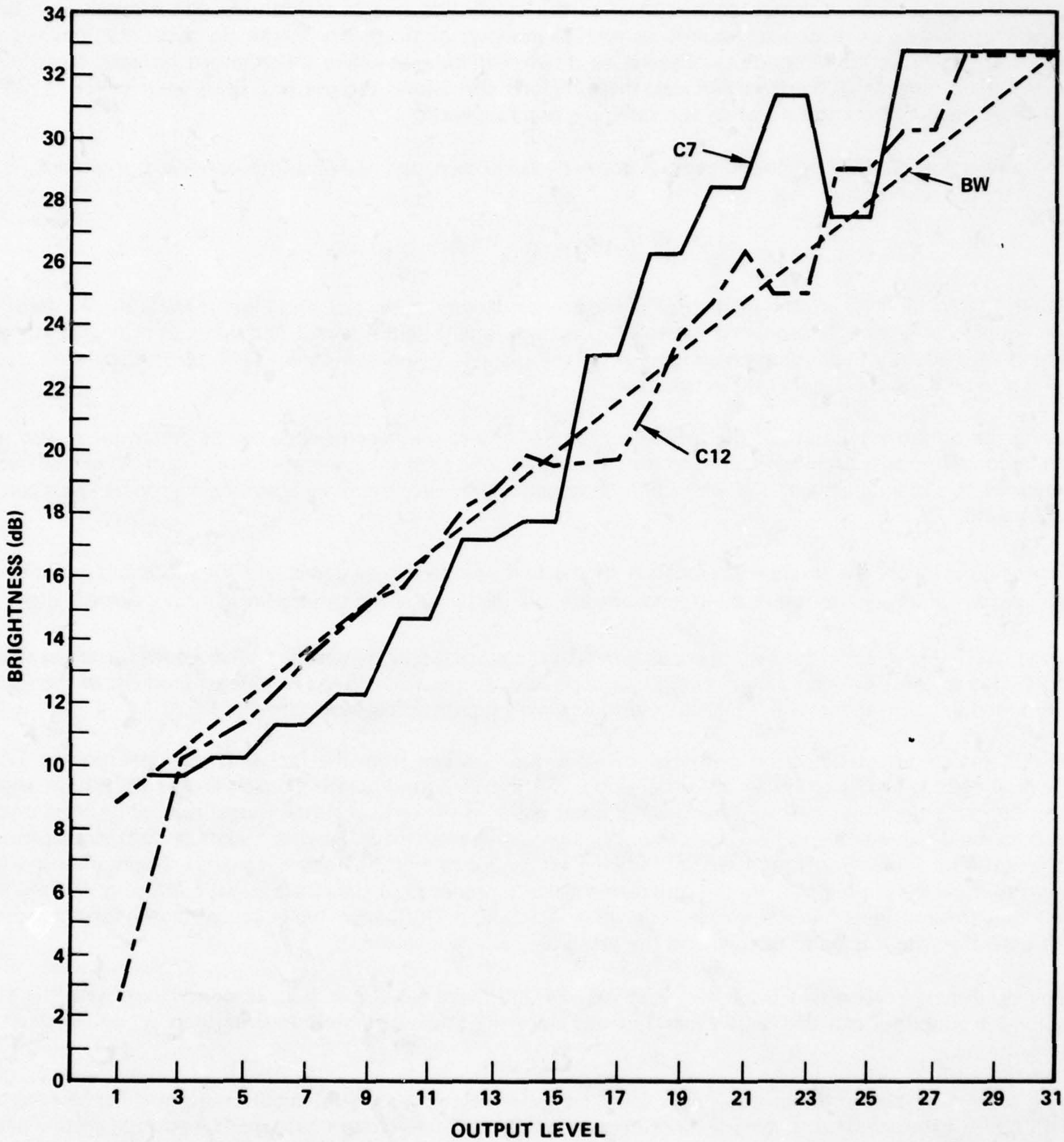
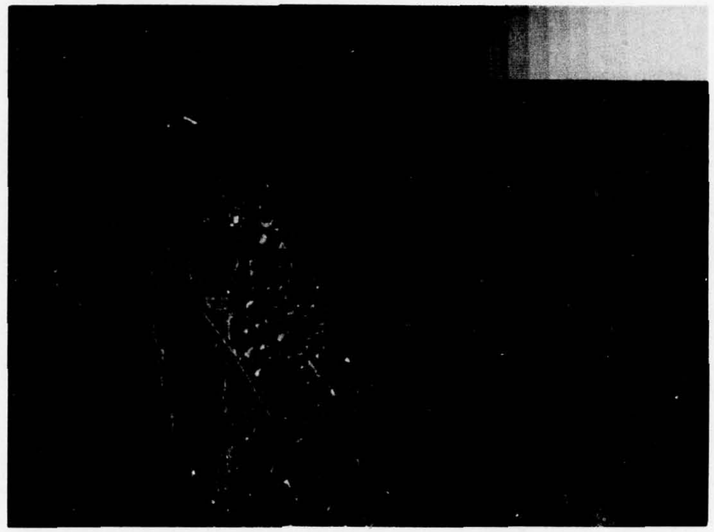


Figure 26 – Brightness Gradients of the Two Color Codes and the Black and White Standard



CODE BW

COLOR CODE 1

COLOR CODE 2

Figure 27 – The Black and White Linear Standard and the Two Color Codes Selected for Evaluation

PHASE III: MAN-IN-THE-LOOP EVALUATION

GENERAL

The color codes which were mutually agreed to have the most potential for enhancing operator performance by the Goodyear Aerospace and Avionics Lab project engineers were compared with the monochromatic baseline code in empirical human factors tests. Interpreters were tested in SAC-, TAC-, and RECCE-mission situations. These tests and results are described in detail in the following paragraphs.

SAC TESTS

Subjects

Seven Goodyear Aerospace image interpreters and two radar engineers participated as experimental subjects (Ss) in this investigation.

Equipment

The color display facility described earlier was employed to display the color and black and white radar scenes to the subjects.

Radar Imagery

Forward-Looking Advanced Multimode Radar (FLAMR) images were government furnished for use in this research program. Twenty-two 40-foot-resolution radar scenes were provided on magnetic tapes. Each scene was approximately 2.5 NMI in range by 2.3 NMI in azimuth (about 5.76 NMI^2). These scenes were reviewed with respect to radar quality and appropriate target/offset aimpoints (OAPs).

Targets

The three tapes containing the 22 scenes were examined for appropriate SAC targets and offset aimpoints. By design, SAC targets/offset aimpoints are chosen to be as conspicuous as possible and often are the only prominent feature in a scene. Use of such targets located in a rather small field of view in a test designed to demonstrate a difference between or among various display conditions would not have much potential for discriminating among the test conditions. In other words, it would be so easy to find them on the baseline monochromatic scene that little, if any, hope exists for demonstrating improvement using color no matter how much the color appears to enhance the image quality. Consequently, less-prominent targets and OAPs were selected in an attempt to demonstrate an operator performance difference between chromatic and achromatic conditions.

Eleven radar scenes were selected for use in the investigation. Two scenes were chosen for the familiarization/practice trials and nine for the test session. Three targets/OAPs were selected on each of the radar images to permit a scene to be used three times with a different target/OAP each time. For illustration, however, three targets/OAPs are shown on each scene in Figures 28 through 47. Ten scenes are presented here, with one of the training scenes omitted. While each scene was presented to the subjects with each color code and in black and white, the scenes are illustrated here in one color code or the other. The corresponding black and white image is presented to provide the reader with a comparison.

A list of the SAC training and testing targets is included in Table 2. Targets 1-A through 2-C were used in training, and targets 1 through 27 in testing.

TABLE 2 – SAC TARGET/OAP DESCRIPTIONS

TARGET/OAP	DESCRIPTION	BACKGROUND
1-A	Road intersection	Cultivated fields
1-B	Junction of two fence/tree rows	Agricultural
1-C	Road intersection	Agricultural
2-A	Small groundwater pump facility	Agricultural
2-B	Road intersection	Agricultural
2-C	Apex of V-shaped treeline	Agricultural
1	Corner of a fence enclosing a missile site	Desert
2	Cloverleaf interchange	Urban/industrial
3	Canal junction	Desert
4	Building	Rural/coastal
5	Road intersection	Primarily urban
6	Large hangar-type building	Waterfront/airfield
7	Freeway overpass	Agricultural/residential boundary
8	Road intersection	Primarily urban/industrial
9	Peak of a hill	Agricultural/desert
10	Missile site	Desert
11	Large building	Urban/industrial
12	Highway interchange	Desert
13	Road intersection	Rural/residential
14	Road intersection	Residential/agricultural mix
15	Long segmented warehouse	Waterfront/airfield
16	Street intersection	Residential/agricultural mix
17	Two metal cylindrical storage tanks	Cleared terrain, smooth dirt
18	Road intersection	Agricultural/desert
19	Graded road pattern	Desert
20	Large building	Urban/industrial
21	Junction of canal and fence row	Desert
22	Road junction	Housing development in rural area
23	Street junction	New housing development
24	Rectangular fenced area	Commercial/residential/airfield
25	Road intersection	Agricultural near town
26	Corner of residential area	Residential/commercial
27	Curve in road	Agricultural/desert boundary

This table is repeated in Appendix C and includes the location cues that were provided on each of the six training and 27 test trials.

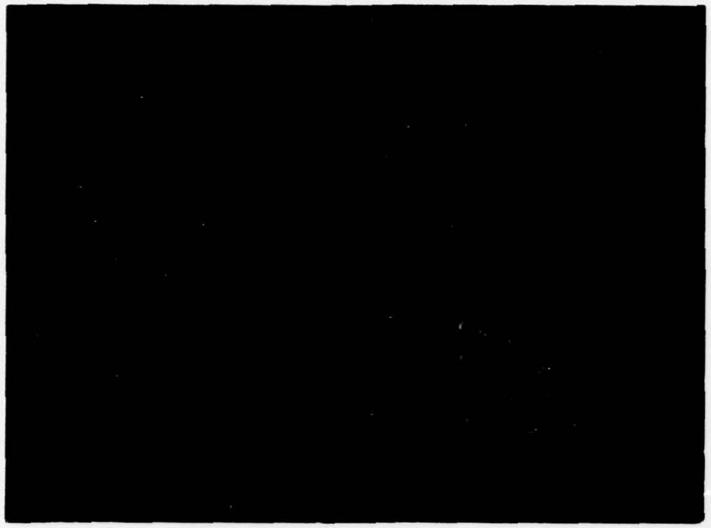


Figure 28 – SAC Training Targets in Color Code 1

Figure 29 – SAC Training Targets in Black and White

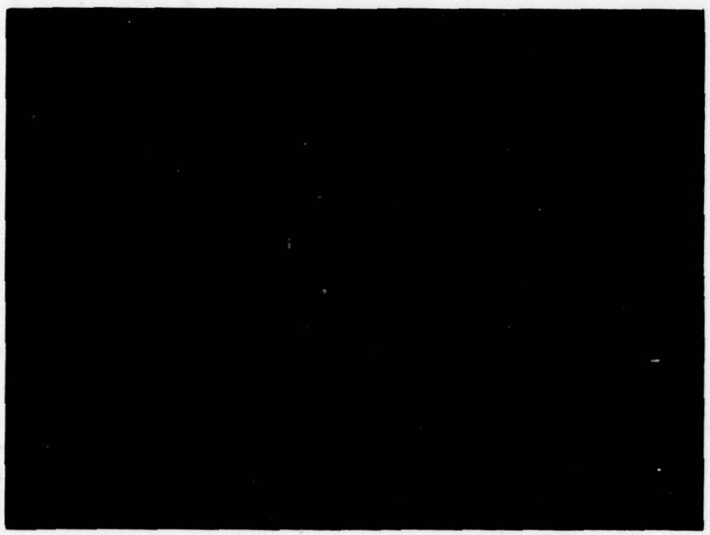


Figure 30 – SAC Test Targets 1, 10, and 19 in Color Code 2

Figure 31 – SAC Test Targets 1, 10, and 19 in Black and White

Figure 32 – SAC Test Targets 2, 11, and 20 in Color Code 1

Figure 33 – SAC Test Targets 2, 11, and 20 in Black and White

Figure 34 – SAC Test Targets 3, 12, and 21 in Color Code 2

Figure 35 – SAC Test Targets 3, 12, and 21 in Black and White

Figure 36 – SAC Test Targets 4, 13, and 22 in Color Code 1

Figure 37 – SAC Test Targets 4, 13, and 22 in Black and White

Figure 38 – SAC Test Targets 5, 14, and 23 in Color Code 2

Figure 39 – SAC Test Targets 5, 14, and 23 in Black and White

Figure 40 – SAC Test Targets 6, 15, and 24 in Color Code 1

Figure 41 – SAC Test Targets 6, 15, and 24 in Black and White

Figure 42 – SAC Test Targets 7, 16, and 25 in Color Code 2

Figure 43 – SAC Test Targets 7, 16, and 25 in Black and White

Figure 44 – SAC Test Targets 8, 17, and 26 in Color Code 1

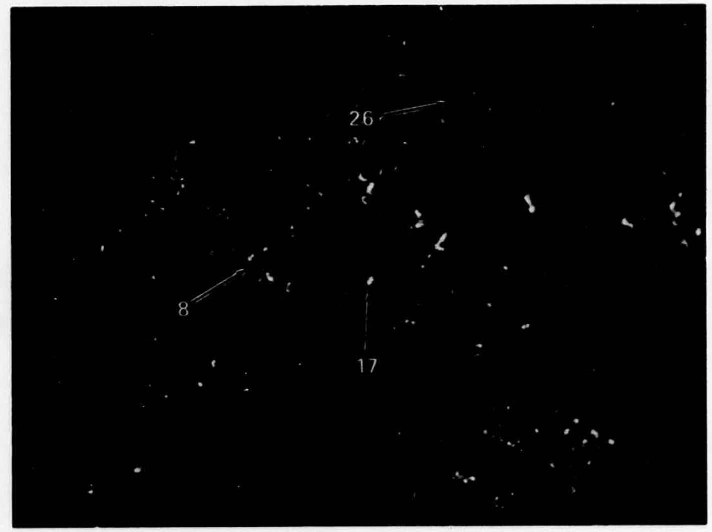


Figure 45 – SAC Test Targets 8, 17, and 26 in Black and White

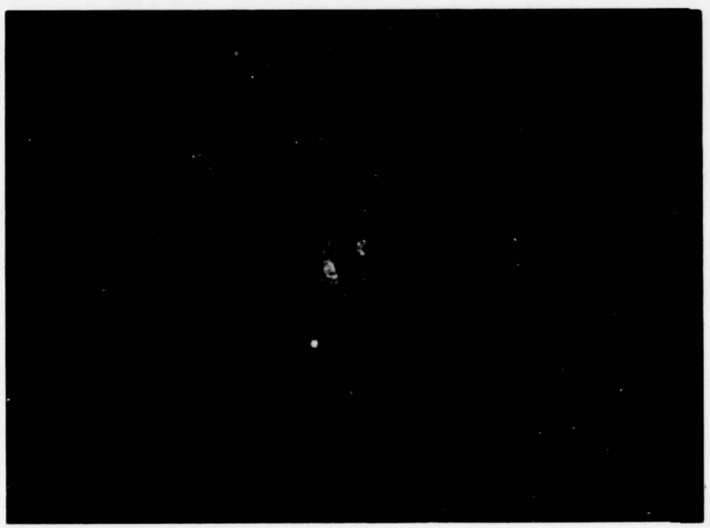


Figure 46 – SAC Test Targets 9, 18, and 27 in Color Code 2

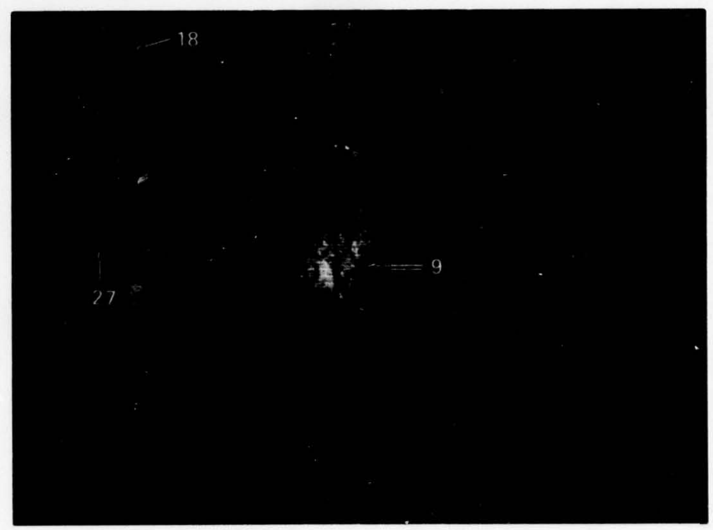


Figure 47 – SAC Test Targets 9, 18, and 27 in Black and White

Procedure

General Instructions – Prior to conducting the test, each subject was provided with a general description of the aims and objectives of the study. A brief summary described the various SAC, TAC and RECCE tasks in which he would be participating. A copy of this general briefing is included in Appendix D.

Briefing Materials – An individual folder was provided to the subjects for each target/OAP. The folder included a vertical aerial photograph covering about 40 square miles with an approximate scale of 1:96,000. An arrow or circle was placed on the photo to identify the aimpoint.

In addition, a photographic enlargement (250%) of the target area was provided to facilitate examination of contextual information immediately surrounding the target/OAP. This also permitted a more accurate analysis of the target/OAP itself.

A brief description of the aimpoint was included along with cues identifying salient features to aid the subject in finding the target/OAP.

Familiarization Training – Two radar scenes were selected to be used in a training session to familiarize the participants with the equipment, briefing materials, and the actual procedure to be followed in the testing phase. Three targets were selected from each scene, which resulted in six training scenes.

A target/OAP folder as described above was provided the subject and he examined the contents until he was confident of the target/OAP. When he said "ready," the radar scene was presented on the display. A stopwatch was started at this time and stopped when the subject said "there" and designated the target/OAP.

This procedure was followed for two training trials per subject. One of the two color codes was selected for the first trial and the other for the second. After the trial, the scene was displayed to the subject in the other color code and in black and white for comparison.

The subjects were instructed to work as quickly and accurately as possible.

Testing – Following the familiarization session the human factors test was conducted. The nine subject/observers were tested individually as described above. Each subject attempted to find the prebriefed target/OAP of interest on 27 separate test trials. Nine separate scenes were employed and each subject observed each scene three times; once under each of the two color-coded conditions and once with the black and white baseline code.

Table 3 is a summary of the experimental conditions. The numbers shown in the 27 cells represent the nine subjects and the rows and columns represent the tape-file, scene, target, and color code/black and white conditions, respectively.

Each subject was presented scenes numbered one through 27 in order. While this may result in an order effect manifested in performance improving across trials, it does not create a bias among the primary experimental variables, *i.e.,* color versus black and white.

Following each experimental trial the test conductor recorded the accuracy and time of the subject's response.

TABLE 3 – SAC TARGET AND COLOR CODE PRESENTED TO EACH SUBJECT ON EACH TEST TRIAL

TAPE FILE	SCENE	TARGET	CODE C1			CODE C2			CODE BW		
4078-4		1	1*	2	3	4	5	6	7	8	9
	1	10	4	5	6	7	8	9	1	2	3
		19	7	8	9	1	2	3	4	5	6
4078-6		2	2	3	4	5	6	7	8	9	1
	2	11	5	6	7	8	9	1	2	3	4
		20	8	9	1	2	3	4	5	6	7
4079-4		3	3	4	5	6	7	8	9	1	2
	3	12	6	7	8	9	1	2	3	4	5
		21	9	1	2	3	4	5	6	7	8
4079-5		4	1	4	7	2	5	8	3	6	9
	4	13	5	8	2	6	9	3	4	7	1
		22	9	3	6	7	1	4	8	2	5
4079-6		5	1	3	5	7	9	2	4	6	8
	5	14	7	9	2	4	6	8	1	3	5
		23	4	6	8	1	3	5	7	9	2
4079-7		6	2	4	6	8	1	3	5	7	9
	6	15	8	1	3	5	7	9	2	4	6
		24	5	7	9	2	4	6	8	1	3
4077-4		7	6	8	1	3	5	7	9	2	4
	7	16	3	5	7	9	2	4	6	8	1
		25	9	2	4	6	8	1	3	5	7
4077-5		8	1	5	9	4	8	3	7	2	6
	8	17	2	6	7	5	9	1	8	3	4
		26	3	4	8	6	7	2	9	1	5
4077-6		9	1	6	2	3	5	8	4	7	9
	9	18	3	5	8	4	7	9	1	6	2
		27	4	7	9	1	6	2	3	5	8

*Subject Number

Results and Discussion

The raw data were summarized and the black and white and color codes are compared in the following paragraphs with respect to the percent of targets/OAPs correctly detected, the time to detect and the rate of detection.

Target/OAP Detection – The percent of targets correctly detected was calculated for each of the two color codes and the black and white standard. These percentages are plotted in Figure 48. The subject/observers correctly located 80.2 percent of the target/OAPs with color code No. 1, 86.4 percent with color code No. 2, and 87.7 percent with the standard black and white image.

A z-test between proportions* (or percents) revealed that the difference observed between the black and white and color code No. 1 is not statistically significant ($z = 1.302$; $p > 0.19$).

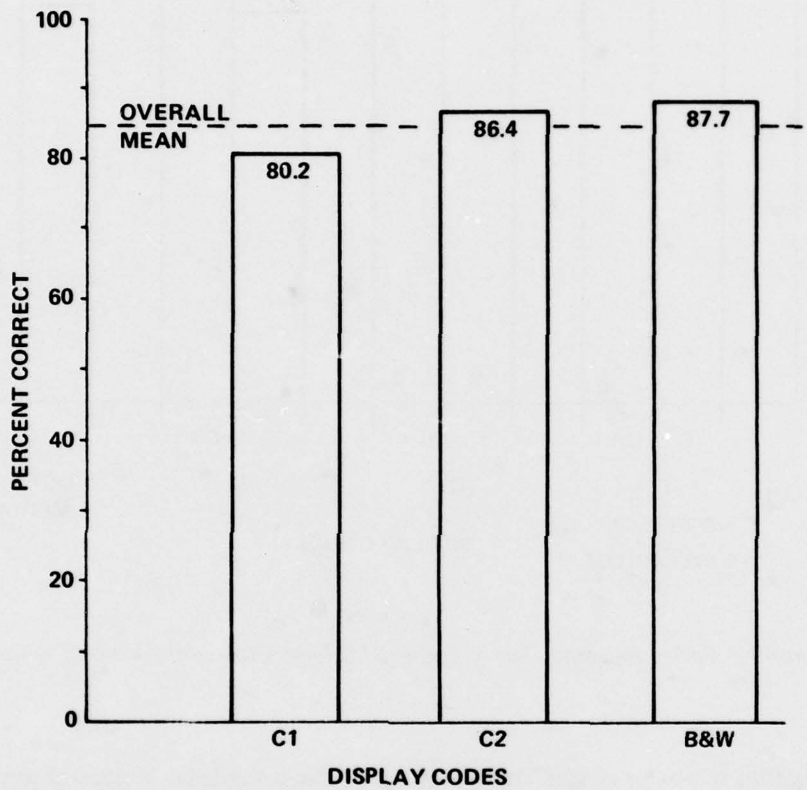


Figure 48 – Percent of Correctly Detected SAC Targets/OAPs for Each Display Code Tested

Response Time – When the observers correctly located the targets/OAPs they did so within a median time of 13 seconds. In fact, color code No. 1 produced a median correct response time of 12.8 seconds, code No. 2 a response time of 11.8 seconds, and the black and white standard a median response time of 11.0 seconds. These results are presented graphically in Figure 49. In addition to presenting the time required to correctly locate targets/OAPs the figure contains the results of correct plus incorrect designation times as well.

*The z-test is described in Appendix E for the reader desiring further information. A general discussion on statistical procedures for evaluating human factors studies also is included.

As previously stated for the slight differences in operator detection, no significant statistical difference exists between the median response times shown in Figure 49.

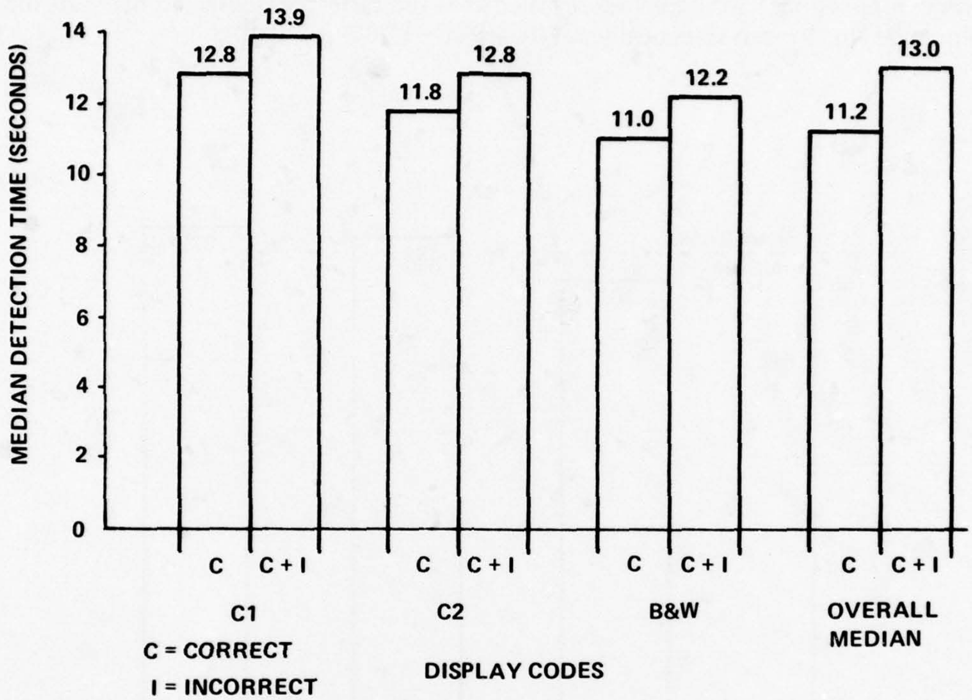


Figure 49 – Median Response Time to Locate SAC Targets/OAPs for Each Display Code

Prior to the investigation it was predicted that color would have the least impact of any on SAC operator performance. Since most of the salient features used by SAC operators for orientation, checkpoint navigation, etc., are terrain features, little potential exists for enhancing performance by extending the dynamic range of an image which has been "clipped". Only a slight difference appears between the terrain features imaged in black and white and color. In addition, a prebriefed location-known target or offset aimpoint is easily located in a 2 NMI field of view. It is therefore difficult to demonstrate a difference due to the chromaticity variable investigated because of the ease of the task.

The fact that the monochromatic image produced recognition and response times that were slightly better suggests that past experience with the black and white images may have had a small influence.

Acquisition Rate – In evaluating SAC performance it is imperative, in addition to examining the detection performance and response times separately, that particular emphasis be placed on the rate at which observers correctly recognized features of interest. Because of this mission-sensitive measure, the percent of correctly recognized targets and OAPs was calculated in 5-second intervals from zero through 30 seconds. These results are contained in Table 4 and plotted in Figure 50. The figure shows that the rates of acquisition for color code No. 2 and black and white are nearly identical. Z-tests performed between C2 and BW percentages at each of the five-second intervals confirms this observation. In fact, even the largest difference of 17.3 percent observed at 20 seconds between C1 and BW was found to be statistically insignificant at the 95-percent confidence level ($z = 1.8$).

The results of this study indicate, at least for the color schemes investigated, that enhancing the apparent dynamic range of the displayed radar scene does not produce a similar enhancement in SAC operator target/OAP recognition performance ($z = 1.8$; $p > 0.07$).

TABLE 4 – NUMBER OF TARGETS AND PERCENT OF CORRECT RESPONSES ACROSS TIME

TIME (SECONDS)	DISPLAY CODE							
	C1*		C2*		BW*		TOTAL*	
	NUMBER	PERCENT	NUMBER	PERCENT	NUMBER	PERCENT	NUMBER	PERCENT
0-5	11	13.6	16	19.8	16	19.8	43	17.7
0-10	25	30.1	21	35.8	34	42.0	88	36.2
0-15	37	45.7	46	56.8	47	58.0	130	53.5
0-20	44	54.3	54	66.7	58	71.6	156	64.2
0-25	50	61.7	61	75.3	62	76.5	173	71.2
0-30	55	67.9	65	80.2	64	79.0	184	75.7

*No. ÷ 81 = Percent. Total ÷ 243 = Percent.

TAC TEST

Subjects

The same subjects described for the SAC test plus three additional radar engineers participated in the TAC-oriented task.

Equipment

The color display facility employed in the SAC test and described earlier and in Appendix A was used in this TAC-oriented task evaluation.

Radar Imagery

Sixteen 20-foot resolution FLAMR radar scenes which were government furnished were reviewed for potential tactical-type targets. The scope of the research as defined in the statement of work addressed the detection of vehicular-type targets but no such targets could be confirmed since simultaneous ground truth was not available. Consequently it was decided to simulate various military targets by implanting or "salting" them into the imagery.

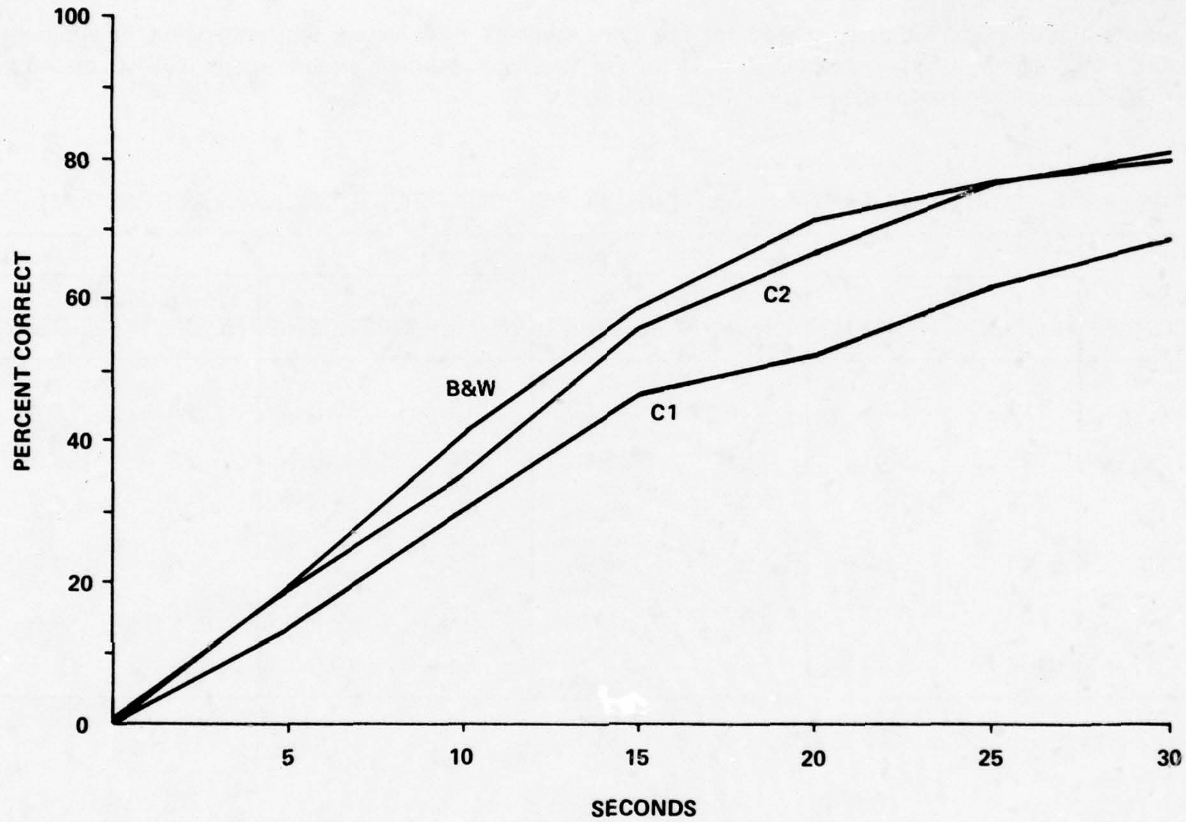


Figure 50 – Percent of SAC Targets/OAPs Correctly Detected as a Function of Time

Targets/Salting Procedure

One scene of the 20-foot resolution FLAMR imagery included the USMC Supply Center at Barstow, California. The Nebo Test Site (1973) was imaged on this radar pass. The site includes various military vehicles and artillery pieces oriented at different angles to the flightpath.

A software program was written which superimposes a grid over the displayed radar scene, the cells of which contain 32 by 32 pixel elements. This grid permits the investigator to determine the record-by-element coordinate of the center of an area of interest. Typing this coordinate into the keyboard results in a 32-record by 32-element printout of image levels proportional to the radar cross-section in dBs. The 255 possible image levels are equal to 0.375 dB steps. The printout is centered on the desired coordinate.

Once the record of the area is printed out it can be matched with the radar scene, thereby enabling the determination of the image levels of a given target or background. The investigator then can alter the value of any single pixel by entering the desired level through the display facility keyboard. Values can be increased or decreased.

In order to achieve the most valid method of "salting" targets into the various 20-foot FLAMR scenes, a printout of the entire Nebo Site was obtained. This record provided both the values and number of pixels for each of the targets in the array, eliminating the need to guess during the "salting" procedure. These values were compared with the values of a nearby patch of background clutter to determine the signal-to-clutter ratio.

Figure 51 contains histograms of desert background and peak values of jeeps, tanks, and trucks recorded by the FLAMR system over the Nebo Array. With each of the input steps approximately 1.5 dB, the desert covers about 12 dB of dynamic range while the targets cover approximately 18 dB. The maximum signal to noise shown in the figure between trucks at step 22 and maximum desert at step 10 is 18 dB. The maximum signal to average clutter on the Nebo imagery is about 24 dB. Since the Nebo Array was situated in a nearly clutter-free environment, the 24-dB maximum signal to average clutter was established as the upper limit for determining values of salted targets.

Targets were implanted to yield signal-to-average immediate background ratios ranging from 7 to 15 dB. Assuming a σ_0 of −17 dB for the background, this represents target cross sections of 40 square feet to 250 square feet. Targets implanted with values equal to or lower than the background simply would have limited operator performances proportional to the number of targets simulated at the lower levels which are "invisible."

Given this simulation philosophy or strategy, a number of tactical-type mobile targets were examined to determine their physical and operational configurations. The resulting list of 12 targets which were generated is shown as Table 5. Actual target values and their associated clutter values are included in Appendix E with 31-pixel by 31-pixel histograms of the target scene.

In addition, six radar scenes were selected for familiarization training and a different target was implanted in each scene. These targets are identified in Table 5 as A through F. The number of vehicles, weapons, or active positions of each target is shown in parentheses behind the target in the table.

The training and testing targets are shown in Figures 52 through 87. Each target is shown in black and white and alternately in color code No. 1 and color code No. 2.

Procedure

General Briefing – Each of the 12 subjects was individually briefed on the intent and purpose of the TAC evaluation. They were informed that they would be presented with 12 radar scenes, four in color code No. 1, four in color code No. 2, and four in black and white. They also were advised of the types of targets that they could expect to find and that a short practice session would be given to familiarize them with the test conditions.

Briefing Materials – The general briefing instructions and sketches of target signatures that were provided the subjects during the briefing are reproduced in Appendix D.

Familiarization Training – During the familiarization trials, the subject was presented with three different radar scenes, one in color code No. 1, one in color code No. 2, and one in black and white. Prior to each training trial he was told what kind of target to find, *e.g.*, convoy, and he was asked to count the number of vehicles, weapons, or active positions (in the case of SAM or AAA sites) in the target.

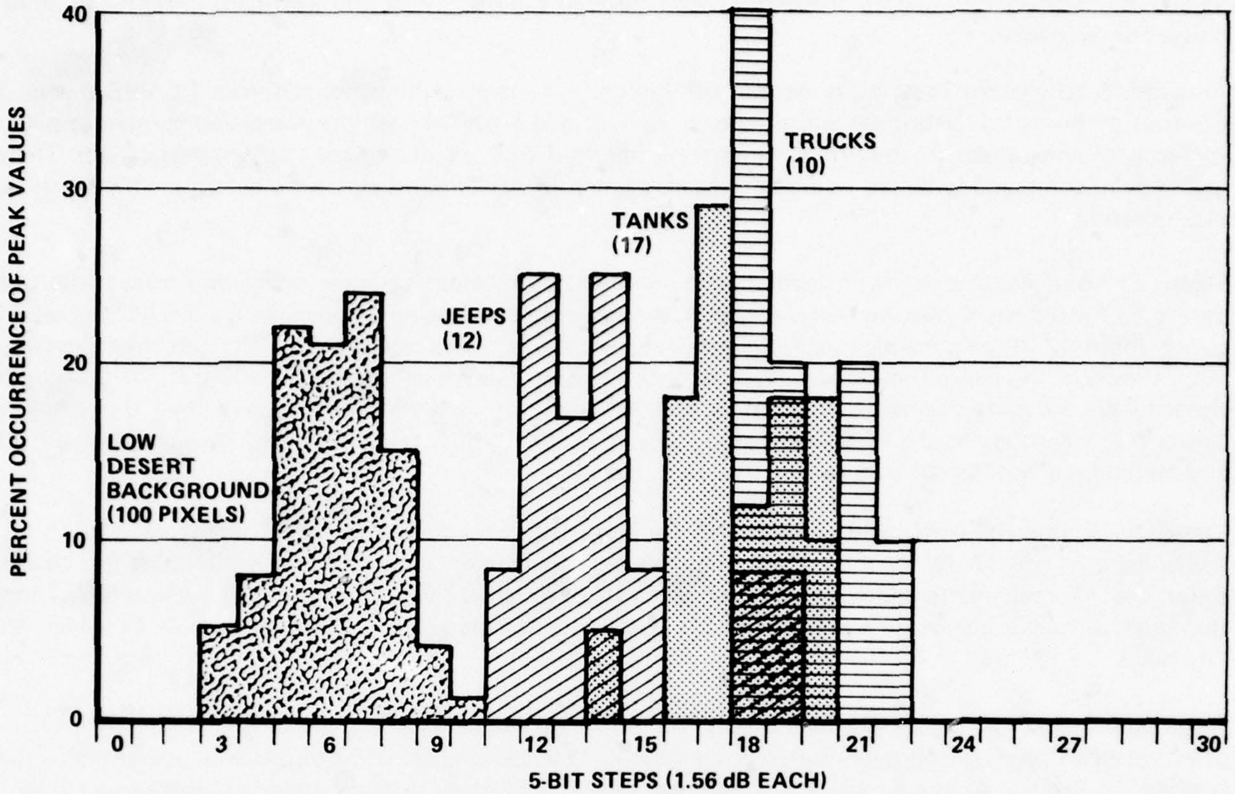


Figure 51 – Background and Target Distributions of 1974 Nebo Array Measured on FLAMR Imagery

The color or black and white step wedge was displayed on the CRT. When the subject said "ready", the experimenter switched from the step wedge to the radar scene and started a stopwatch. When the subject found the target, designated it and said "there" the watch was stopped. The subject then counted and reported the number of vehicles he detected. The experimenter recorded whether the subject was right or wrong, the number of vehicles reported, and the response time to designate the target. During training the subject was provided feedback regarding his response(s) and after the trial was shown the scene in the other two codes for comparison.

Testing – Following the familiarization phase, the testing was conducted. As in the training session subjects were informed that a target of a particular type was situated somewhere in the radar scene and advised of the general background of the scene. When the subject said "ready", the radar scene was displayed and the stopwatch begun. The watch was stopped when the subject said "there!" The subject counted the weapons, vehicles, or active positions and reported the number aloud. The detection time was recorded by the experimenter. He also recorded whether or not the subject designated the target of interest.

The target/display code combinations presented to each of the 12 subjects are shown in Table 6. Inspection of this table reveals that each target/scene was viewed by a different combination of six subjects.

It was decided to use the same targets and scenes for both the TAC and RECCE tests. The six subjects not shown in Table 6 as being tested on a particular target in the TAC task were tested on that target in the

RECCE situation. For example, subjects one through six were exposed to traget No. 1 preceded by a TAC briefing and subjects seven through twelve were tested on the same simulated target after a RECCE briefing.

The permutation of subjects across code target combinations shown in the table resulted in each subject viewing six different radar targets/scenes, two at each display code.

Results

Target Detection — The target detection data were summarized and the percent of correctly detected targets calculated. These percentages are presented in Figure 88 for each of the three display codes employed in the test. Each of the histograms represents a summary of 24 observations since each of the 12 subjects observed each color code twice.

TABLE 5 – SIMULATED TRAINING TARGETS (A THROUGH F) AND TEST TARGETS (1 THROUGH 12) USED IN THE TAC EVALUATION

NUMBER	TARGET	TAPE-FILE NO.
A	Fixed SAM (7)*	3299-1
B	Convoy (6)	3299-2
C	Hawk SAM (7)	4049-5
D	Vehicle Park (10)	4049-7
E	Artillery (7)	4050-6
F	Chaparral SAM (7)	3299-5
1	Artillery (7)	3299-2
2	Vehicle Park (13)	4049-4
3	Artillery (7)	4049-3
4	AAA (7)	3299-5
5	Fixed SAM (7)	3299-3
6	SP Guns (6)	3299-6
7	Convoy (6)	4050-1
8	Chaparral SAM (7)	4050-2
9	FARP**(8)	4050-3
10	Vehicle Park (12)	4049-2
11	AAA (7)	4049-1
12	Hawk SAM (7)	4049-4

*Number of vehicles, weapons, or positions in target
**Forward Aerial (Helicopter) Refueling Point

TABLE 6 – EXPERIMENTAL CONDITIONS FOR EACH OF 12 SUBJECTS IN THE TAC TEST

TARGET	CODE		
	C1	C2	BW
1	1, 2	3, 4	5, 6
2	2, 3	4, 5	6, 7
3	3, 4	5, 6	7, 8
4	4, 5	6, 7	8, 9
5	5, 6	7, 8	9, 10
6	6, 7	8, 9	10, 11
7	7, 8	9, 10	11, 12
8	8, 9	10, 11	12, 1
9	9, 10	11, 12	1, 2
10	10, 11	12, 1	2, 3
11	11, 12	1, 2	3, 4
12	12, 1	2, 3	4, 5

Figure 52 – TAC Training Target A, Code 1

Figure 53 – TAC Training Target A, Code BW

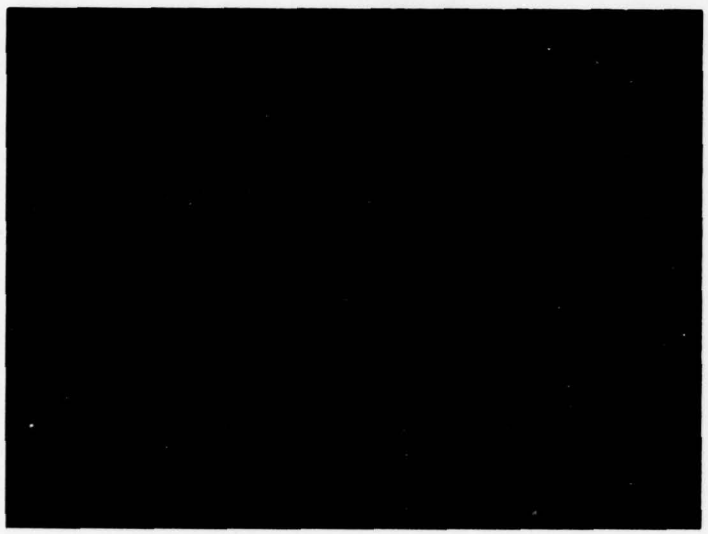


Figure 54 – TAC Training Target B, Code 2

Figure 55 – TAC Training Target B, Code BW

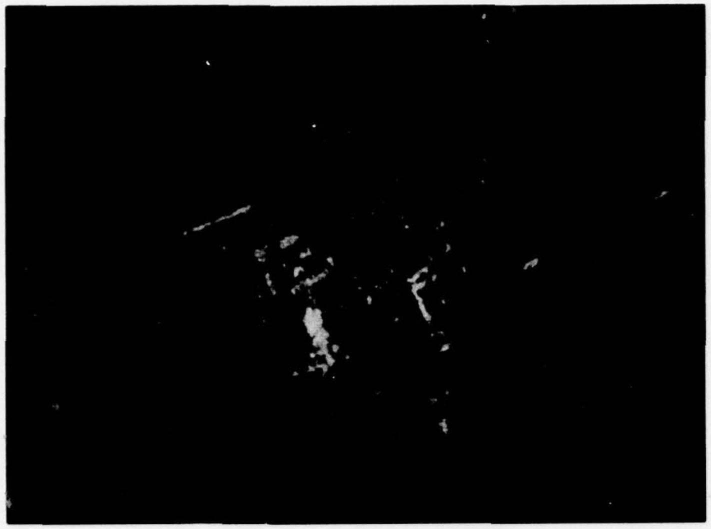


Figure 56 – TAC Training Target C, Code 1

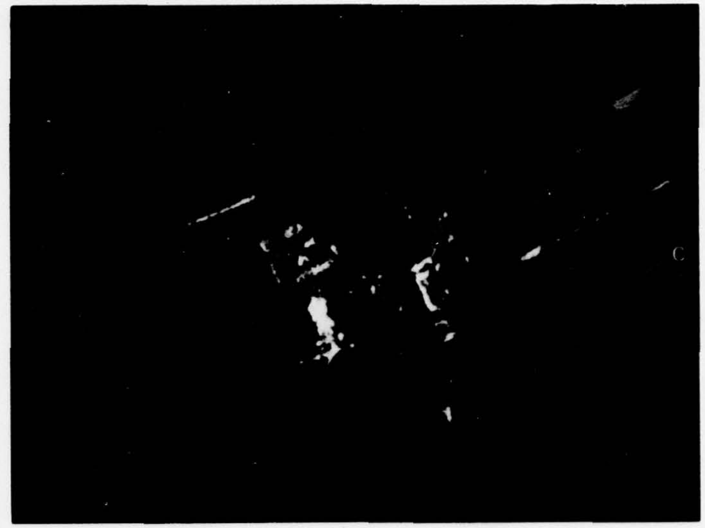


Figure 57 – TAC Training Target C, Code BW

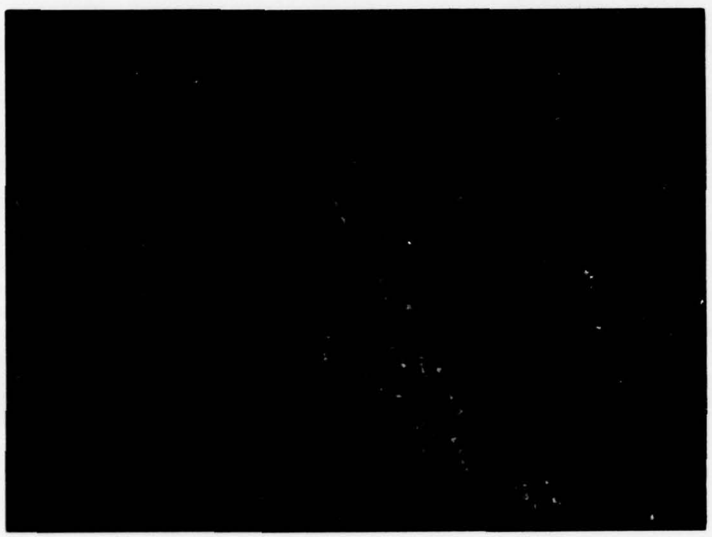


Figure 58 – TAC Training Target D, Code 2

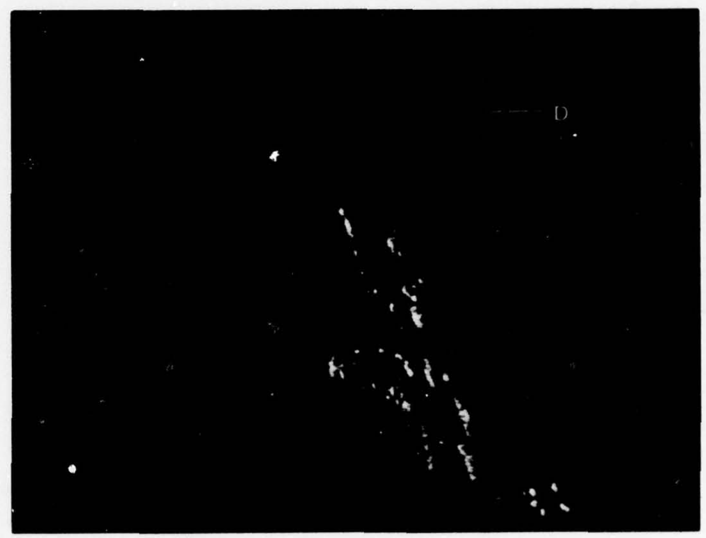


Figure 59 – TAC Training Target D, Code BW

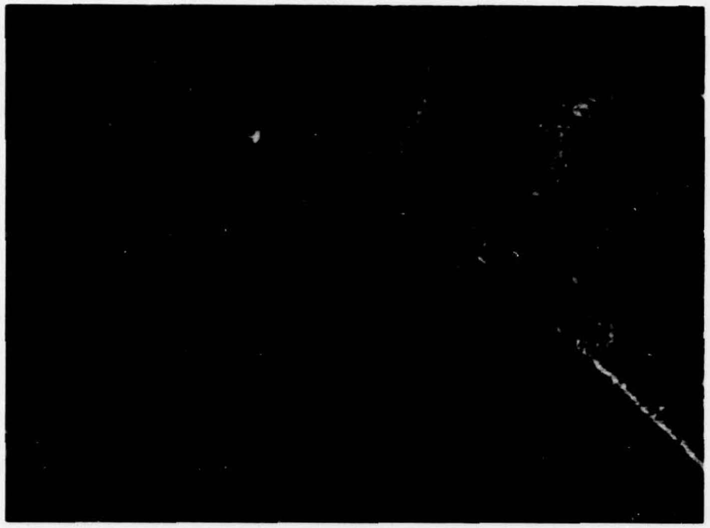


Figure 60 – TAC Training Target E, Code 1

Figure 61 – TAC Training Target E, Code BW

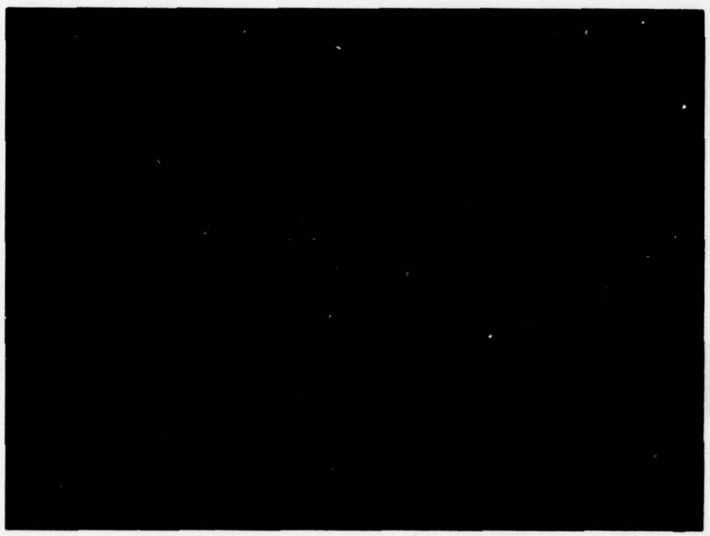


Figure 62 – TAC Training Target F, Code 2

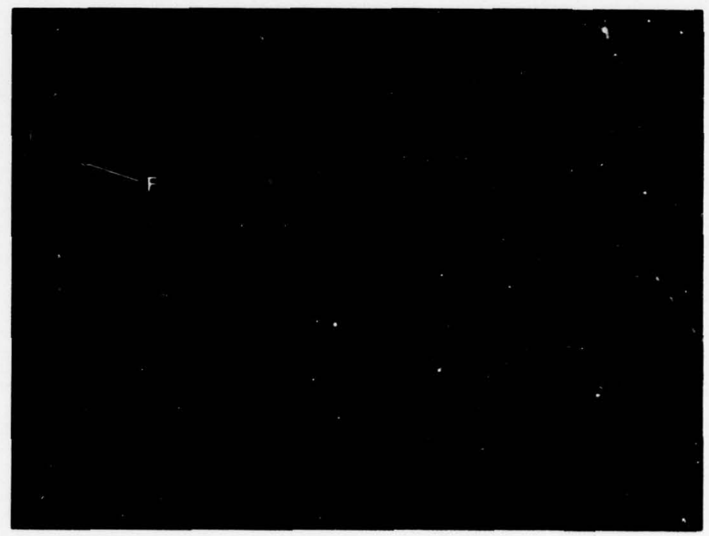


Figure 63 – TAC Training Target F, Code BW

Figure 64 – TAC Target 1, Code 1

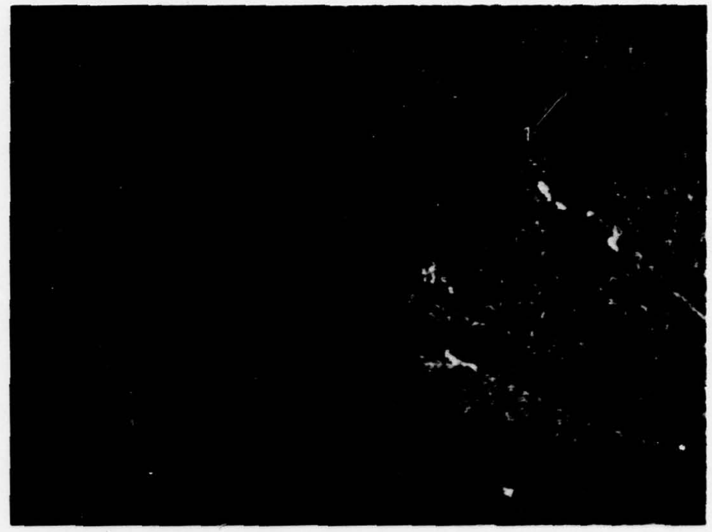


Figure 65 – TAC Target 1, Code BW

Figure 66 – TAC Target 2, Code 2

Figure 67 – TAC Target 2, Code BW

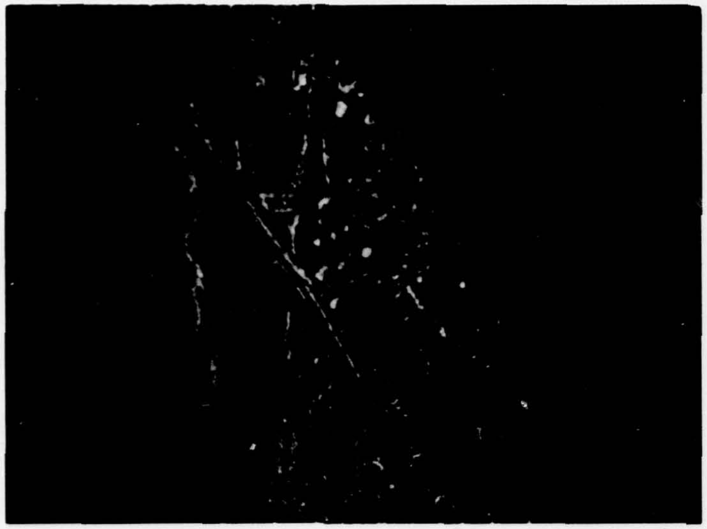


Figure 68 – TAC Target 3, Code 1

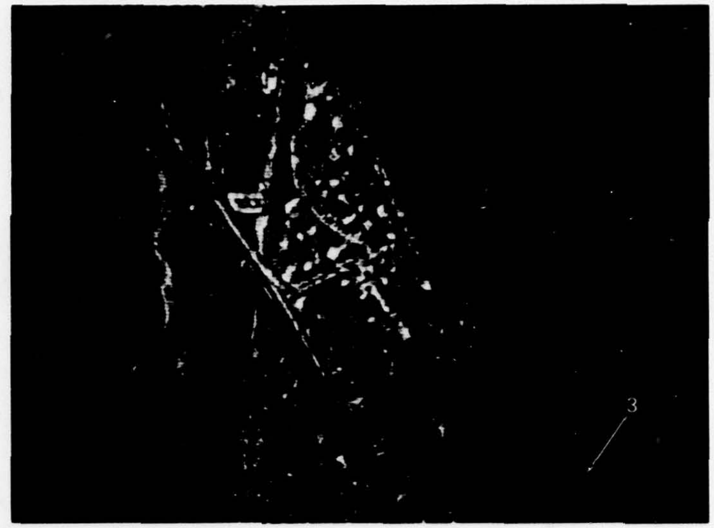


Figure 69 – TAC Target 3, Code BW

Figure 70 – TAC Target 4, Code 2

Figure 71 – TAC Target 4, Code BW

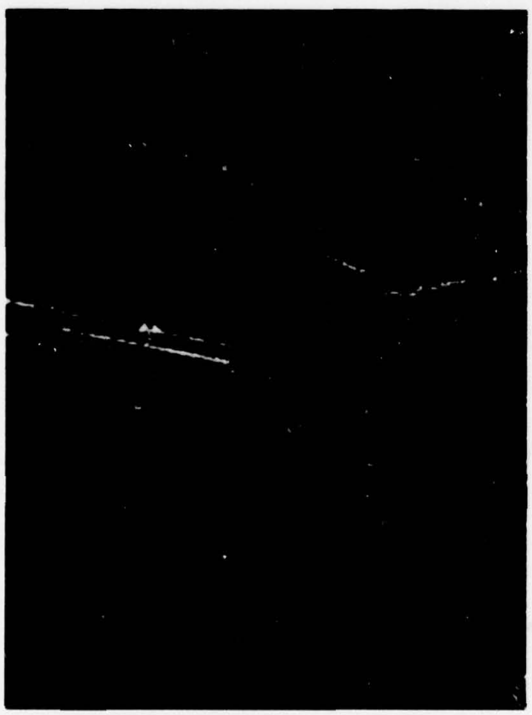


Figure 72 – TAC Target 5, Code 1

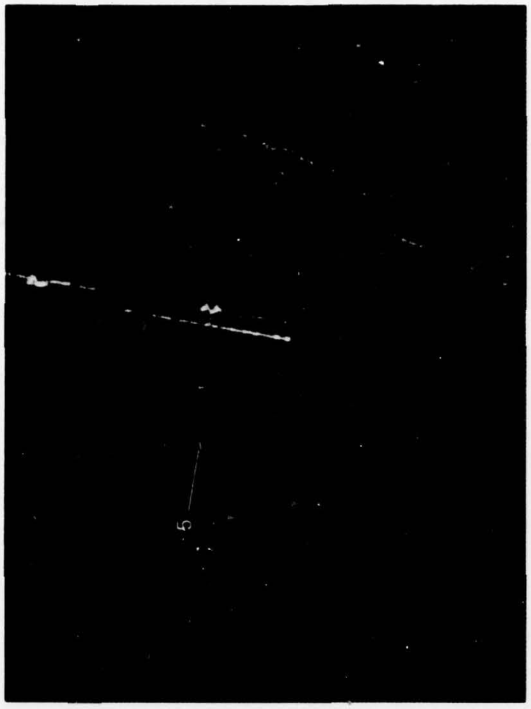


Figure 73 – TAC Target 5, Code BW

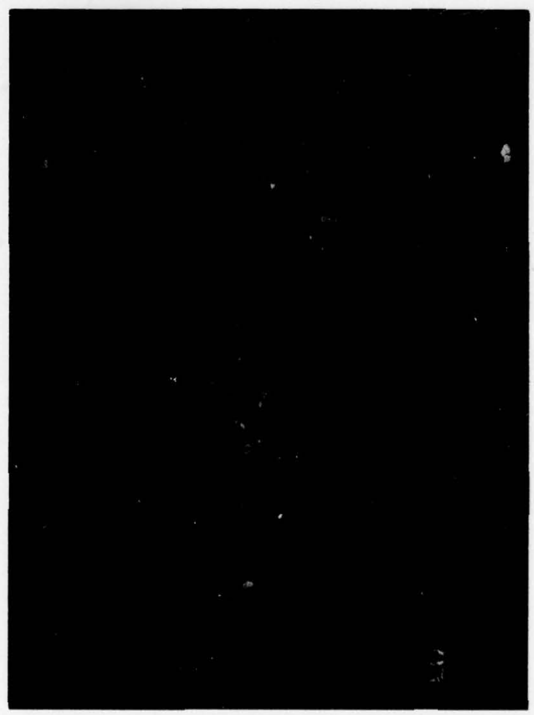


Figure 74 – TAC Target 6, Code 2

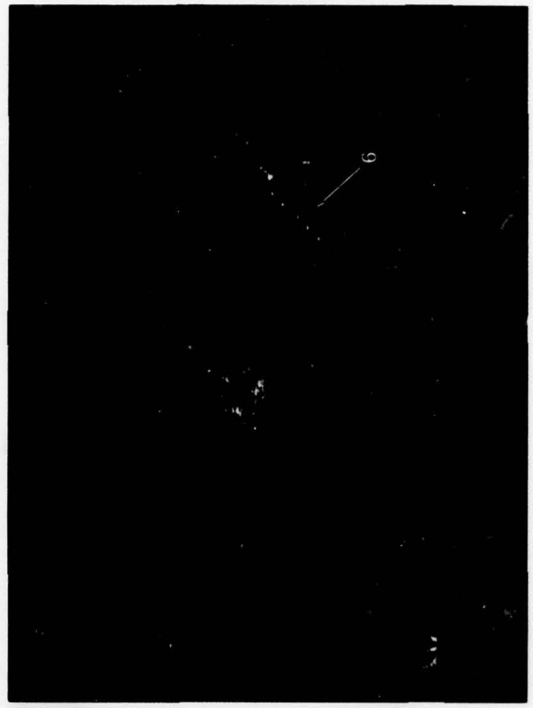


Figure 75 – TAC Target 6, Code BW

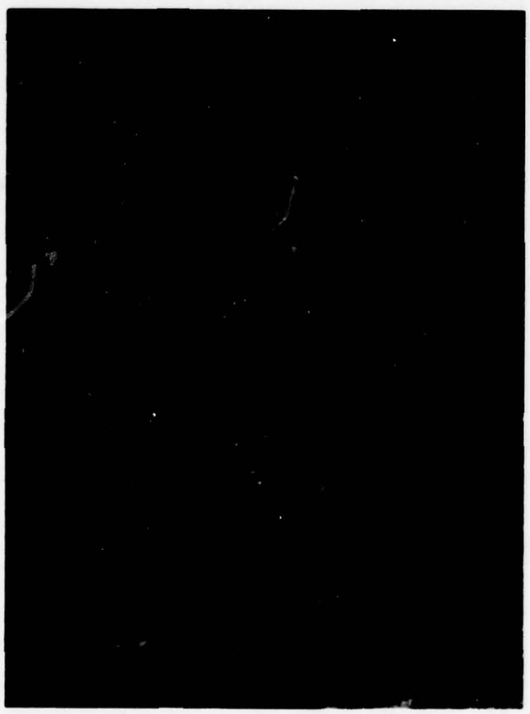


Figure 76 – TAC Target 7, Code 1

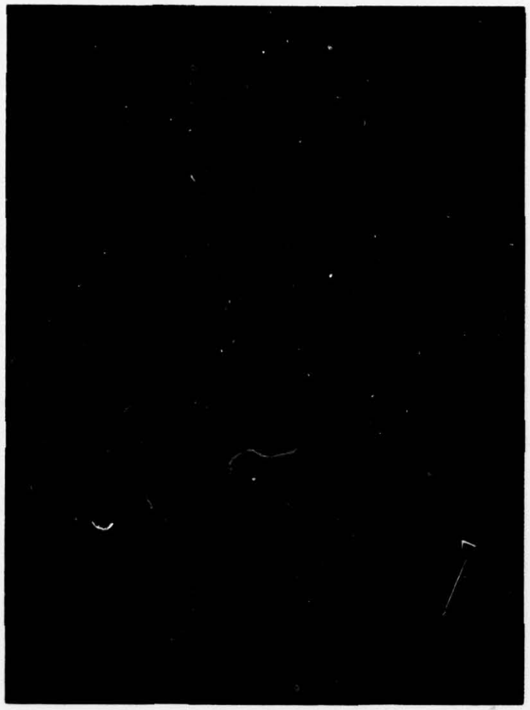


Figure 77 – TAC Target 7, Code BW

Figure 78 – TAC Target 8, Code 2

Figure 79 – TAC Target 8, Code BW

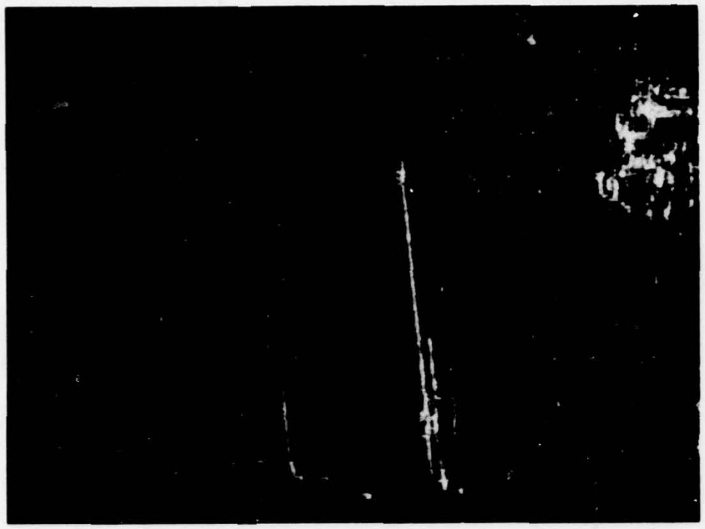


Figure 80 – TAC Target 9, Code 1

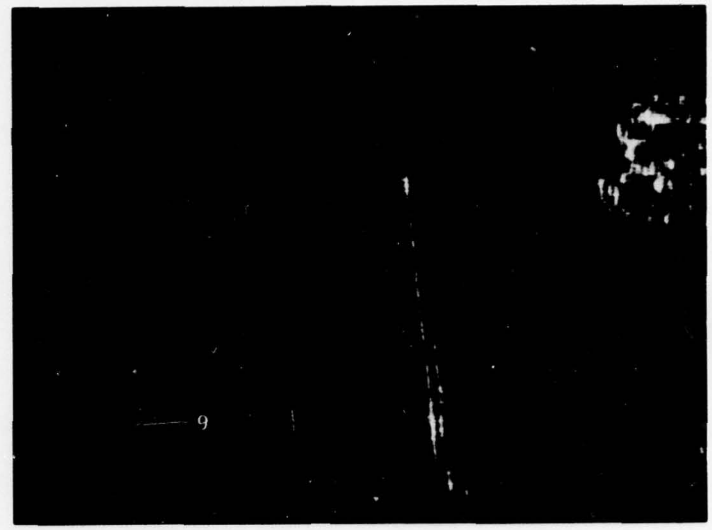


Figure 81 – TAC Target 9, Code BW

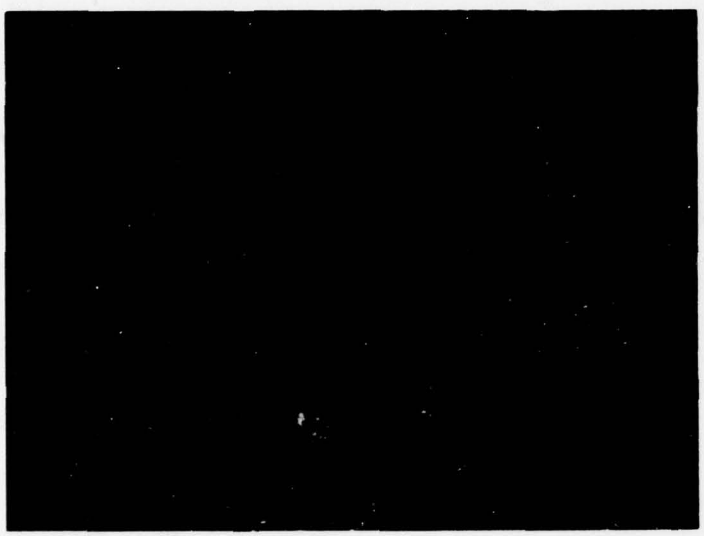


Figure 82 – TAC Target 10, Code 2

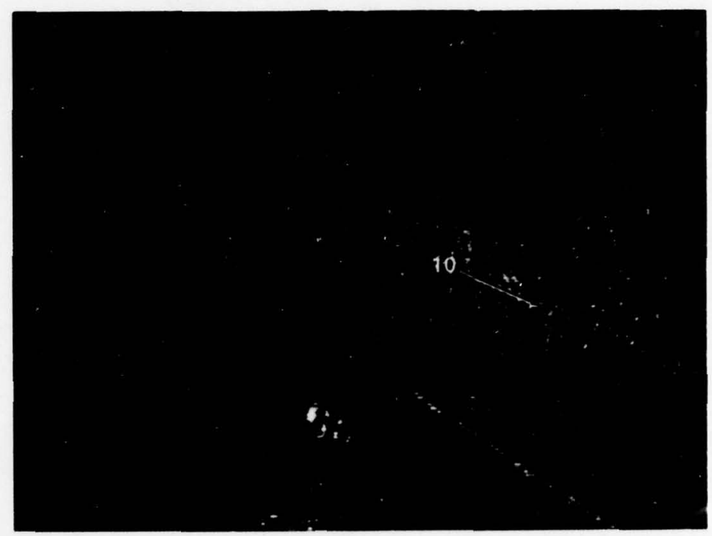


Figure 83 – TAC Target 10, Code BW

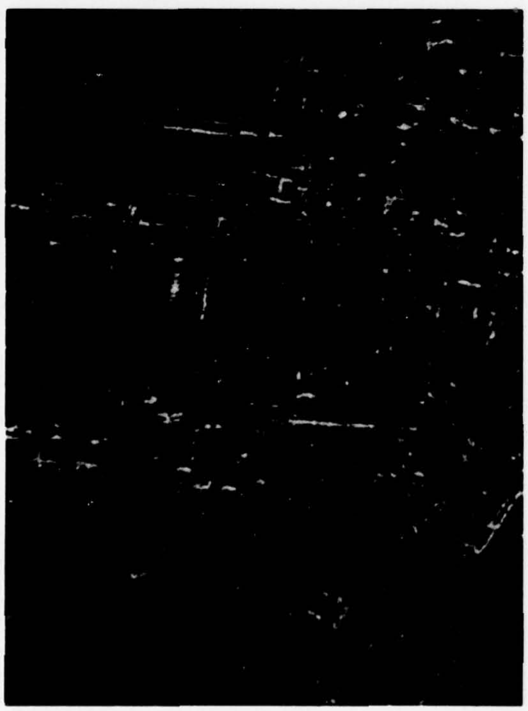


Figure 84 – TAC Target 11, Code 1

Figure 85 – TAC Target 11, Code BW

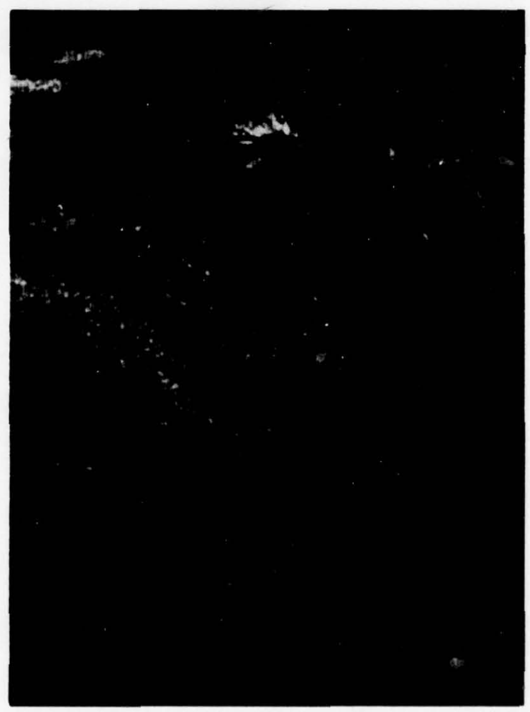


Figure 86 – TAC Target 12, Code 2

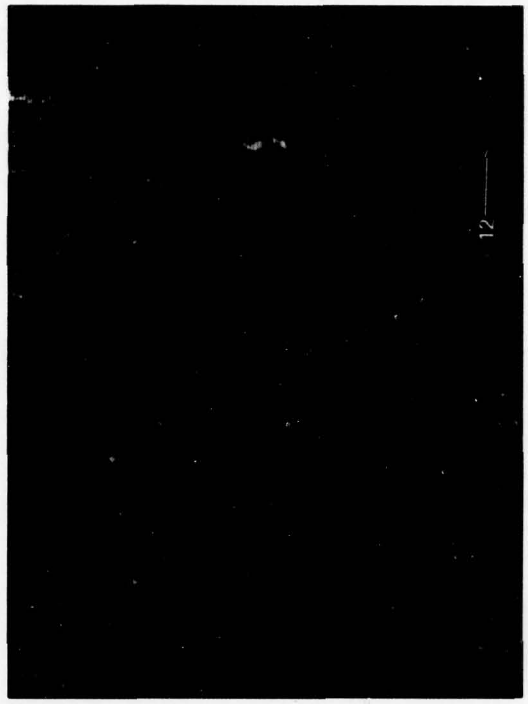


Figure 87 – TAC Target 12, Code BW

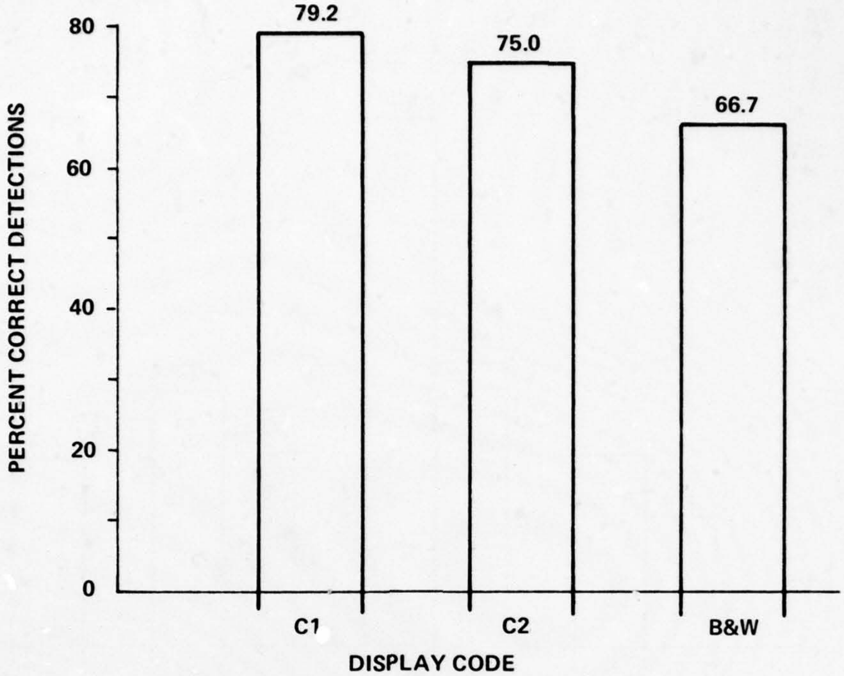


Figure 88 – Percent of TAC Targets Correctly Identified for Each Display Code

The figure shows that the color code generated to facilitate small target detection (C1) produced the highest number of correct detections, 79.2 percent. Seventy-five percent of the targets were detected with Code 2 and 66.7 percent with the black and white standard.

A z-test for differences between proportions failed to demonstrate a statistically significant difference between performances obtained with the C1 versus BW codes ($p > 0.32$).

The reader should be aware that statistical tests are dependent upon the sample size of observations. Equivalent scores produced by 100 observations (versus 24) in this case would yield statistical significance with the z-test. And while these statistical tests are warranted in the analysis of human factors studies of this sort, it is still important that operational decision-makers evaluate the observed differences among test conditions in making final conclusions. It may be important in one situation if performance can be improved by 10 percent over the status quo irrespective of statistical results providing the test procedures and analyses are valid.

Response Time – The median detection times for correct and correct plus incorrect responses were calculated. These results are shown in Figure 89. Correct detections were obtained at median times of 5.9 seconds, 8.1 seconds, and 10.1 seconds with C1, BW, and C2 codes, respectively. Statistical tests failed to demonstrate that C1 produced quicker response times than either BW ($X^2 = 1.073$; $p > 0.29$) or C2 ($X^2 = 1.334$; $p > 0.2$). One possible explanation is offered to account for the response times of C2 being higher than those obtained for C1 and BW. Most of the targets of interest occur in the grey and red levels of the C2 step wedge and the combined effect yields a target complex characterized with a mixture of brightness and hue, *i.e.,*

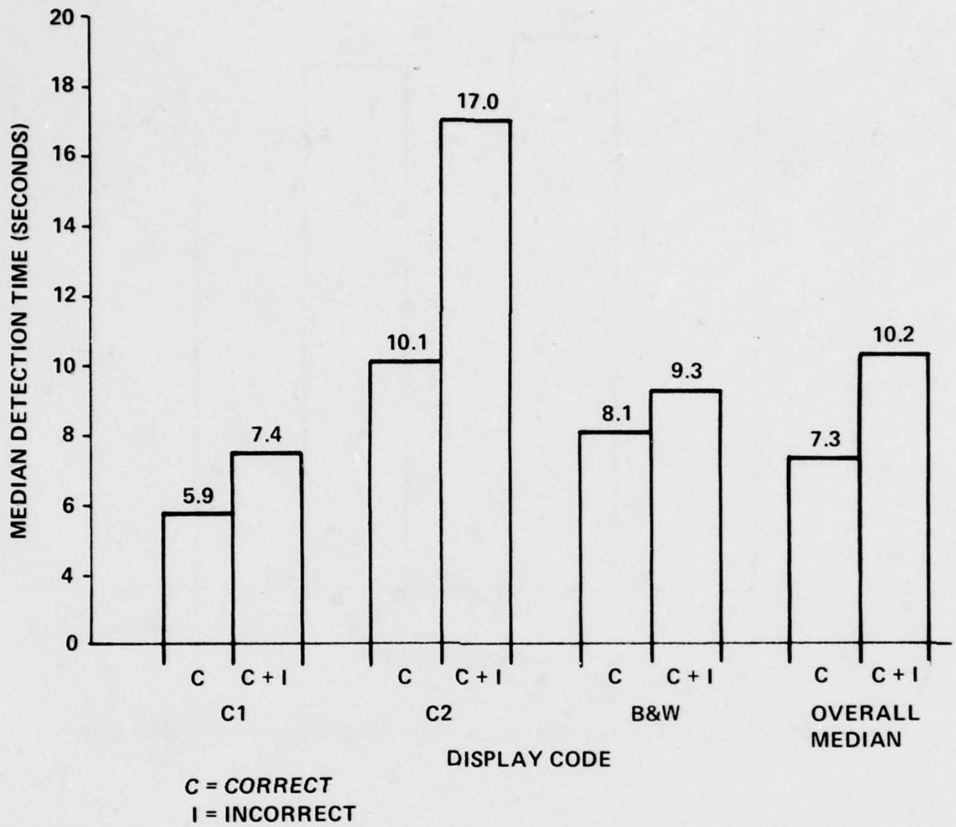


Figure 89 – Median Detection Times of TAC Targets for Each Display Code

grey and red, which is confusing. Brightness appears to be the salient cue for observers attempting to detect targets. When hue interacts with brightness, it possibly can interfere with performance. If this is the case, it is most likely due to a perceptual set developed through experience that could be overcome with additional exposure to color-coded imagery.

Acquisition Rate – The percent of targets recognized as a function of time was calculated for each of the three display codes. These results are contained in Table 7. These performances also are plotted in Figure 90. While response times longer than those recorded in the table and figure occurred, TAC operators rarely have longer than 30 seconds to detect, recognize, and designate a target. For this reason, the results are presented within the operational time frame of 30 seconds.

It is rather obvious in Figure 90 that the color code (C1) generated to produce high target detection yielded more correct target detections at a higher rate than the other two codes. The C1 performance rapidly produces about 30 percent correct detections within the first five seconds. This performance rate is somewhat constant for C1 throughout the first 15 seconds, with the subjects correctly detecting about 71 percent of the targets.

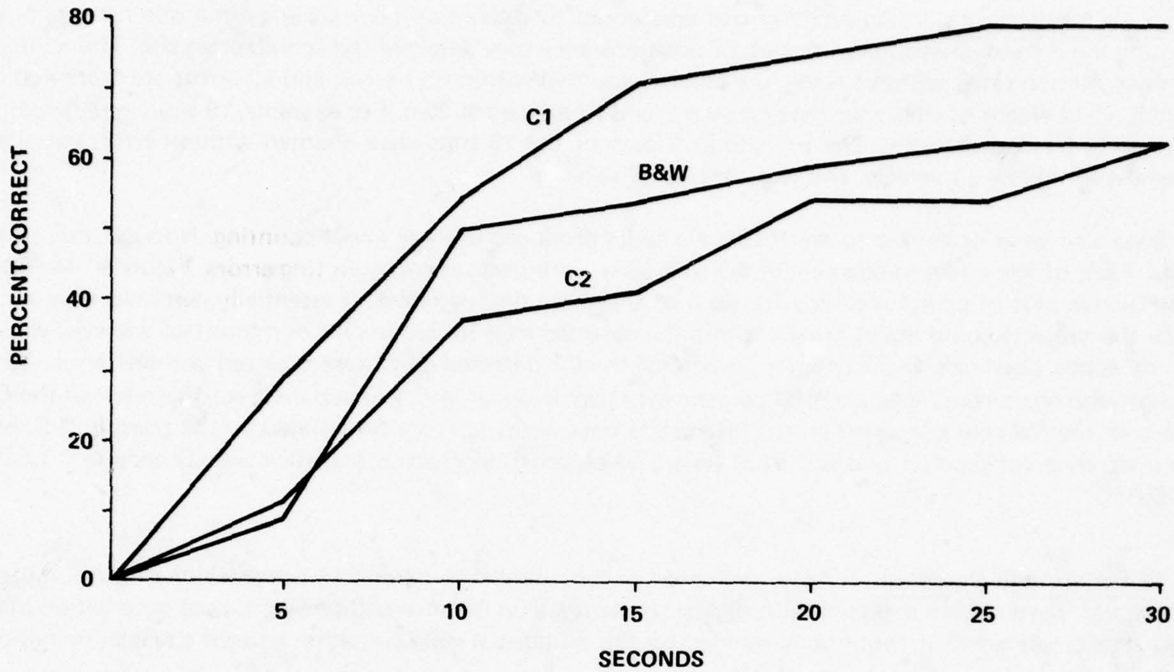


Figure 90 – Percent of TAC Targets Correctly Detected as a Function of Time

Although the C1 performance appears in Figure 90 to be clearly superior to the C2 and BW performance, z-tests failed to produce a significant statistical difference ($p > 0.28$ at 30 seconds). Once again it appears as if the small sample size at each of the elapsed time intervals is too small to produce statistical significance even though the performance seems to be consistent.

TABLE 7 – NUMBER OF TARGETS AND PERCENT CORRECT RESPONSES ACROSS TIME FOR TAC TEST

TIME (SECONDS)	DISPLAY CODE							
	C1*		C2*		BW*		TOTAL*	
	NUMBER	PERCENT	NUMBER	PERCENT	NUMBER	PERCENT	NUMBER	PERCENT
0-5	7	29.2	3	12.5	2	8.3	12	16.7
0-10	13	54.2	9	37.5	12	50.0	34	47.2
0-15	17	70.8	10	41.7	13	54.2	40	55.6
0-20	18	75.0	13	54.2	14	58.3	45	62.5
0-25	19	79.2	13	54.2	15	62.5	47	65.3
0-30	19	79.2	15	62.5	15	62.5	49	68.1

*No. ÷ 24 = Percent. Total ÷ 72 = Percent.

Target Count Accuracy – An analysis was conducted to determine how accurate the observers were in counting the individual weapons, vehicles, or positions once they detected the actual target site. The number of target sites counted without error, the number counted within a ±1 error, and ±2 errors are presented in Table 8. The percent of sites counted exactly, ±1, and ±2 also are shown. For example, 19 sites were detected viewing the C1 coded scenes. The vehicles in fifteen of the 19 sites were counted without error, two sites were miscounted by ±1 vehicle, and two sites by ±2 vehicles.

The data also were examined to see if specific codes produced over- or under-counting. No such indication exists. Each of the codes yielded about a 3-to-1 (over-to-under) ratio of counting errors. Figure 91 includes a cumulative plot of count accuracy for each of the three display codes. It essentially describes how accurately the subjects could count targets within the detected sites to within plus or minus two vehicles, weapons, or active positions. Seventy-eight percent of the C1 detected sites were counted without error; 89.4 percent with one error or less, and 100 percent with two errors or less. The apparent enhancement of the C1 code over the BW code suggested by the histograms once again was unsubstantiated by the z-test ($p > 0.49$). The difference between C1 and C2 (78.9 versus 50 percent) approaches statistical significance ($z = 1.839$; $p < 0.07$).

Target Pattern and Detection – An examination of the results was conducted to see whether or not targets with regular patterns are detected with higher regularity than unpatterned targets. Casual observation indicated that target signal strength compounded by the number of vehicles within a target site is more important than target pattern as a salient cue in detection. For example, one artillery site with a pattern identical to the briefing materials, but with low signal strength, was detected only once out of six attempts. On the other hand, an unpatterned vehicle park with more vehicles and stronger signals was detected every time it was presented.

TABLE 8 – NUMBER AND PERCENT OF DETECTED TARGET SITES CORRECTLY AND INCORRECTLY COUNTED

TARGET COUNT (ERRORS)		DISPLAY CODE		
		C1 (19)*	C2 (18)*	BW (16)*
NUMBER	None	15	9	11
	± 1	2	7	2
	± 2	2	1	2
	Total	19	17	15
PERCENT	None	78.9	50.0	68.8
	± 1	10.5	38.9	12.5
	± 2	10.5	5.6	12.5
	Total	100.0	94.4	93.8

*No. correctly detected out of 24.

RECCE TEST

Subjects

The same 12 subjects who participated in the TAC-type situation were employed in this evaluation.

Equipment

The Color Display Facility described earlier and in Appendix A was used in this study to display color and black and white radar scenes.

Radar Imagery

The same FLAMR scenes selected for the TAC evaluation were utilized in the RECCE-type situation described in the following paragraphs.

Targets

The targets imbedded in the 12 FLAMR scenes described previously also were used in this test.

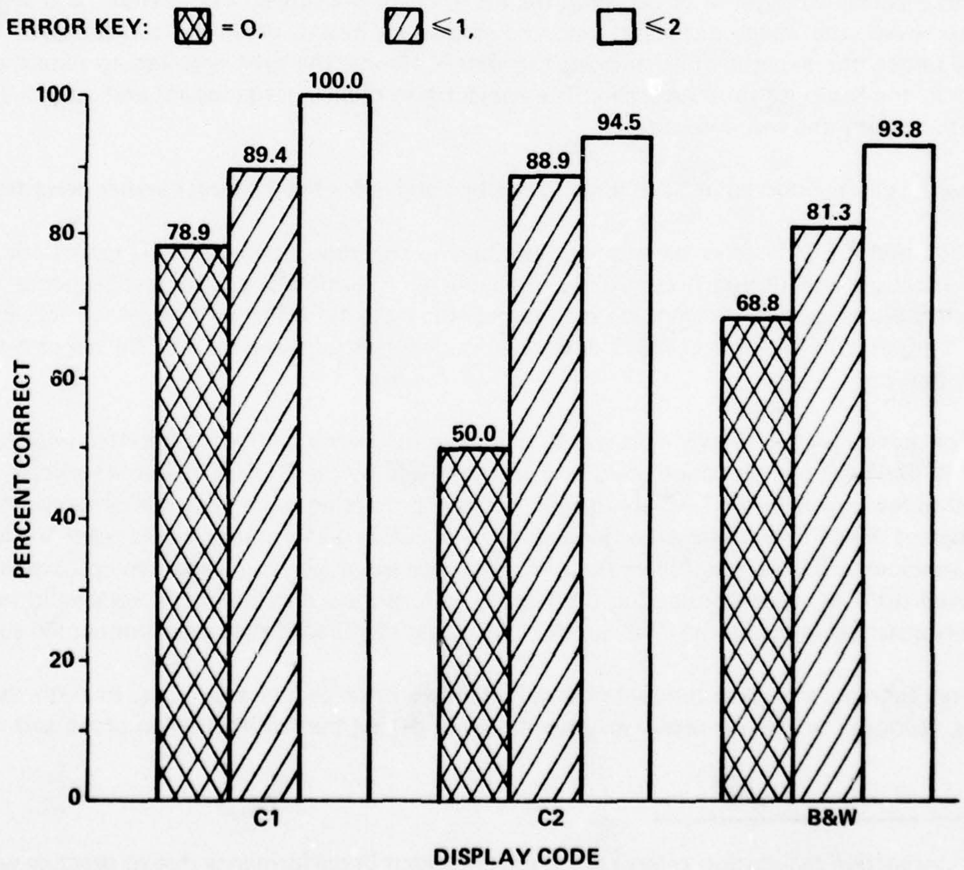


Figure 91 – Cumulative Count Accuracy for the Three Display Codes in the TAC Test

Procedure

General Briefing – The only difference between the TAC and RECCE situations occurs in the *a priori* knowledge of the target(s) of interest. In the TAC evaluation, subjects were informed of the exact target, *e.g.,* convoy, SAM, etc., that they were to find. In the RECCE briefing the subjects were provided with a list of targets of primary concern and informed that they were to detect them and classify them. In the first case, subjects anticipate a given signature or concept of the target's appearance and this influences their search patterns they search roads for convoys; open areas and hilltops for SAMs; high clutter areas for vehicle parks, etc. In the RECCE situation there is a broader search requiring inspection of all types of backgrounds in which the entire list of targets might be expected.

Hence, in the RECCE evaluation the briefing for each target scene was the same; the experimenter said, "Find one of the targets included on the list, tell me what it is, and count the number of vehicles, weapons, or active positions." Unlike the TAC situation, the subject was not advised of the general target background.

Briefing Materials – The instructions and sketches of target signatures that were provided to the subjects during the briefing are reproduced as part of Appendix D.

Familiarization Training – Radar scenes were selected for RECCE familiarization so that each subject could be exposed to a particular type of target. With the list in hand, the subject said "ready" and again the stepwedge was removed, the image displayed, and the stopwatch begun. When the subject said "there", and classified the target, the experimenter stopped the watch. Hence, the time required to detect and classify was included in the response time recorded. The subject also made a target count and reported it, and was advised of his accuracy and response time.

Testing – Testing was conducted in the manner described above for the 12 target scenes described earlier.

While the TAC and RECCE tasks have been described in separate sections in this report for clarity, the actual familiarization and testing occurred simultaneously. A summary of the test sequence is shown in Table 9. Each subject was tested beginning with target No. 1 and finishing with target No. 12. For example, subject No. 1 began with TAC target No. 1 with color code No. 1 followed by RECCE target No. 2 in black and white, and so on.

The reason for combining these two tests was to minimize the learning effects associated with testing them successively. If the TAC test was conducted first and followed by the RECCE test, the subjects would have been exposed to the targets in the TAC conditions, thereby producing some potential proactive facilitation* in the subsequent RECCE test. As a consequence the RECCE performance could have produced scores higher than anticipated if it were to follow the TAC test, because of learning which would have undoubtedly occurred during the TAC test. Conducting the tests simultaneously also permits a more valid relative comparison of performances between the TAC and RECCE situations than if they were conducted successively.

Familiarization training also was conducted simultaneously prior to any test trials. In both the TAC and RECCE tests, feedback on performance was provided only during the familiarization phase and never in the test sessions.

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*In this case, proactive facilitation refers to the enhancement in performance due to practice which would result in inflated performance scores on the test conducted last.

TABLE 9 – EXPERIMENTAL CONDITIONS FOR TAC AND RECCE TASKS FOR THE 12 SUBJECTS

TARGET NO.	TARGET	TAC CODE C1	TAC CODE C2	TAC CODE BW	RECCE CODE C1	RECCE CODE C2	RECCE CODE BW
A	Fixed SAM (7)*	1-4	5-8	9-12	5-8	9-12	1-4
B	Convoy (6)	5-8	9-12	1-4	9-12	1-4	5-8
C	Hawk SAM (7)	9-12	1-4	5-8	1-4	5-8	9-12
D	Vehicle Park (10)	1-4	5-8	9-12	5-8	9-12	1-4
E	Artillery (7)	5-8	9-12	1-4	9-12	1-4	5-8
F	Chaparral SAM (7)	9-12	1-4	5-8	1-4	5-8	9-12
1	Artillery (7)	1, 2	3, 4	5, 6	7, 8	9, 10	11, 12
2	Vehicle Park (13)	2, 3	4, 5	6, 7	8, 9	10, 11	12, 1
3	Artillery (7)	3, 4	5, 6	7, 8	9, 10	11, 12	1, 2
4	AAA (7)	4, 5	6, 7	8, 9	10, 11	12, 1	2, 3
5	Fixed SAM (7)	5, 6	7, 8	9, 10	11, 12	1, 2	3, 4
6	SP Guns (6)	6, 7	8, 9	10, 11	12, 1	2, 3	4, 5
7	Convoy (6)	7, 8	9, 10	11, 12	1, 2	3, 4	5, 6
8	Chaparral SAM (7)	8, 9	10, 11	12, 1	2, 3	4, 5	6, 7
9	FARP (8)	9, 10	11, 12	1, 2	3, 4	5, 6	7, 8
10	Vehicle Park (12)	10, 11	12, 1	2, 3	4, 5	6, 7	8, 9
11	AAA (7)	11, 12	1, 2	3, 4	5, 6	7, 8	9, 10
12	Hawk SAM (7)	12, 1	2, 3	4, 5	6, 7	8, 9	10, 11

Results

The results of the reconnaissance study were summarized and are presented in this subsection. For each of the display codes tested the results are discussed in terms of percent of correct target detections, median detection/classification times, rate of detection/classification, and accuracy of classification.

Target Detection – The number of correctly detected target sites were summarized and converted to percentages for each code. These results are shown as Figure 92. A z-test comparing the performances on C1 versus BW did not reach statistical significance ($z = 1.51$; $p > 0.13$). Since the small sample size was the reason suspected for failing to produce a significant difference, the performances of the two color codes were combined to provide a color versus black and white comparison. A weighted mean of the two color codes (0.729) was employed to estimate the population proportion (or percent) in the analysis. The detection performance achieved while viewing color was not found to be statistically higher than that produced by the black and white image ($z = 1.59$; $p > 0.11$).

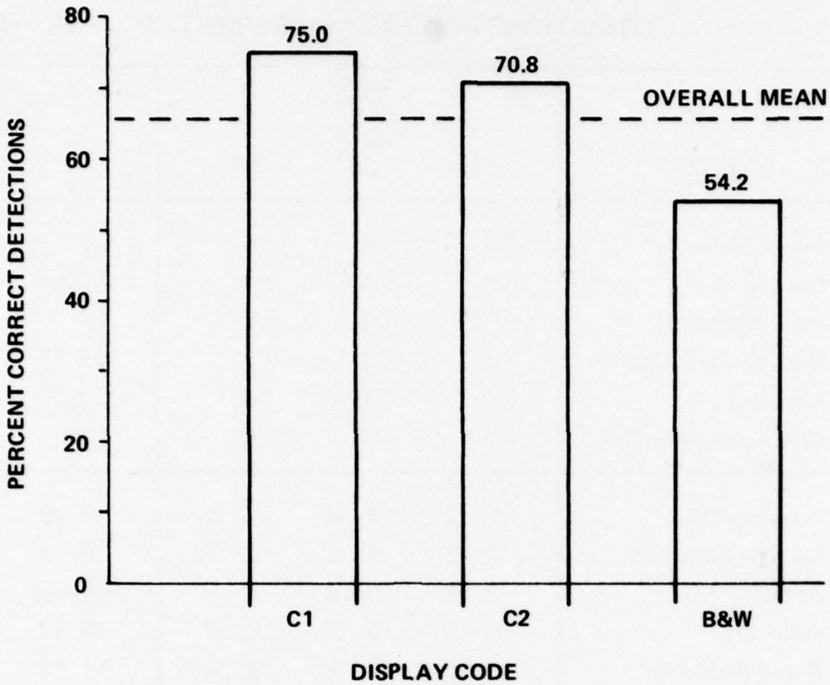


Figure 92 – Percent of Correctly Detected RECCE Targets for Each Display Code

Detection/Classification Time – The response times required by the subjects to correctly detect and classify targets were compiled. In addition, the median time required to detect targets and false alarms also was computed. Both of these summaries are contained in Figure 93 for each display code.

The difference observed between median response times for C1 and BW was found to be statistically insignificant ($x^2 = 0.896$; $p > 0.3$).

Acquisition Rate – The rate at which operators are able to detect small targets is as important in the RECCE mission as for the TAC mission. And, since the operational time frames for finding targets are similar, Table 10 and Figure 94 present acquisition rates for each code up to 30 seconds.

Inferential statistical procedures were unable to confirm a significant difference between the 30-second performances illustrated in the figure even though C1 appears to produce superior performance ($z = 0.621$; $p > 0.53$).

Target-Count Accuracy – The accuracy with which the test subjects could count the number of vehicles, weapons, or positions was calculated from the raw data. The number and percent of detected target sites counted with zero, ≤1, and ≤2 errors are included in Table 11. Figure 95 includes a cumulative plot of the target count accuracy for each of the three codes. It is a percentage plot of how accurately subjects counted vehicles, weapons, or positions to within plus or minus two errors. For example, 55.6 percent of the C1 target sites were counted without error; 72.2 percent with one error or less; and 77.8 percent with two errors or less.

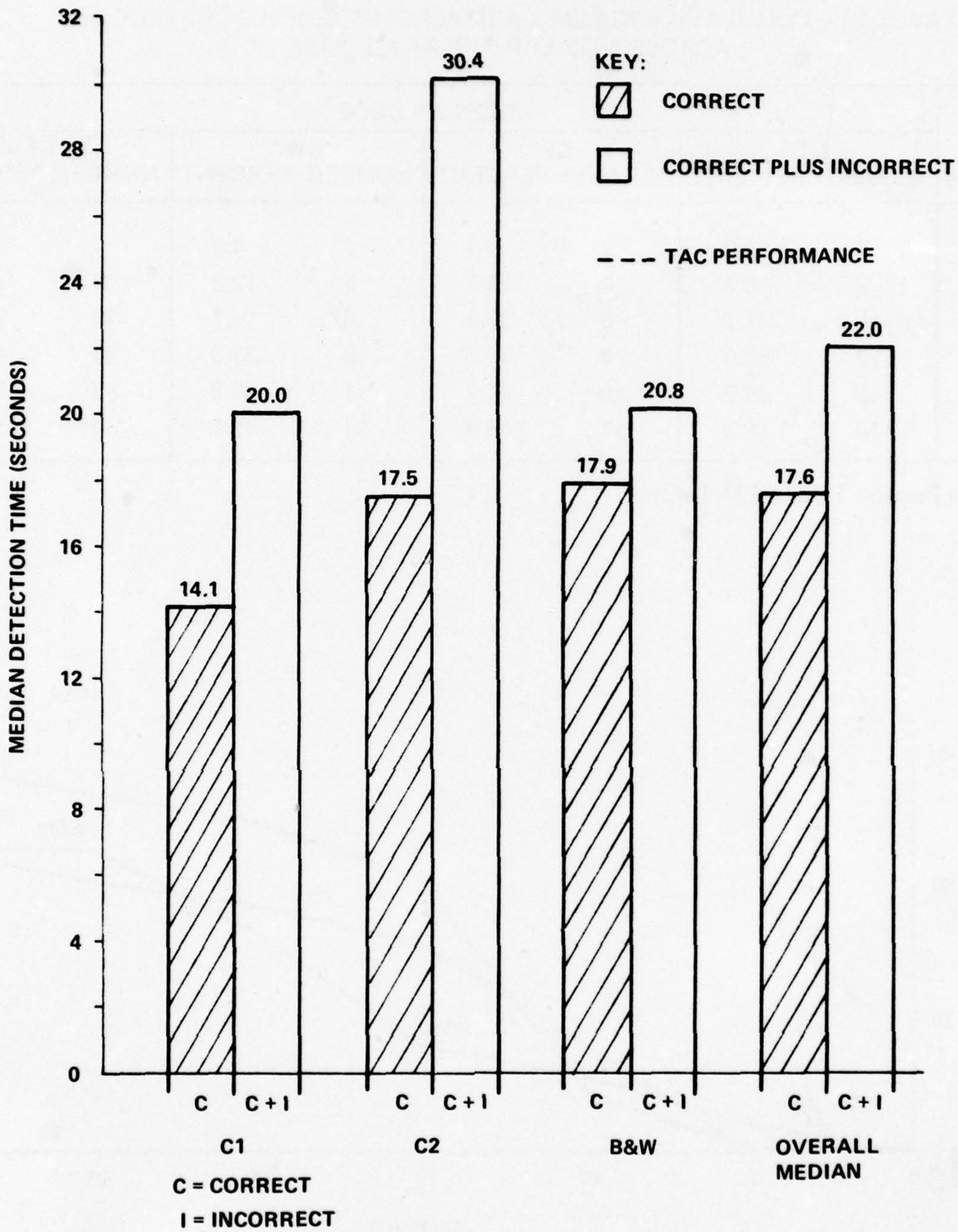


Figure 93 – Median Correct and Correct plus Incorrect Detection/Classification Times in the RECCE Test

None of the observed differences between conditions proved to be statistically significant ($z = 1.35$; $p > 0.17$ for C2 versus BW with no counting errors).

TABLE 10 – CUMULATIVE NUMBER AND PERCENT CORRECT DETECTIONS ACROSS TIME FOR THE RECCE TASK

TIME (SECONDS)	DISPLAY CODE							
	C1*		C2*		BW*		TOTAL*	
	NUMBER	PERCENT	NUMBER	PERCENT	NUMBER	PERCENT	NUMBER	PERCENT
0-5	0	0	0	0	1	4.2	1	1.4
0-10	2	8.3	4	16.7	3	12.5	9	12.5
0-15	10	41.7	8	33.3	4	16.7	22	30.6
0-20	12	50.0	9	37.5	8	33.3	29	40.3
0-25	13	54.2	10	41.7	11	45.8	36	50.0
0-30	14	58.3	11	45.8	11	45.8	38	52.8

*No. ÷ 24 = Percent. Total ÷ 72 = Percent.

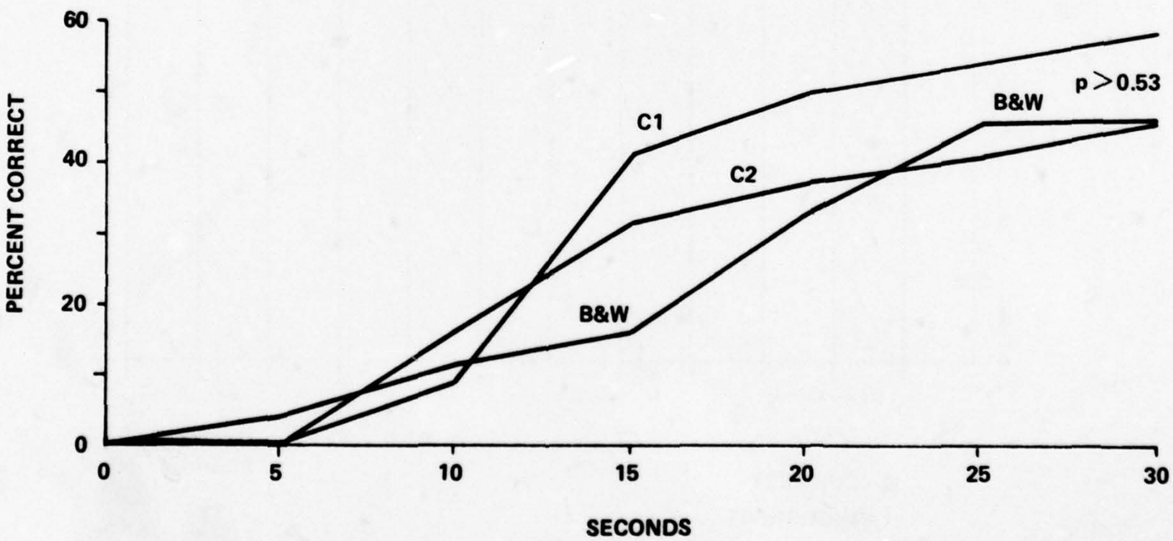


Figure 94 – RECCE Target Site Acquisition/Classification Rates for Each Display Code

TABLE 11 – NUMBER AND PERCENT OF DETECTED TARGET SITES CORRECTLY AND INCORRECTLY COUNTED

	TARGET COUNT (ERRORS)	DISPLAY CODE		
		C1 (18)*	C2 (17)*	BW (13)*
NUMBER	None	10	12	6
	± 1	3	2	3
	± 2	1	0	1
	Total	14	14	10
PERCENT	None	55.6	70.6	46.2
	± 1	16.7	11.8	23.1
	± 2	5.6	0.0	7.7
	Total	77.8	82.4	76.9

*No. correctly detected out of 24.

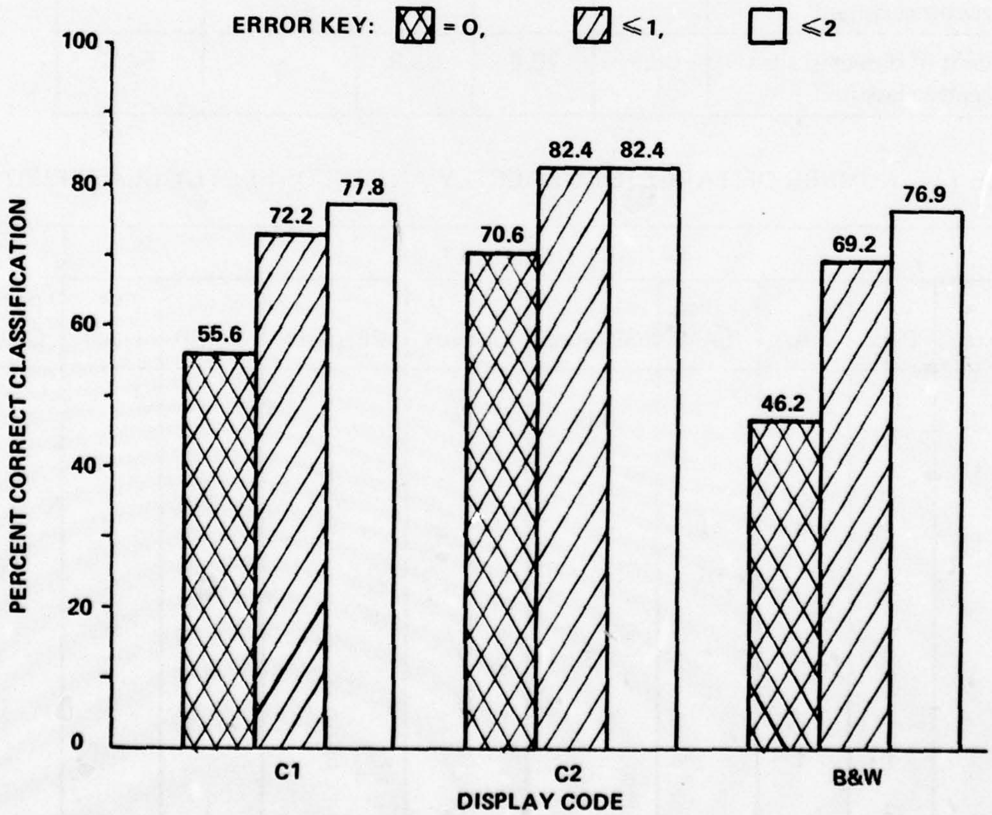


Figure 95 – Cumulative Count Accuracy for the Three Display Codes in the RECCE Test

Target Classification – Of the total 72 RECCE observations, the subjects correctly detected 48 targets and classified 31 of these correctly for a 64.6-percent classification accuracy. Table 12 is a summary of the target classification performance for each of the display codes. Code 1 produced 66.7-percent correct classification, C2 produced 70.6 percent, and BW produced 53.8 percent. No statistical difference exists between any two comparisons (for C2 versus BW, $z = 0.946$; $p > 0.34$). Table 13 includes a summary of the targets correctly and incorrectly classified and what the subjects mistakenly called them when the targets were incorrectly classified. The percent that each target was correctly classified also is shown. Because two artillery sites, two vehicle parks, and two AAA sites were used in the test, their results were combined in Table 13. That is why nine targets are listed in the table instead of 12.

TABLE 12 – NUMBER OF TARGET SITES CORRECTLY DETECTED AND CLASSIFIED AND PERCENT CORRECTLY CLASSIFIED

	DISPLAY CODES				
	C1	C2	BW	TOTAL	MEAN
Number of sites correctly detected	18	17	13	48	16
Number of sites correctly classified	12	12	7	31	10.3
Percent of detected sites correctly classified	66.7	70.6	53.8	–	64.6

TABLE 13 – NUMBER OF TARGETS CORRECTLY AND INCORRECTLY CLASSIFIED

ACTUAL TARGET	TARGET DESIGNATION: Arty	Park	AAA	Fixed SAM	SP Guns	Convoy	Chaparral	FARP	Hawk	PERCENT CORRECT
Arty	2	2			1					40
Park	1	4	2				1			50
AAA			9	1			1			81.8
Fixed SAM				5						100
SP Guns					3	2				60
Convoy						2				100
Chaparral		1	1				3			60
FARP		2						1		33.3
Hawk							1	1	2	50

As expected, targets randomly dispersed, *e.g.*, truck parks, and/or having multiple configurations, *e.g.*, Hawk and chaparral, and/or normally situated in unpredictable backgrounds, *e.g.*, FARP, produced the lowest classification accuracies. In addition, the likelihood of mistaking one for another is also high. This is somewhat confirmed in Table 13. On the other hand, targets having regularly predicted signatures, *e.g.*, SAMs and AAAs, or backgrounds, *e.g.*, convoys are usually on roads, produced the highest accuracy in classification. The only apparent reason for the poor classification of the artillery site which has a very regular formation involves the backgrounds and signal strength of the two targets employed. One of the sites was located in a fairly cluttered background. And although the signature is readily obvious, subjects could have hurried their response. The fact that they erred twice calling the target a vehicle park suggests this interpretation. Confusing it with self-propelled guns means that the fire control center was not detected.

The other site was very subdued and was never detected in the RECCE situation and only once in the TAC situation.

TAC versus RECCE

Where comparisons between TAC and RECCE performance seemed appropriate, the results were summarized and are discussed in this subsection. Comparisons in this category include percent of correctly detected targets, median response time for detection, detection rate, and target count accuracy. These response measures are discussed in the following paragraphs. SAC results are not included in this discussion because neither the task nor targets were identical to those in the TAC and RECCE evaluations.

Target Detection – The target detection performances achieved in the TAC and RECCE tests are shown in Table 14. It appears that knowing what the target is ahead of time facilitates detection accuracy. For each display code, the percent of targets is nominally higher. The 12.5-percent difference between BW TAC and BW RECCE is not statistically significant ($z = 0.886$; $p > 0.37$).

TABLE 14 – PERCENT OF TARGETS CORRECTLY DETECTED FOR TAC AND RECCE

MISSION TYPE	DISPLAY CODE			MEAN
	C1	C2	BW	
TAC	79.2	75.0	66.7	73.6
RECCE	75.0	70.8	54.2	66.7

Detection Time – The median response times to detect targets in the TAC and RECCE tests are shown in Figure 96. Maximum values of the histograms represent the RECCE values and the dashed lines are indicative of TAC detection time. Both the TAC and RECCE performances seem to have relatively similar distributions across the display codes with the TAC times approximately 40 to 50 percent of RECCE responses. The two main differences in the tasks account for the difference. In the TAC task the subject knew what target signature to anticipate. In the RECCE mission he did not know and, in addition, he had to classify the target once he detected it. The RECCE times shown in Figure 96 include the required time to detect plus classify the targets.

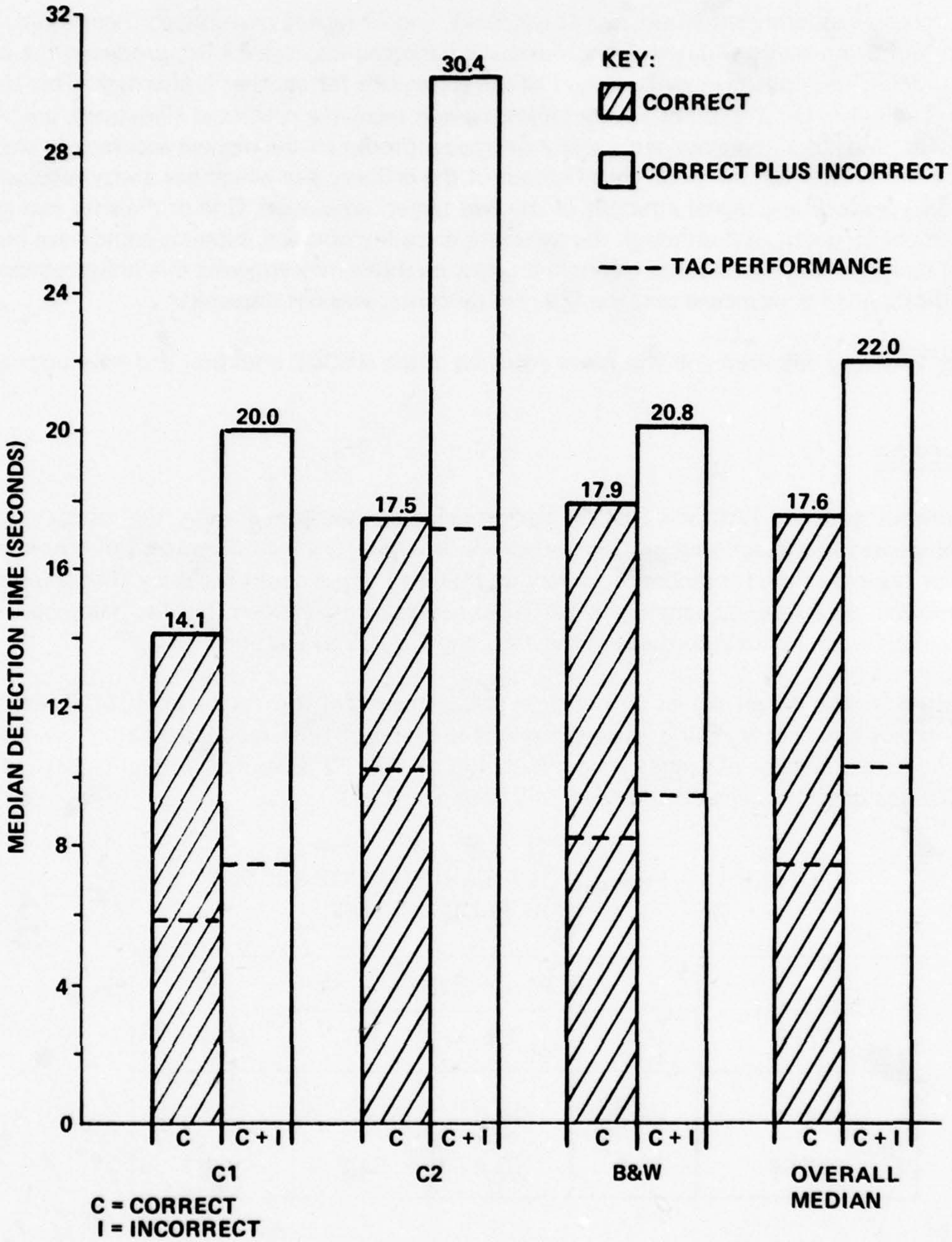


Figure 96 – Median Correct and Correct plus Incorrect Detection Time in the RECCE Test

Since the relationship among median response times in the TAC and RECCE tasks seems somewhat fixed to some variable, the results were examined even further. The relationship could be explained if a constant amount of time was required to classify the target once detected with each of the display codes. To test this hypothesis, the TAC times were subtracted from the RECCE times. RECCE minus TAC times of 8.2, 7.4, and 9.8 seconds resulted for C1, C2, and BW codes, respectively. Although these numbers are similar, it is difficult to conclude from them that they represent solely the time required to classify the targets.

It is probable that the subjects required nearly identical times to classify detected targets irrespective of the display code. The time differentials above most likely include a constant classification time, *e.g.,* 5 to 6 seconds, plus some search time.

Nonetheless, in this test, subjects required about twice as much time to detect and classify a target in the RECCE task as they did to detect a target in the TAC test. This indicates that *a priori* knowledge about a particular target signature improves detection time, as well as detection accuracy, over the RECCE-type task in which the operator does not know specifically what target he is attempting to find.

Acquisition Rate – As the results above indicate, that the median target detection times for TAC targets are less than the RECCE response times, it follows that the rate of acquisition must be greater for TAC. Figure 97 confirms this conclusion.

Target Count Accuracy – A comparison of TAC and RECCE target count accuracy reveals that the TAC scores are nominally higher in every case except the C2-zero error condition where a large reversal occurs (see Figure 98). Further examination of the data did not produce any readily apparent explanation for this reversal.

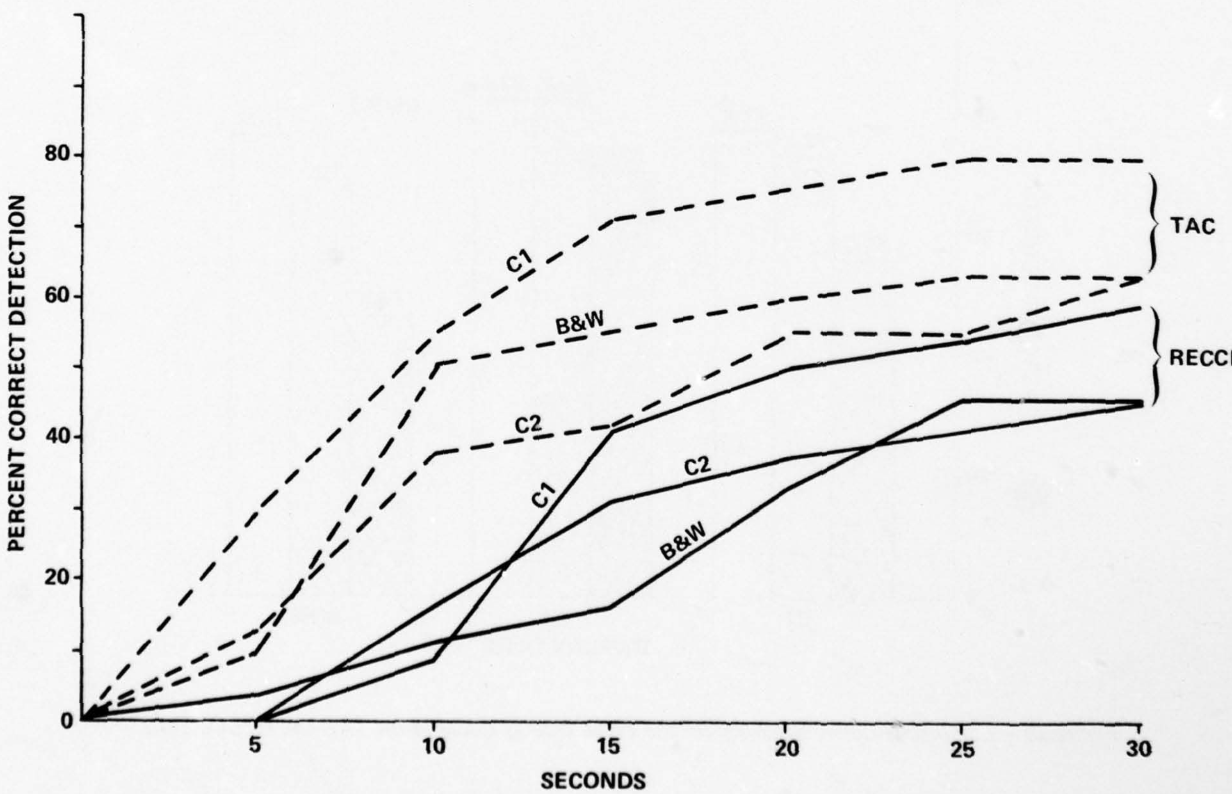


Figure 97 – Rate of Correct Target Detections for Each Code and Each Mission Type

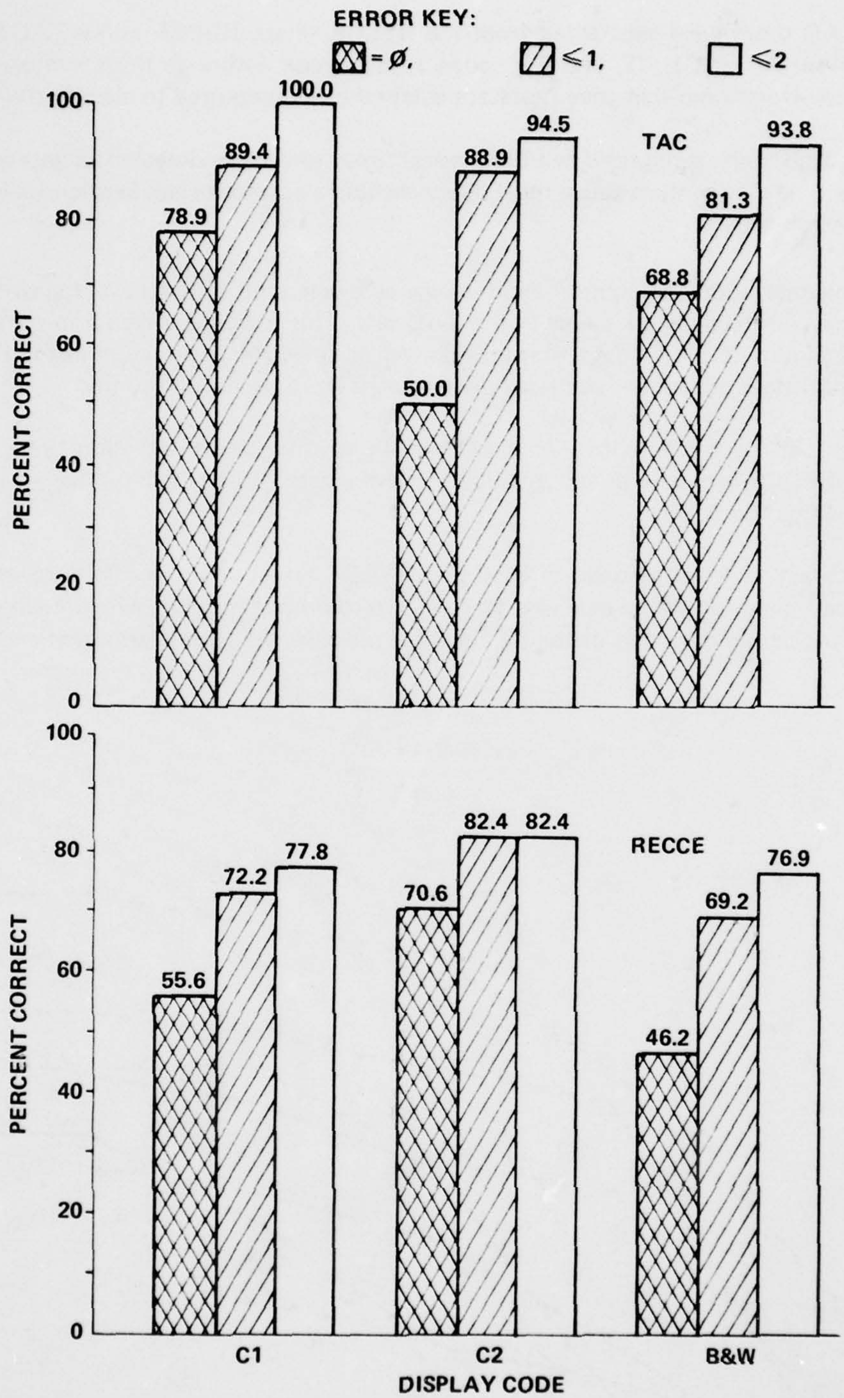


Figure 98 – Cumulative Count Accuracy for the Three Display Codes in the TAC and RECCE Tests

As a result of this occurrence, the RECCE data was analyzed to determine whether count accuracy was somewhat dependent upon a correct target classification. Do operators give a better vehicle count when they know the target's classification? The results shown in Table 15 indicate that this is indeed the case. The table presents the percent of accurate (zero-error) counts for each display code for correctly and incorrectly classified targets.

Operator count accuracy was 15 percent higher with C1, 43 percent higher with C2, and 54.7 percent higher with the BW code when they correctly classified the target before counting, compared with when they incorrectly classified the target.

In all four of the TAC/RECCE comparisons it has been shown that knowing a target's identity or classification prior to a mission enhances target detection, acquisition time, and count accuracy.

TABLE 15 – PERCENT OF TARGETS COUNTED WITHOUT ERROR FOR CORRECT AND INCORRECT CLASSIFICATION

TARGET CLASSIFICATION ACCURACY	DISPLAY CODE			MEAN
	C1	C2	BW	
Correct	75.0	83.0	71.4	74.2
Incorrect	60.0	40.0	16.7	37.5

CONCLUSIONS

From the results presented in the previous section, the following conclusions have been drawn.

SAC Study

Color does not improve target/OAP recognition performance with 40-foot resolution radar imagery

Color and achromatic display codes produce rates of target detection which are very similar

Color-coded 40-foot resolution radar images do not enhance SAC operator performance.

TAC Study

Pseudo-color has potential for increasing target detection over achromatic displays

Color codes constructed to promote detection can produce higher target acquisition rates.

RECCE Study

Pseudo-color has potential for enhancing target detection

Pseudo-color has potential for enhancing target classification.

General

Knowing a target's identity facilitates its detection

Knowing a target's identity reduces the time required to find it

Knowing a target's identity facilitates target count accuracy

Color coding has a higher potential for enhancing operator performance with radar imagery having better than the 20-foot resolution utilized in this study since there is a higher signal-to-clutter ratio where a more definite threshold between targets and clutter exists.

Using low color/low brightness contrast colors for coding the lower intensity terrain features, and high color/high brightness contrast for coding targets appears to present the best color/brightness contrast combination for coding radar images

It is better to use colors to which the visual system is less sensitive, *e.g.,* blues, reds, and browns, for terrain feature coding and colors to which the visual system is most sensitive, *e.g.,* greens and yellows, for target coding

Pure saturated colors have maximum potential use when they are used at levels slightly above high clutter values to facilitate discrimination among medium-to-strong targets.

A system designed to use color should provide a radar gain control at the display to permit the operator to maximize the potential of the color code(s) employed.

RECOMMENDATIONS

From the results and conclusions and from observations made throughout the research program, the following recommendations are offered:

1. This investigation has identified potential for pseudo-color radar imagery that deserves further investigation before operational recommendations can be made.
2. An investigation similar to the one reported here should be conducted with radar imagery having better than 20-foot resolution.
3. Pseudo-color investigations should be considered that employ radar resolutions capable of producing individual vehicle/weapon classification-type image quality.
4. Observing radar images with some of the color codes tested indicates that color may reduce operator fatigue. The colored imagery appears "easier" to view. Adding the additional cues of hue and saturation may add qualitative information which can result in less strain than ordinarily produced in a visual system searching black and white quantitative-only information. This should be investigated.

APPENDIX A

DIGITAL IMAGE PROCESSING,
COLOR DISPLAY SYSTEM DESCRIPTION,
AND
FLAMR DIGITAL IMAGE PARAMETERS

General Description

Figure A-1 is a block diagram of the Goodyear Aerospace digital image processing and color display facility used in the tests. The facility will accept digital imagery recorded on either seven- or nine-track computer-compatible tapes (CCT) at 800 or 1600 bits per inch.

The image processing and reformatting minicomputer is used for any image manipulations required prior to display. For example, the computer and its peripherals are used for converting the original image tapes to log amplitude format with the proper scaling. In addition, the computer is used to select the image pixel spacings for control of the displayed image scale. The image data supplied to the display is quantized log amplitude at eight bits per pixel.

The display data weighting front panel control selects the displayed image dynamic range and effective radar gain (brightness) while reducing the quantization level to 6 bits per pixel for input to the display memory. The output of the 512- by 512-pixel by 6-bit display memory is at television rates. The scan converter output can be varied from 1 bit per pixel to 6 bits per pixel to evaluate the effects of quantization level on the displayed image. An image quantized with the full 6 bits per pixel (64 grey shades) level may be displayed in the black and white mode only. In the color mode, the maximum quantization level is 5 bits per pixel (32 grey shades). The color encoder codes each 5-bit pixel level into three 5-bit output words for the red, green, blue (RGB) color monitor. Thus each 5-bit input word may be encoded into any one of 2^{15} possible combinations of display hue, saturation, and brightness. The display minicomputer is used to generate color codes in an interact mode and change the displayed color codes at up to television frame rates in the flicker mode. The display brightness/image level transfer function is controlled by the display linearizer and contrast control circuits. The display is linearized in the sense that the 64 input levels result in 64 levels equally spaced in apparent brightness (equal dBs per step). The display contrast may be adjusted while maintaining the desired linearity by adjusting an eight-position digiswitch contrast control rather than the color monitor front panel contrast control. Reducing the contrast lowers the dBs per step. Three digital-to-analog converters provide the three inputs to the RGB high-resolution color monitor.

Detailed Description of Image Processing

The image-processing and tape-handling capabilities of the facility are best described by explaining the available programs.

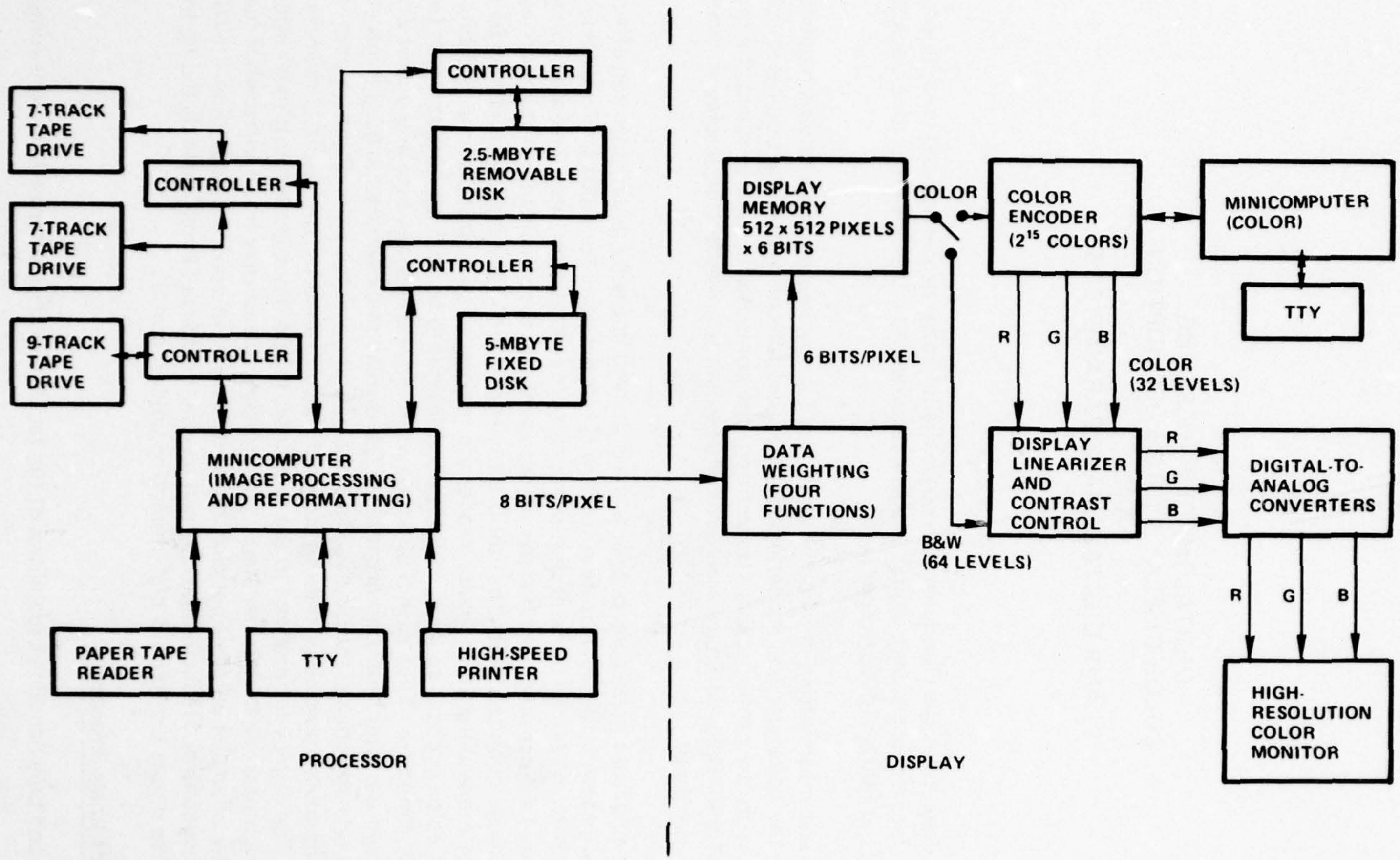


Figure A-1 – Digital Image Processing and Color Display Facility

Tape Reformatting – This program is used to modify original digital image tapes into the format required by the display. In general, the display requires an eight-bit word per pixel where the word is proportional to the logarithm of the pixel radar cross-section. Thus

$$No._{in} = K_1 \log A + K_o$$

where

$No._{in}$ = display input number ($0 \rightarrow 255$)

K_o = gain constant (dBs)

K_1 = scaling constant (dBs/level)

A = pixel amplitude.

For example, assume that the original image tape has eight-bit words with the words proportional to the pixel amplitude. This tape has a maximum possible image dynamic range of 48 dB; *i.e.,*

$$D.R. = 20 \log \frac{A_{max}}{A_{min}} = 20 \log \frac{255}{1} = 48 \text{ dB}$$

The desired scaling constant K_1 may be determined using

$$K_1 = \frac{(No._{max} - No._{min})}{\log_{10} (A_{max}/A_{min})}$$

where $No._{max}$, $No._{min}$, A_{max}, and A_{min} are indicated in Figure A-2.

Thus, if the entire 48-dB dynamic range is to be scaled to cover all 255 levels of the new tape,

$$K_1 = \frac{(255 - 0)}{\log (255/1)} = 106$$

and each level change on the reformatted tape is equivalent to an 0.188-dB change in radar cross section. Note that for this case K_o equals zero.

Display Programs – Once the image tapes are in the desired format, the display programs are used to read them into the display memory. The programs allow selection of the spacing, location, and range of image pixels. Thus, if an image tape has more than 512 pixels per line, the operator can select the 512-pixel segment desired or else display the entire line by skipping pixels. Records also may be skipped to control image scale in the orthogonal direction.

A grid may be overlaid on the displayed image with 32- by 32-pixel spacings between grid lines for accurately locating features. The grid moves with the image and a brighter grid line is inserted every 255 records for keeping track of the distance from the start of the tape.

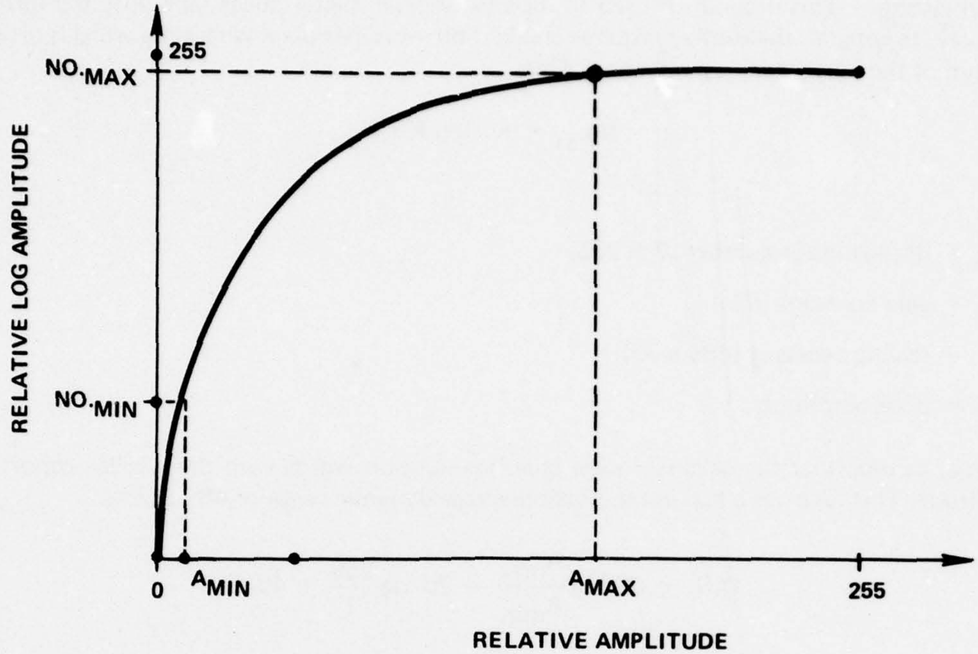


Figure A-2 – Amplitude to Log Amplitude Conversion

Target "Salting" Programs – Targets may be inserted into existing images using the "salting" program. First the grid display program is used to locate the center coordinates (elements and records) of the areas to be salted. Then the pixel levels are printed out covering a 32- by 32-pixel area centered on the desired point. The pixel levels within this area are modified as required using the teletype as an input. The result is a new image tape with the targets added.

Color Display

Data Weighting – One of four weighting functions may be selected before loading the digital image into the display memory. These weighting functions may be used to control the image gain and dynamic range as well as modifying the basic log amplitude weighting of the input data.

As an example, assume that the input data is from a typical FLAMR image tape used in this test. The 255-level input word covers a 96-dB radar dynamic range (0.375 dB/level).

Figure A-3 shows four typical transfer functions for the data weighting module. In this case, 50 dB of the available 96 dB is to be displayed. For position one of the weighting module, all input levels below 50 are assigned level zero in the output. From input level 50 to input level 182 there is a linear relationship between input and output. All input levels above 182 are assigned output level 63.

Thus, the 6-bit image stored in the refresh memory covers 50 dB of the original radar data in nominal 0.75-dB steps. The next three weighting functions cover the same dynamic range but at different effective radar gains. Changing the weighting function from position one to position two decreases the image brightness equivalent to a 3-dB reduction in radar gain by shifting the transfer function eight input levels.

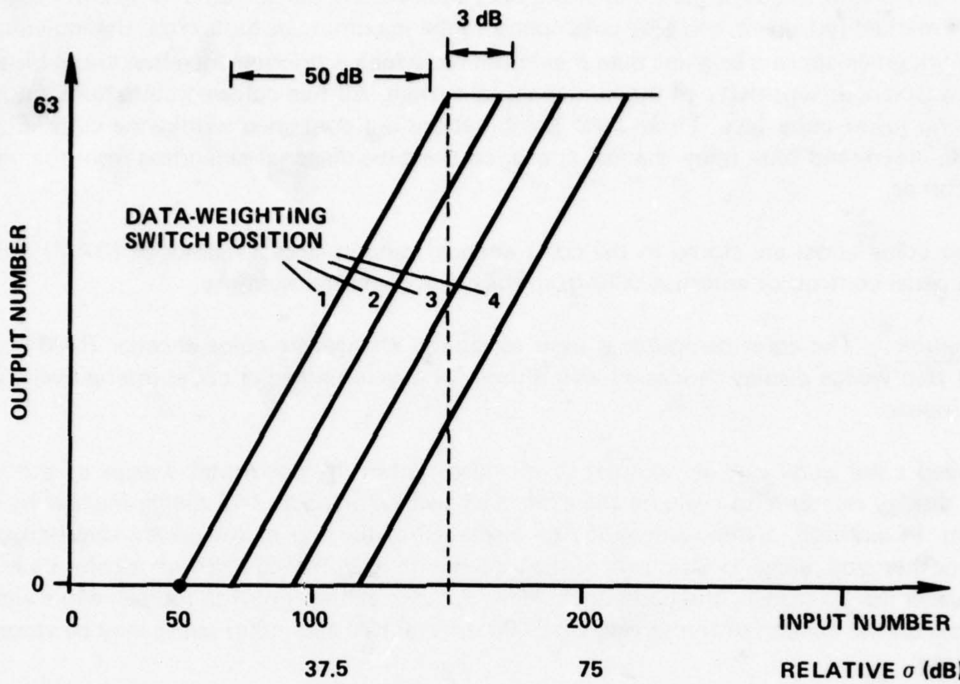


Figure A-3 – Data Weighting Effect

Display Memory – The display memory accepts the 6 bits per pixel image data a line at a time at up to real-time rates. The entire memory is continuously read out at standard television rates (60 frames per second) using up to 6 bits per image pixel. The full six bits only can be displayed in the black and white mode since the color encoders are only 5-bit. In the black and white mode, the 64 image levels appear as 64 equally spaced brightness levels.

Display Linearizer and Contrast Control – The linear conversion between input levels and display brightness is made possible by the display linear circuits. Figure A-4 shows a typical CRT transfer function where the 64 input levels are proportional to grid voltage. The relative apparent brightness is proportional to the logarithm of the display intensity. The desired characteristic (shown as a dotted line) is obtained by weighting the 64-level input with the opposite of the CRT response. A ten-bit digital-to-analog converter allows 1024 possible grid voltage levels, any one of which can be assigned to one of the 64 input levels in the linearizer read-only memory (ROM). Reducing the contrast reduces the display brightness range while maintaining linearity as indicated in Figure A-4.

Note that three identical linearizer channels are required to feed the RGB color monitor.

Color Encoder – The color encoder codes each 5-bit input word into three 5-bit outputs that control the three guns of the RGB color monitor. Thus, each of the 32 input levels can be assigned any one of 32,768 possible red, green, blue output combinations. All of the possible hue, saturation, and brightness combinations may be depicted with the color cube shown in Figure A-5. The cube is oriented so that the vertical axis corresponds to perceived (photometric) brightness. When all three guns are off, the display is black.

Turning on any one of the three guns alone produces colors along the corresponding lower edge of the cube. The corners marked red, green, and blue correspond to the maximum outputs from the individual guns. Note that maximum green appears brighter than maximum red which is brighter than maximum blue, corresponding to the wavelength sensitivity of the human visual system. All two-color combinations appear within the corresponding lower cube face. Three-color combinations are contained within the cube. Equal combinations of red, green, and blue (grey shades) appear on the cube diagonal extending from the black corner to the white corner.

The 32-step color codes are stored in the color encoder random-access memories (RAM) either manually using front panel controls or automatically from the color computer memory.

Color Computer – The color computer is used to rapidly change the color encoder RAM contents in the flicker and step wedge display modes. It also is used for developing color codes interactively using the teletype as an input.

The displayed color code can be completely changed within 10 horizontal sweeps of the monitor. This allows the display operator to evaluate the effects of two color codes in a timely manner by flickering between them. In addition, a step wedge may be displayed at the top of the screen simultaneously with an image or another step wedge on the rest of the screen with each having a different color code. This feature allows the operator to display the code under development at the top of the screen while viewing possible color choices on the bottom of the screen. Up to 90 different 32-step color codes may be stored in the computer memory.

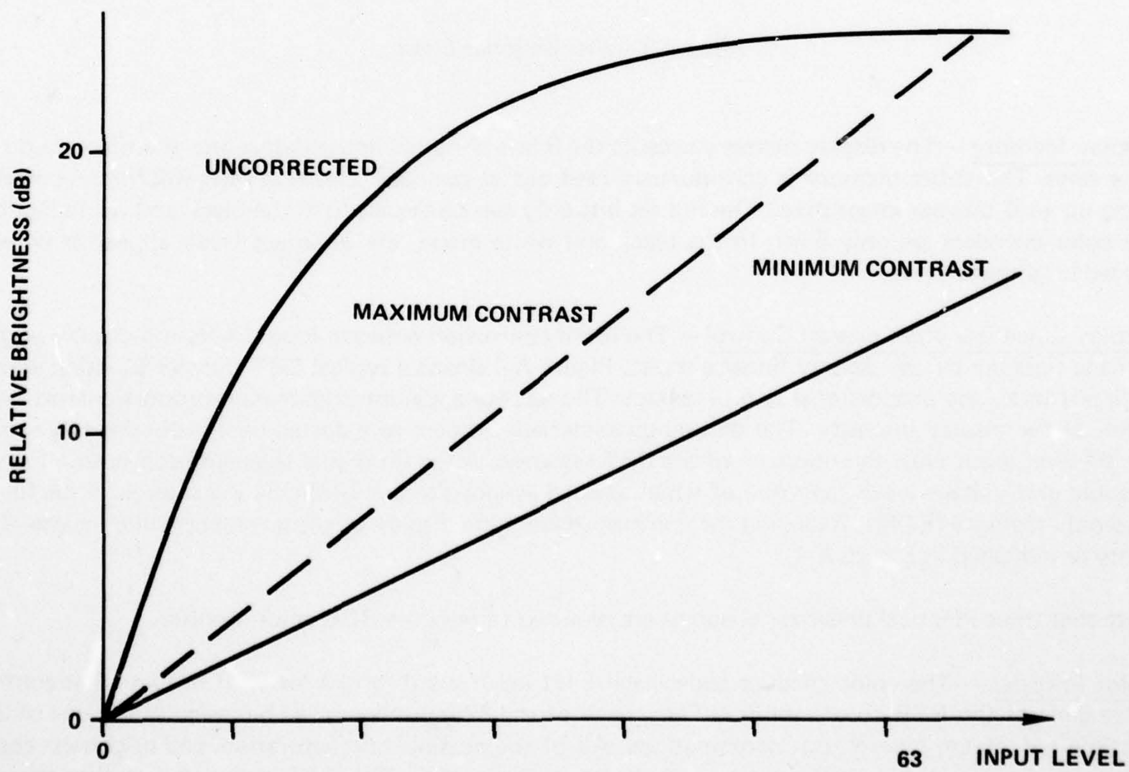
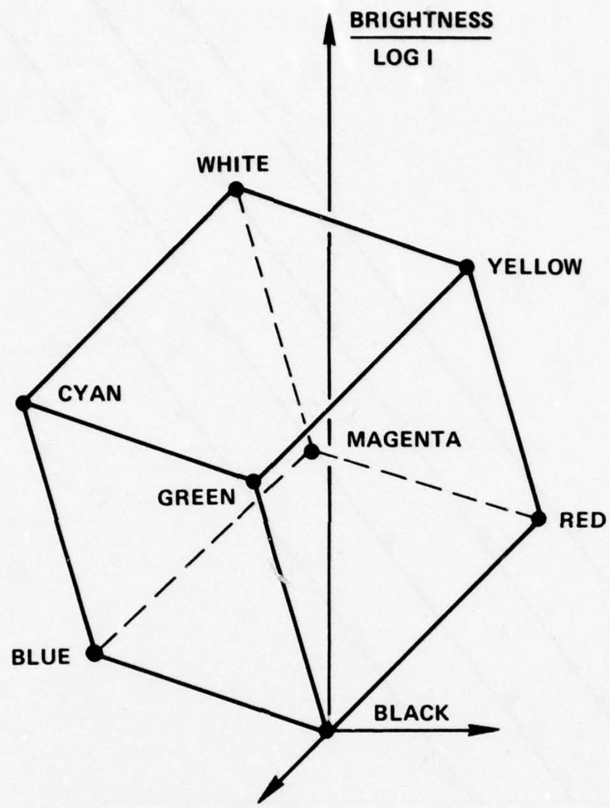


Figure A-4 – Cathode-Ray Tube Transfer Functions



COLOR CUBE

Figure A-5 – Color Code Development

Color Monitor – The color display facility uses a red, green, blue color monitor with a special high-resolution dot matrix tube. Figure A-6 shows the display characteristic (input level versus relative brightness) at maximum contrast and low ambient lighting for each color and for grey shades (black and white). The black and white characteristic corresponds to the perceived brightness when all three guns have equal inputs. The display dynamic range at the maximum contrast setting (from cutoff to just blooming) is 21 dB; thus, the brightness varies by 0.7 dB per input level for 31 steps.

Note that red is 2.5 dB and green 4.8 dB brighter than blue for equal input levels.

This corresponds to a relative green, red, and blue sensitivity of 0.52, 0.31, and 0.17, respectively, under the low ambient lighting conditions normally used when viewing the display.

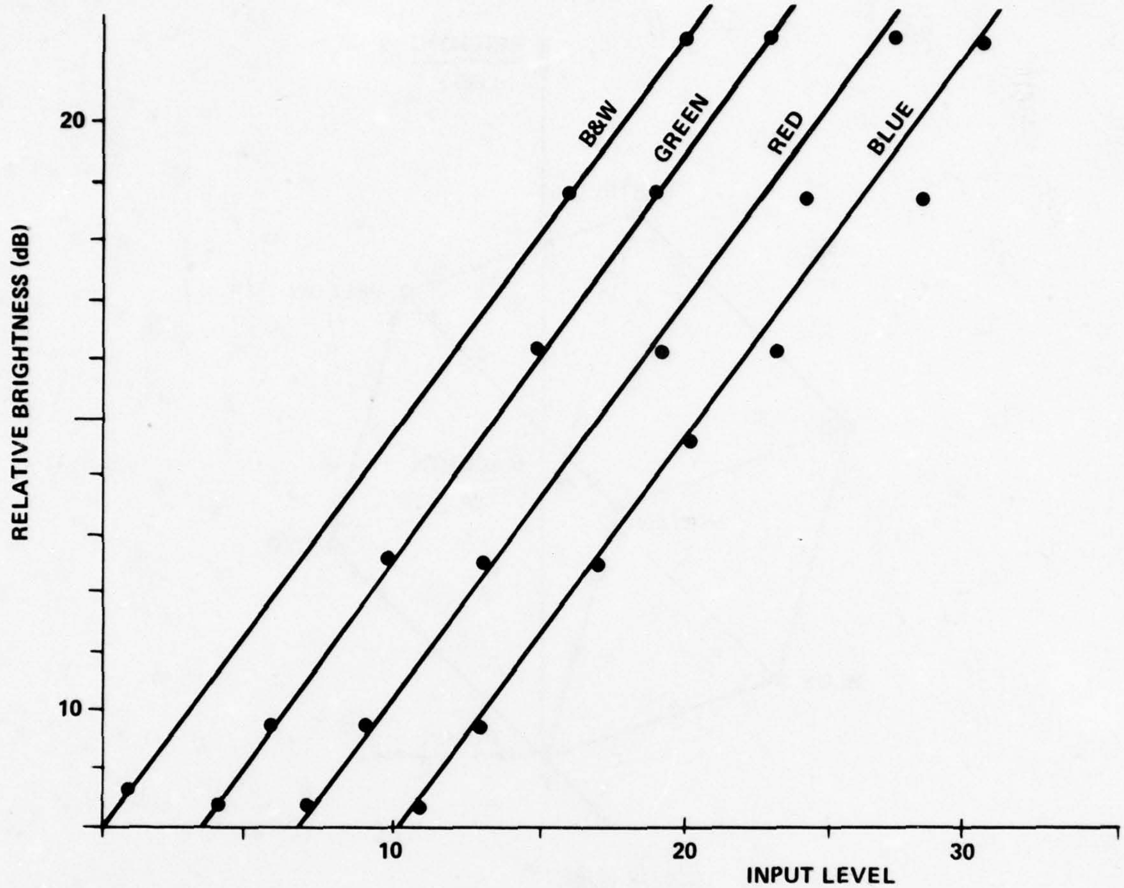


Figure A-6 – Display Characteristics for Each Color and Black and White

FLAMR Digital Image Parameters

The Forward-Looking Advanced Multimode Radar (FLAMR) digital image tapes used in the test had the following parameters:

Sampling Interval	20 feet per sample (high resolution) 40 feet per sample (medium resolution)
Resolution	Specified as nominally same as sampling interval
Image Format (per frame)	384 range samples (elements) 352 azimuth samples (records)
Quantization	8-bit log pixel amplitude (3/8 dB per step)
Measured Dynamic Range	70-dB maximum signal to average noise
Looks	4 noncoherently integrated range (frequency) looks.

The FLAMR image displayed in these tests represented 50 dB of the available dynamic range, *i.e.*, 1.6 dB per step for 5-bit-per-pixel image.

APPENDIX B

PRINTOUTS OF COLOR CODE LEVELS

CODE NO. 1

STEP	RED	GREEN	BLUE
Ø	Ø	Ø	Ø
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7
8	8	8	8
9	9	9	9
1Ø	1Ø	1Ø	1Ø
11	11	11	11
12	12	12	12
13	13	13	13
14	14	14	14
15	15	15	15
16	16	16	16
17	17	17	17
18	18	18	18
19	19	19	19
2Ø	2Ø	2Ø	2Ø
21	21	21	21
22	22	22	22
23	23	23	23
24	24	24	24
25	25	25	25
26	26	26	26
27	27	27	27
28	28	28	28
29	29	29	29
3Ø	3Ø	3Ø	3Ø
31	31	31	31

CODE NO. 2

STEP	RED	GREEN	BLUE
Ø	Ø	Ø	Ø
1	1	Ø	Ø
2	2	Ø	Ø
3	3	Ø	Ø
4	4	Ø	Ø
5	5	Ø	Ø
6	6	Ø	Ø
7	7	Ø	Ø
8	8	Ø	Ø
9	9	Ø	Ø
1Ø	1Ø	Ø	Ø
11	11	Ø	Ø
12	12	Ø	Ø
13	13	Ø	Ø
14	14	Ø	Ø
15	15	Ø	Ø
16	16	Ø	Ø
17	17	Ø	Ø
18	18	Ø	Ø
19	19	Ø	Ø
2Ø	2Ø	Ø	Ø
21	21	Ø	Ø
22	22	Ø	Ø
23	23	Ø	Ø
24	24	Ø	Ø
25	25	Ø	Ø
26	26	Ø	Ø
27	27	Ø	Ø
28	28	Ø	Ø
29	29	Ø	Ø
3Ø	3Ø	Ø	Ø
31	31	Ø	Ø

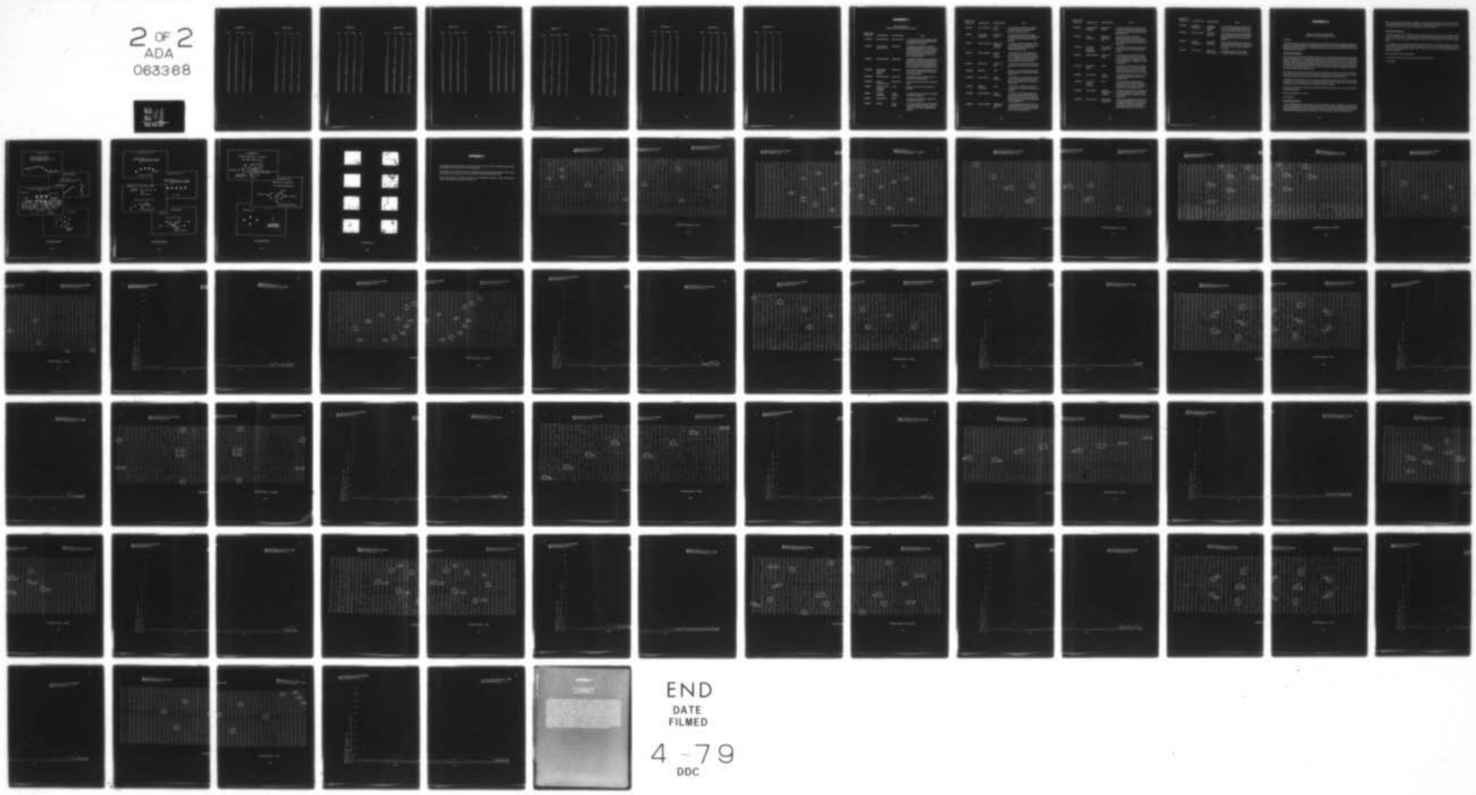
CODE NO. 3

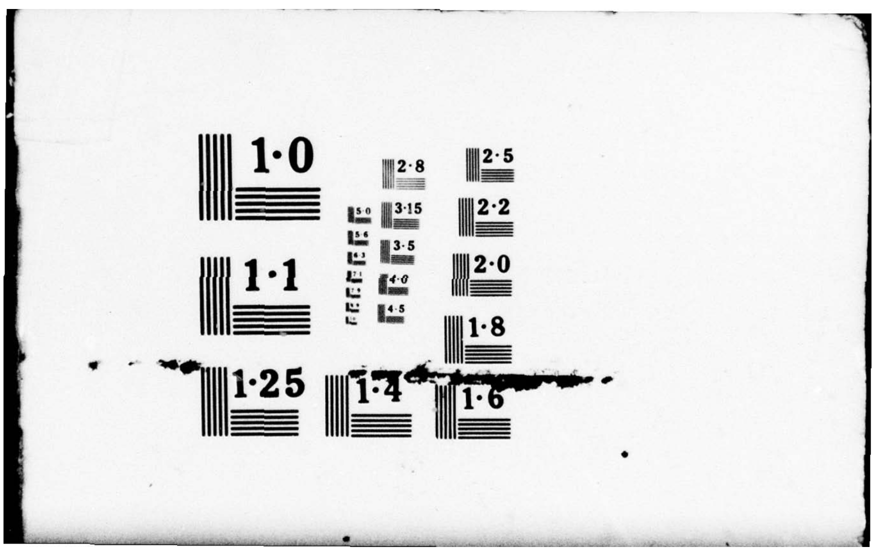
STEP	RED	GREEN	BLUE
0	0	0	0
1	0	0	1
2	0	0	2
3	0	0	3
4	0	0	4
5	0	0	5
6	0	0	6
7	0	0	7
8	0	0	8
9	0	0	9
10	0	0	10
11	0	0	11
12	0	0	12
13	0	0	13
14	0	0	14
15	0	0	15
16	0	0	16
17	0	0	17
18	0	0	18
19	0	0	19
20	0	0	20
21	0	0	21
22	0	0	22
23	0	0	23
24	0	0	24
25	0	0	25
26	0	0	26
27	0	0	27
28	0	0	28
29	0	0	29
30	0	0	30
31	0	0	31

CODE NO. 4

STEP	RED	GREEN	BLUE
0	0	0	0
1	0	1	0
2	0	2	0
3	0	3	0
4	0	4	0
5	0	5	0
6	0	6	0
7	0	7	0
8	0	8	0
9	0	9	0
10	0	10	0
11	0	11	0
12	0	12	0
13	0	13	0
14	0	14	0
15	0	15	0
16	0	16	0
17	0	17	0
18	0	18	0
19	0	19	0
20	0	20	0
21	0	21	0
22	0	22	0
23	0	23	0
24	0	24	0
25	0	25	0
26	0	26	0
27	0	27	0
28	0	28	0
29	0	29	0
30	0	30	0
31	0	31	0

AD-A063 368 GOODYEAR AEROSPACE CORP LITCHFIELD PARK ARIZ ARIZONA DIV F/G 17/9
THE EFFECTS OF PSEUDO-COLOR ON THE APPARENT DISPLAYED DYNAMIC R--ETC(U)
DEC 77 G L LAMONICA F33615-76-C-1242
UNCLASSIFIED GERA-2272 AFAL-TR-77-186 NL




1·0
1·1
1·25
1·4
1·6
1·8
2·0
2·2
2·5
2·8
3·15
3·5
4·0
4·5
5·0
5·6

CODE NO. 5

STEP	RED	GREEN	BLUE
0	1	0	0
1	2	0	0
2	4	0	0
3	6	0	0
4	8	0	0
5	10	0	0
6	12	0	0
7	14	0	0
8	16	0	0
9	18	0	0
10	20	0	0
11	22	0	0
12	24	0	0
13	26	0	0
14	28	0	0
15	29	10	0
16	29	17	0
17	29	21	0
18	29	23	0
19	29	25	0
20	29	27	0
21	29	29	0
22	29	30	0
23	29	30	20
24	29	30	24
25	29	30	26
26	29	30	28
27	29	30	30
28	31	31	31
29	31	31	31
30	31	31	31
31	31	31	31

CODE NO. 6

STEP	RED	GREEN	BLUE
0	0	0	0
1	1	1	1
2	2	2	2
3	3	3	3
4	2	1	7
5	5	1	2
6	3	3	0
7	4	3	7
8	8	5	0
9	4	7	0
10	0	10	11
11	11	7	6
12	13	9	0
13	16	8	3
14	15	10	0
15	10	13	0
16	9	15	1
17	18	20	0
18	24	14	0
19	26	22	0
20	29	24	0
21	20	23	12
22	0	31	20
23	0	31	31
24	30	0	0
25	31	0	0
26	31	31	31
27	31	31	31
28	31	31	31
29	31	31	31
30	31	31	31
31	31	31	31

CODE NO. 7

STEP	RED	GREEN	BLUE
0	0	0	0
1	0	0	0
2	2	2	2
3	2	2	2
4	5	1	2
5	5	1	2
6	4	3	7
7	4	3	7
8	4	7	0
9	4	7	0
10	11	7	6
11	11	7	6
12	16	8	3
13	16	8	3
14	10	14	1
15	10	14	1
16	24	14	0
17	24	14	0
18	26	22	0
19	26	22	0
20	20	28	12
21	20	28	12
22	0	31	31
23	0	31	31
24	31	0	0
25	31	0	0
26	31	31	31
27	31	31	31
28	31	31	31
29	31	31	31
30	31	31	31
31	31	31	31

CODE NO. 8

STEP	RED	GREEN	BLUE
0	0	0	0
1	0	0	0
2	2	2	2
3	2	2	2
4	2	1	7
5	2	1	7
6	4	4	0
7	4	4	0
8	7	5	1
9	7	5	1
10	0	10	11
11	0	10	11
12	14	8	6
13	14	8	6
14	18	10	2
15	18	10	2
16	9	15	1
17	9	15	1
18	24	15	0
19	24	15	0
20	27	21	0
21	27	21	0
22	0	31	20
23	0	31	20
24	30	0	0
25	30	0	0
26	31	31	31
27	31	31	31
28	31	31	31
29	31	31	31
30	31	31	31
31	31	31	31

CODE NO. 9

STEP	RED	GREEN	BLUE
0	0	0	0
1	2	2	2
2	3	3	3
3	2	1	7
4	2	3	7
5	2	4	7
6	4	5	3
7	5	6	1
8	4	7	1
9	4	8	3
10	0	10	7
11	11	9	6
12	15	8	5
13	16	9	0
14	16	12	0
15	14	13	0
16	12	14	1
17	9	15	1
18	14	16	12
19	18	18	17
20	23	21	19
21	27	23	19
22	29	24	16
23	30	22	16
24	30	20	16
25	30	16	13
26	31	0	0
27	31	0	31
28	0	31	0
29	0	31	31
30	31	31	0
31	31	31	31

CODE NO. 10

STEP	RED	GREEN	BLUE
0	0	0	0
1	2	2	2
2	3	3	3
3	2	1	7
4	2	3	7
5	2	4	7
6	4	5	3
7	5	6	1
8	4	7	1
9	4	8	3
10	0	10	7
11	11	9	6
12	15	8	5
13	16	9	0
14	16	12	0
15	14	13	0
16	12	14	1
17	9	15	1
18	14	16	12
19	17	18	14
20	19	20	15
21	20	23	15
22	23	25	22
23	27	27	27
24	28	28	28
25	29	29	29
26	30	30	30
27	31	31	31
28	31	31	31
29	31	31	31
30	31	31	31
31	31	31	31

CODE NO. 11

STEP	RED	GREEN	BLUE
0	0	0	0
1	2	2	2
2	3	3	3
3	2	1	7
4	2	3	7
5	2	4	7
6	4	5	3
7	5	6	1
8	4	7	1
9	4	8	3
10	0	10	7
11	11	9	6
12	15	8	5
13	16	9	0
14	16	12	0
15	14	13	0
16	12	14	1
17	9	15	1
18	0	17	13
19	0	18	14
20	0	20	15
21	31	0	0
22	31	0	0
23	31	0	0
24	31	0	0
25	0	31	0
26	0	31	0
27	0	31	0
28	31	31	0
29	31	31	0
30	31	31	0
31	31	31	0

CODE NO. 12

STEP	RED	GREEN	BLUE
0	0	0	0
1	0	0	5
2	0	0	8
3	2	1	7
4	2	3	7
5	2	4	7
6	4	6	5
7	5	8	3
8	6	9	3
9	3	11	5
10	0	12	9
11	12	11	8
12	17	9	7
13	18	11	0
14	18	14	0
15	16	15	0
16	14	16	3
17	11	17	3
18	16	18	14
19	20	20	19
20	21	21	21
21	23	23	23
22	28	0	0
23	28	0	0
24	31	0	31
25	31	0	31
26	0	31	0
27	0	31	0
28	31	31	31
29	31	31	31
30	31	31	31
31	31	31	31

CODE NO. 13

STEP	RED	GREEN	BLUE
0	0	0	0
1	1	0	2
2	2	0	4
3	2	0	6
4	4	0	6
5	4	1	7
6	4	2	8
7	6	3	8
8	8	4	8
9	9	5	7
10	10	6	6
11	11	7	6
12	13	9	3
13	14	11	2
14	15	13	1
15	17	14	1
16	21	14	0
17	23	14	0
18	24	16	0
19	25	17	0
20	26	19	7
21	27	20	14
22	28	20	14
23	29	21	15
24	30	23	15
25	31	25	15
26	31	27	15
27	31	29	15
28	31	30	10
29	31	31	0
30	31	31	31
31	31	31	31

CODE NO. 14

STEP	RED	GREEN	BLUE
0	0	0	0
1	1	0	2
2	2	0	4
3	2	0	6
4	4	0	6
5	4	1	7
6	4	2	8
7	6	3	8
8	8	4	8
9	9	5	7
10	10	6	6
11	11	7	6
12	13	9	3
13	14	11	2
14	15	13	1
15	17	14	1
16	21	14	0
17	23	14	0
18	24	16	0
19	25	17	0
20	26	19	7
21	27	20	14
22	31	0	0
23	31	0	0
24	31	0	31
25	31	0	31
26	0	31	0
27	0	31	0
28	31	31	0
29	31	31	0
30	31	31	31
31	31	31	31

CODE NO. 15

STEP	RED	GREEN	BLUE
0	0	0	0
1	5	0	0
2	6	0	0
3	7	0	0
4	8	0	0
5	9	0	0
6	10	1	0
7	11	2	0
8	11	3	0
9	11	4	0
10	11	5	0
11	12	5	0
12	12	6	0
13	12	7	0
14	12	8	0
15	9	10	0
16	9	11	0
17	9	12	0
18	10	13	0
19	10	14	0
20	12	15	0
21	15	16	0
22	20	16	0
23	23	16	0
24	24	17	0
25	25	19	0
26	26	21	0
27	27	23	0
28	28	25	0
29	29	27	0
30	30	29	0
31	31	31	0

APPENDIX C

SAC TARGET/OAP
DESCRIPTIONS AND LOCATION CUES

TARGET/OAP TAPE FILE	DESCRIPTION	BACKGROUND	CUES
1-A/4078-1	Road intersection	Cultivated fields	(1) at the vertex of an acute angle formed by a road diagonal to the normal section lines, (2) between two small towns.
1-B/4078-1	Junction of two fence/tree rows	Agricultural	(1; at junction of narrow row of trees or vegetation perpendicular to a broad field pattern, (2) the length of the tree row is about the same as the width of most fields in the area, and forms a boundary of two low return areas on either side.
1-C/4078-1	Road intersection	Agricultural	(1) aimpoint is intersection of perpendicular roads which form the boundary of an area of granary/machinery barns, (2) located near curve in a major road on the outward side of the curve and about 1/2 field widths from it.
2-A/4078-3	Small ground-water pump facility	Agricultural	(1) located on concave side of bend in prominent canal, (2) located at the T-junction of two field boundaries.
2-B/4078-3	Road intersection	Agricultural	(1) located at the right-angle corner of triangular field adjacent to canal.
2-C/2078-3	Apex of V-shaped treeline	Agricultural	located on convex side of bend in prominent canal.
1/4078-4	Corner of a fence enclosing a missile site	Desert	aimpoint is apex of lower right corner of enclosure.
2/4078-6	Cloverleaf interchange	Urban/ industrial	(1) located on bend in freeway, (2) aimpoint is center of the overpass.
3/4079-4	Canal-junction	Desert	(1) aimpoint is the spillway in larger canal, (2) located near freeway.
4/4079-5	Building	Rural/ coastal	(1) aimpoint is center of target, (2) located on near-range side of prominent road which "intersects" the freeway, (3) located near coastline.

TARGET/OAP TAPE FILE	DESCRIPTION	BACKGROUND	CUES
5/4079-6	Road intersection	Primarily urban	(1) located about halfway along imaginary line from curve in canal to large corner formed by residential section.
6/4079-7	Large hangar-type building	Waterfront/ airfield	(1) aimpoint is corner nearest in range, (2) building located on long, wide street leading to bay, (3) building is large, textured rectangle.
7/4077-4	Freeway overpass	Agricultural/ residential boundary	(1) aimpoint is center of overpass, (2) main street perpendicular to and passes over freeway, (3) main street and freeway form residential/rural boundary.
8/4077-5	Road intersection	Primarily urban/ industrial	(1) located near built-up commercial area which is adjacent to vacant lands, (2) near curve in freeway under construction, (3) aimpoint is intersection of two perpendicular streets nearest the most built-up area.
9/4077-7	Peak of a hill	Agricultural/ desert	(1) contrast of radar shadow from hill against the background, (2) aimpoint is peak of the hill.
10/4078-4	Missile site	Desert	aimpoint is fire control blockhouse located within the chainlink fence outside of missile launch area.
11/4078-6	Large building	Urban/ industrial	(1) aimpoint is near-range corner of the building, (2) there are three buildings of similar shape and size adjacent to it, (3) located on curved street.
12/4079-4	Highway interchange	Desert	(1) aimpoint is on side away from canal, (2) aimpoint is at junction of access road and overpass.
13/4079-5	Road intersection	Rural/ residential	(1) located on side of freeway away from ocean, (2) one road is prominent and intersects freeway, (3) other road is smaller and intersects larger one where undeveloped area meets developed area.
14/4079-6	Road intersection	Residential/ agricultural mix	(1) located about halfway along small no-return runway which is near the curved canal, (2) aimpoint is junction of road perpendicular to runway and its boundary.

TARGET/OAP TAPE FILE	DESCRIPTION	BACKGROUND	CUES
15/4079-7	Long segmented warehouse	Waterfront/ airfield	(1) length of warehouse is parallel to shoreline and parallel to street separating building from water, (2) aimpoint is far range corner nearest the water.
16/4077-4	Street intersection	Residential/ agricultural mix	(1) located at corner of residential/ agricultural boundary, (2) the second apex of a "stairstep" away from the main street in town, (3) aimpoint is corner nearest the residential area.
17/4077-5	Two metal cylindrical storage tanks	Cleared terrain, smooth dirt	(1) located between freeway under construction and canal, (2) will appear as elongated "peanut."
18/4077-7	Road intersection	Agricultural/ desert	(1) located two field lengths from the end and one width away from large rectangular no-return field which is aligned with a hill in the far range direction, (2) aimpoint is center of intersection.
19/4078-4	Graded road pattern	Desert	(1) located on administration side at missile launch area, near the curve in the road leading to the complex, (2) aimpoint is at apex of second road pattern from the curved road.
20/4078-6	Large building	Urban/ industrial	(1) building is square, (2) aimpoint is on corner nearest concave bend in road (corner nearest in range).
21/4079-4	Junction of canal and fence row	Desert	(1) aimpoint is short distance along the smaller canal from the spillway located at the junction of the two canals, (2) aimpoint is where fence row "meets" the canal.
22/4079-5	Road junction	Housing development in rural area	(1) aimpoint is road junction at far range side of housing development, (2) located about 1/4 the way along line of houses from sharp angle treeline.
23/4079-6	Street junction	New housing development	(1) aimpoint is located about halfway down the length of development, and in about 1/3 of the depth of the area, on the peak of the curved street, (2) located in area which is about three sections from curve in canal.

TARGET/OAP TAPE FILE	DESCRIPTION	BACKGROUND	CUES
24/4079-7	Rectangular fenced area	Commercial/ residential/ airfield	(1) two similar rectangular areas jutting into no-return area, (2) aimpoint is apex of the corner in the rectangle closer to near range.
25/4077-4	Road intersection	Agricultural near town	(1) at intersection of open and planted fields, (2) located about 2½ sections from railroad angled across the image, in the near range direction.
26/4077-5	Corner of residential area	Residential/ commercial	(1) two similar corners pointing toward near range, (2) aimpoint is the corner which forms the "inside" corner of a broad L-shaped no-return area.
27/4077-7	Curve in road	Agricultural/ desert boundary	(1) located on edge of field and desert, (2) located toward near range from hill.

APPENDIX D

BRIEFING MATERIALS EMPLOYED IN THE SAC, TAC, AND RECCE STUDIES

GENERAL

This appendix includes the general briefing statement provided to each test subject explaining the intent and purpose of the research program. The specific instructions for the SAC, TAC, and RECCE studies also are included. In addition, the sketches of target signatures that were provided the subjects during the TAC and RECCE studies also are shown.

General Briefing Statement

We are conducting an experiment to determine whether or not color coding of radar scenes can improve the accuracy and response time in locating large targets, OAPs, and small targets. The first test is a SAC-type situation in which you will be given photos with the targets and/or OAPs pointed out. You can study the photo and make any grease pencil markings on the photo that you feel will help you orient yourself or find the target. When you are ready, the 40-foot-resolution radar scene will be shown to you and all you have to do is find the target/OAP as quickly as you can. You will be given one photo and assigned one target at a time. There will be 27 different targets in all.

The second test is a TAC-type test in which you will be informed of the target that you are to find (convoys, tanks, vehicle parks, etc.). When the radar scene is displayed, it will be your task to find the target of interest and to count the number of vehicles and/or weapons included in the target complex.

The third test will have targets similar to the second test but you will not be told ahead of time what they are. However, you will be given a list of what kinds of targets you will be looking for. When the radar scene is displayed, you again will be tasked to find, classify, and count the targets.

As in the past, the results of individual performances are kept confidential so that they may not be used to evaluate you personally.

We are testing techniques – not you!

Any questions?

SAC Briefing Instructions

You will be presented with 27 radar scenes, each of which will have an OAP or target which you are to find. They will be presented one at a time with one target or OAP. You will have a briefing photo to study that points out the target, and prominent features will be listed on a separate target info sheet. You may annotate and sketch anything you want on the photo, *e.g.,* roads, streams, etc., that you feel will help you.

When you are ready, so state and the investigato. will uncover the scene and start a stopwatch. When you find the prebriefed feature, say "there" and point to it. The photo will be available for you to examine while the radar scene is on the "tube." Work as accurately *and* quickly as possible.

TAC/RECCE Instructions

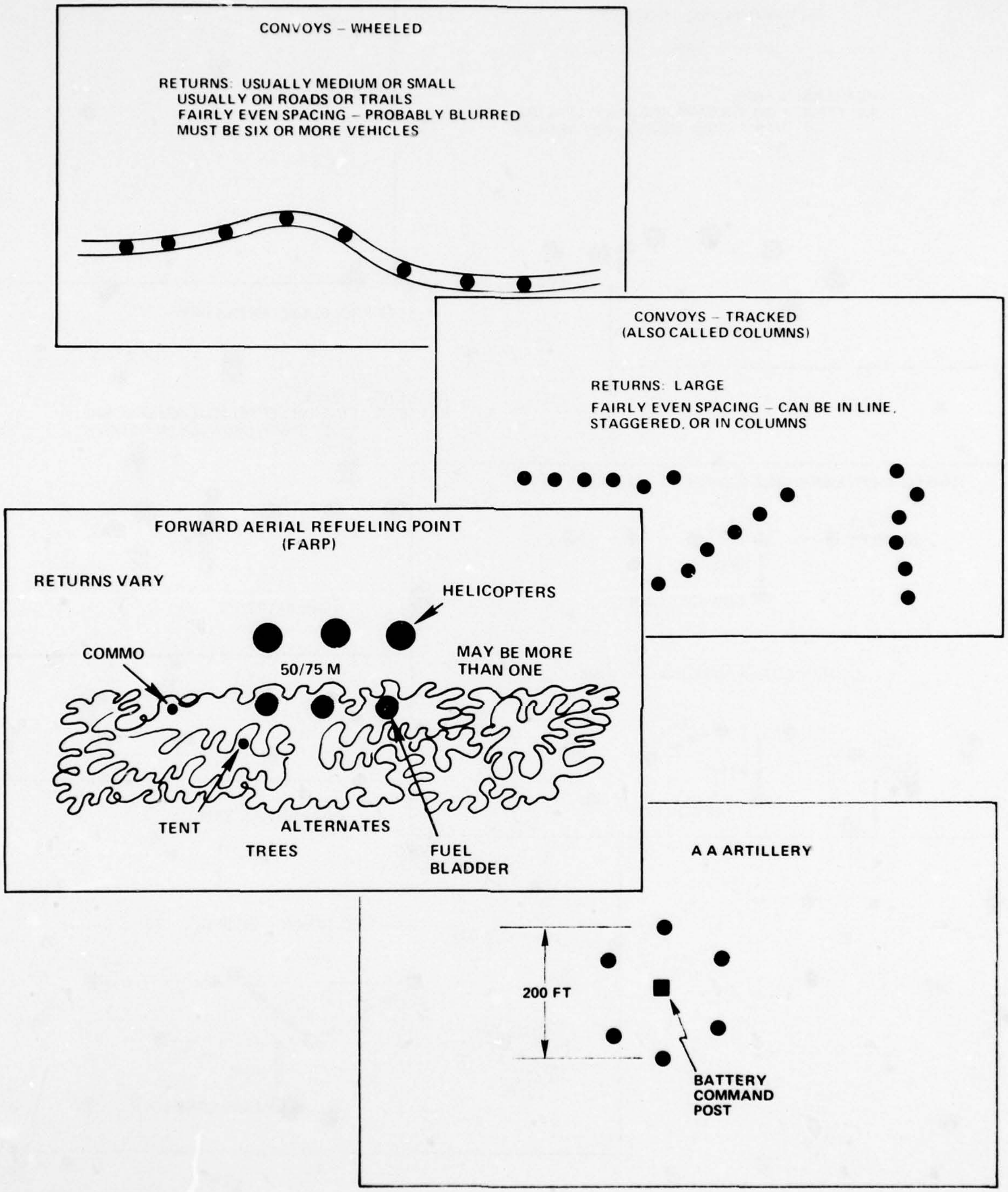
The next 18 scenes are TAC or RECCE targets. The first 6 are for practice. For a TAC target you will be told what the target is prior to viewing it, *e.g.,* Hawk. When the display is uncovered, find the target of interest, say "there," count the number of vehicles or weapons in the target signature, and report the number aloud.

For a RECCE target you will be advised prior to viewing the scene that it is a RECCE target. You will have a list of RECCE targets included in this study. When you say "ready," the scene will be displayed. You are to find one of the targets on the list, say "there," report what it is, and how many separate vehicles or weapons are in the target.

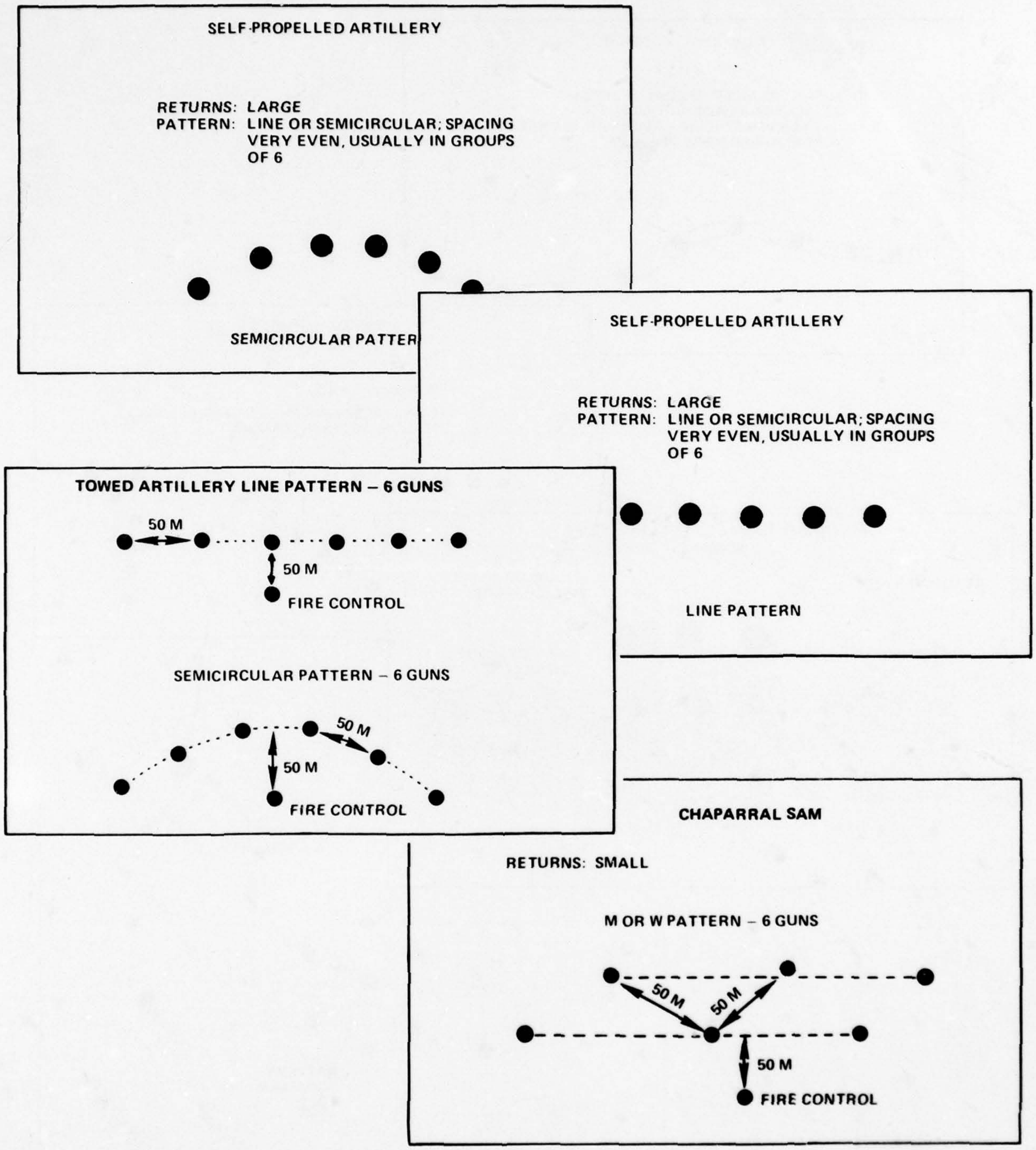
Work as accurately *and* quickly as possible.

You will view some target scenes in color and some in black and white.

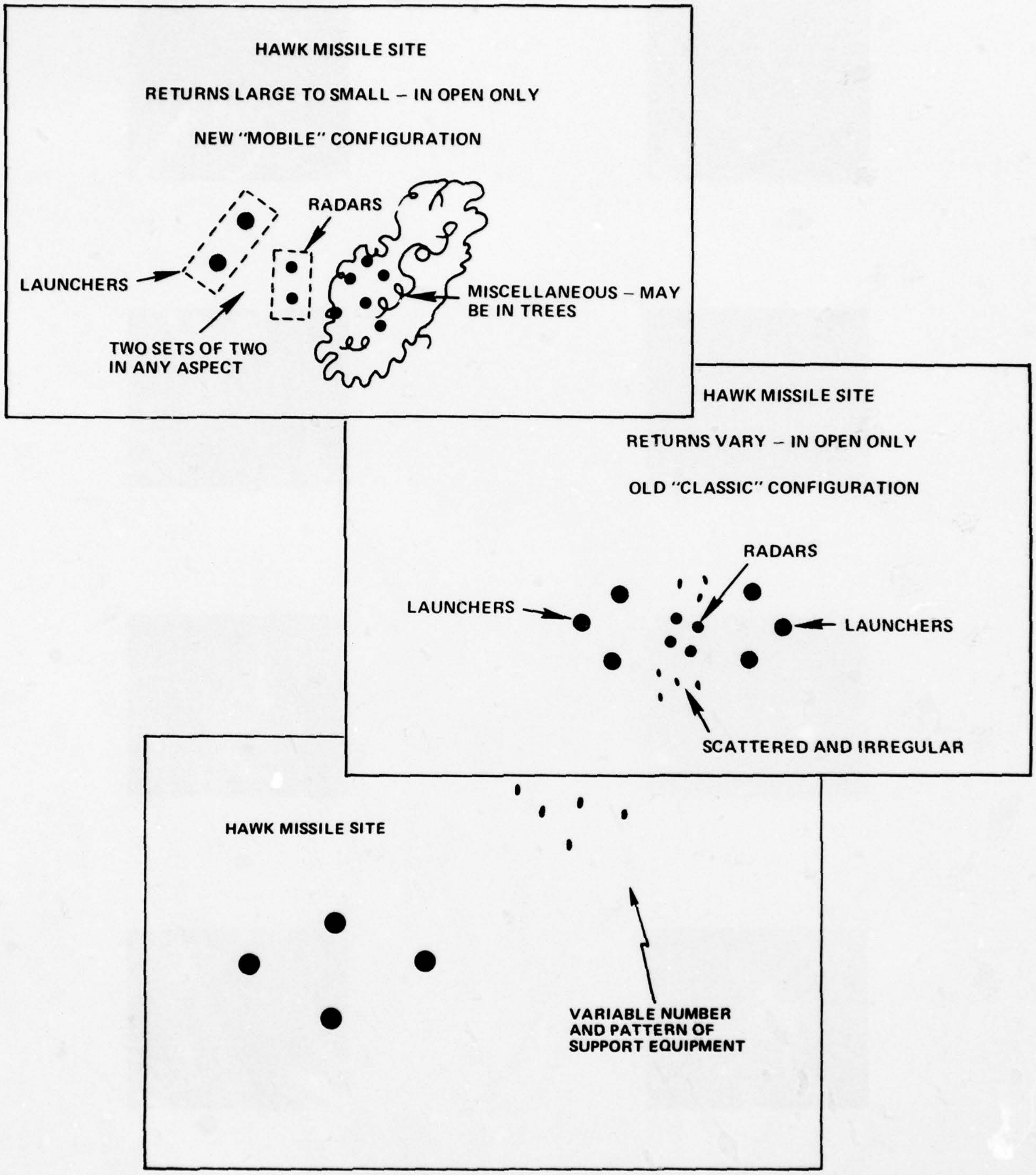
Any questions?



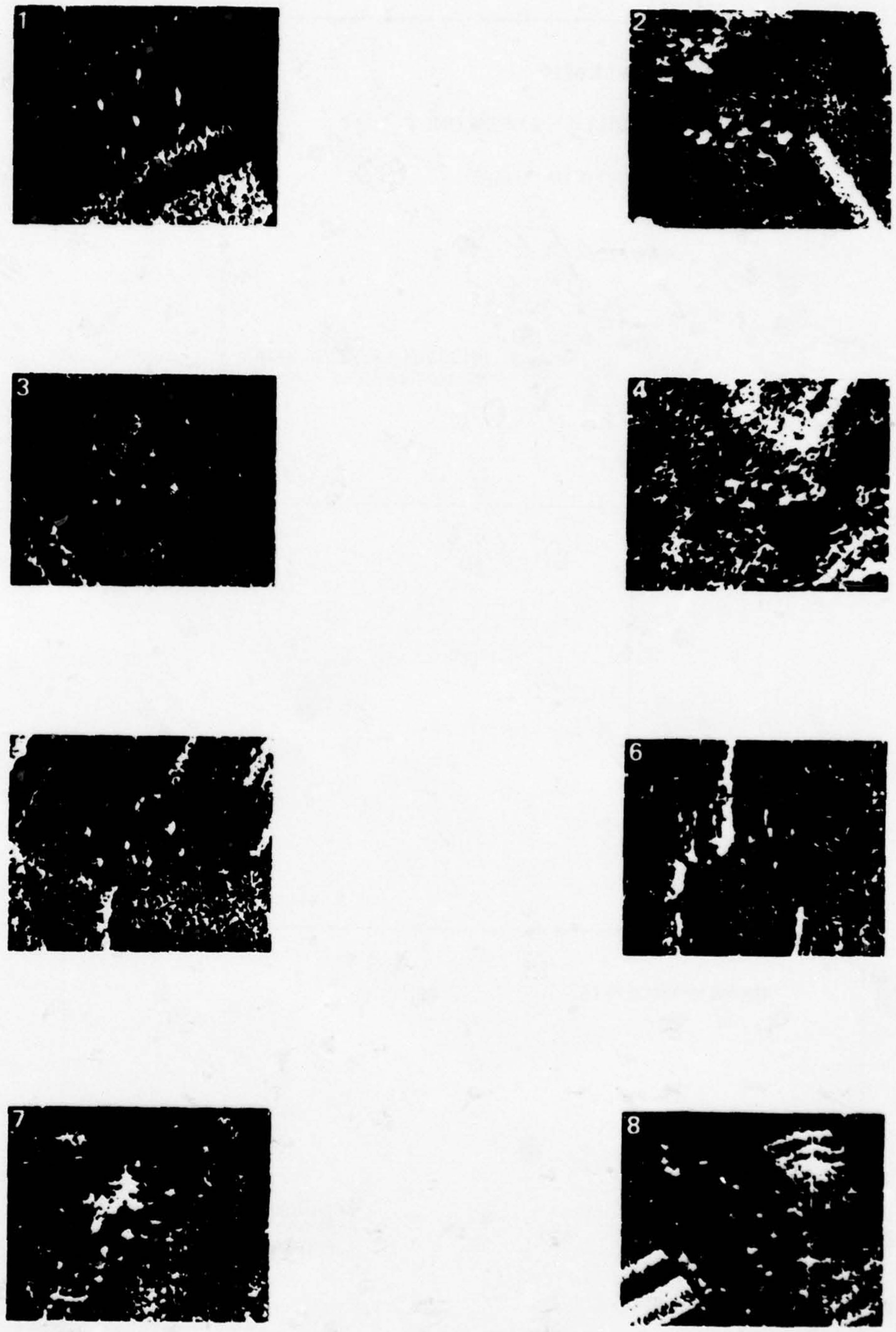
Target Signature Sketches



Target Signature Sketches



Target Signature Sketches



Missile Site Patterns

APPENDIX E

This Appendix contains 31-record by 31-element printouts of the input values of embedded targets and their backgrounds. The first six printouts are of training targets.

Following each printout of a test target is a histogram of the same area. Values included in the printouts and histograms have a possible input range from 0 to 255. Each step represents 0.375 dB.

Targets are outlined on the printouts. Asterisks in the histograms correspond to target and background values. Target histograms are indicated by the circles.

310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330
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TAC/RECCE Training Target C – Hawk

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235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255
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43	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265
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16	114	120	116	108	104	107	120	119	110	108	110	104	118	110	99	121	93	111	103	104	126	103
08	104	107	104	121	120	100	119	122	112	108	115	113	117	116	114	111	100	112	98	108	120	117

TAC/RECCE Training Target D – Vehicle Park

306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327
120	114	113	150	127	126	118	141	133	130	126	122	119	126	126	114	127	134	125	125	130	113
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315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336
130	126	122	119	126	126	114	127	134	125	125	130	119	126	126	119	121	122	123	117	115	112
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119	145	145	120	124	132	123	137	122	133	120	115	131	132	122	130	124	113	113	121	117	112
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116	134	129	125	131	116	136	138	135	124	124	120	123	131	134	119	123	122	116	106	106	116
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132	140	133	129	132	134	130	116	135	127	126	128	130	122	126	126	117	114	120	119	133	135

TAC/RECCE Training Target E – Artillery

1

THIS P
FROM C

35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55
114	102	105	116	106	111	105	117	103	109	150	114	104	116	118	109	107	148	121	120	118
113	105	113	116	117	114	102	113	112	110	112	111	113	111	117	99	106	143	105	118	117
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94	113	101	110	111	113	93	100	107	118	118	104	104	102	104	117	104	113	123	131	91

TAC/RECC

2

43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
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TAC/RECCE Training Target F – Chaparral

305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	32
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BEST QUALITY PRACTICABLE
...NISHED TO DDC

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TAC/RECCE Target No. 1 – Artillery

THIS PAG
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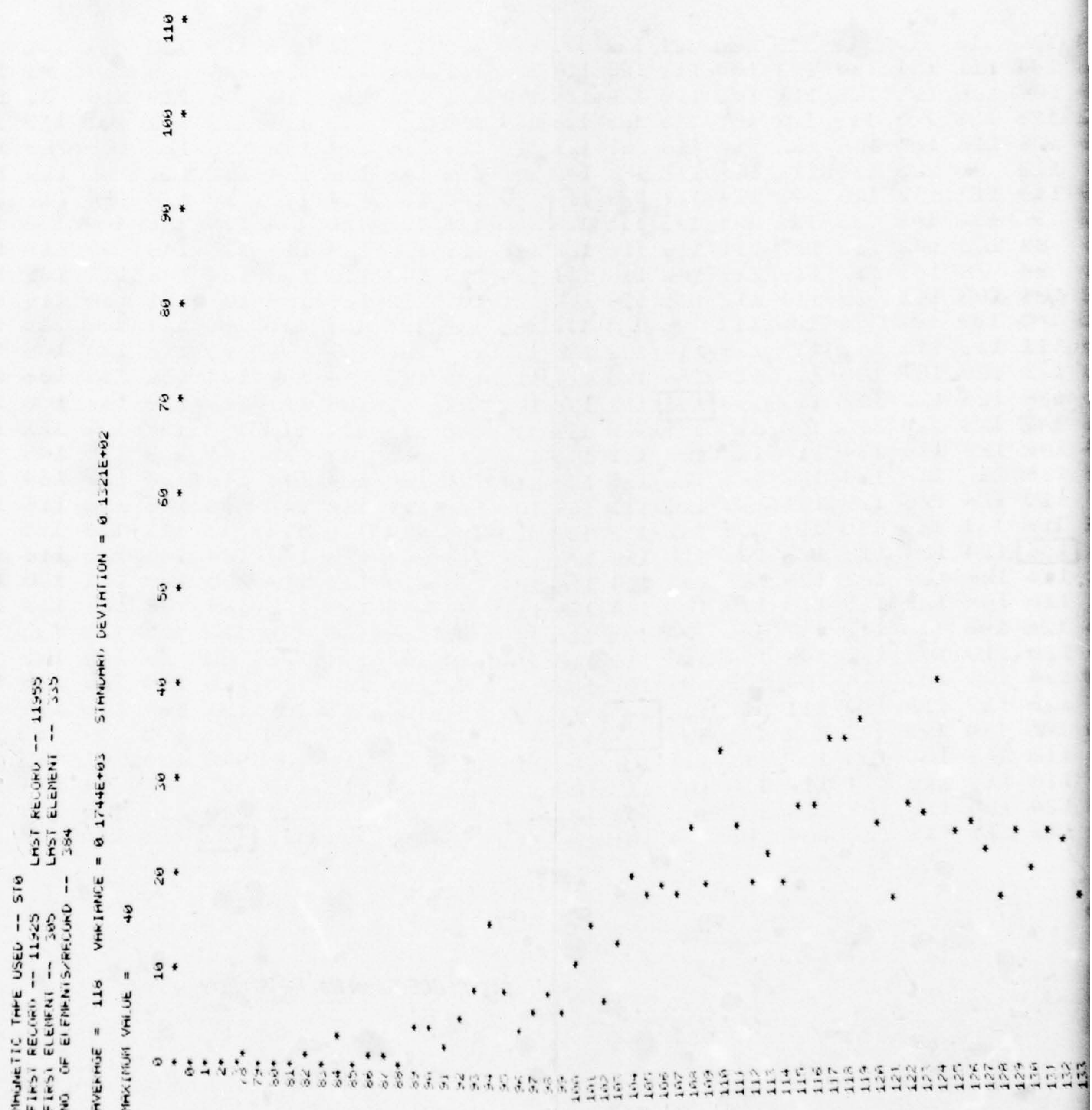

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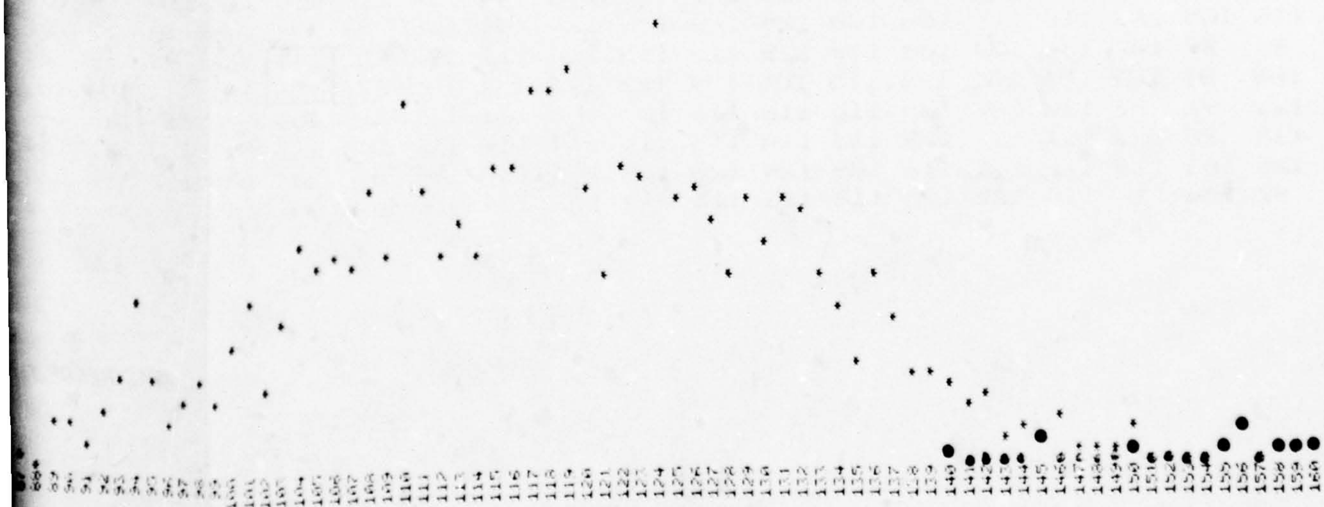

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2

EST QUALITY PRACTICABLE
ISHED TO DDC

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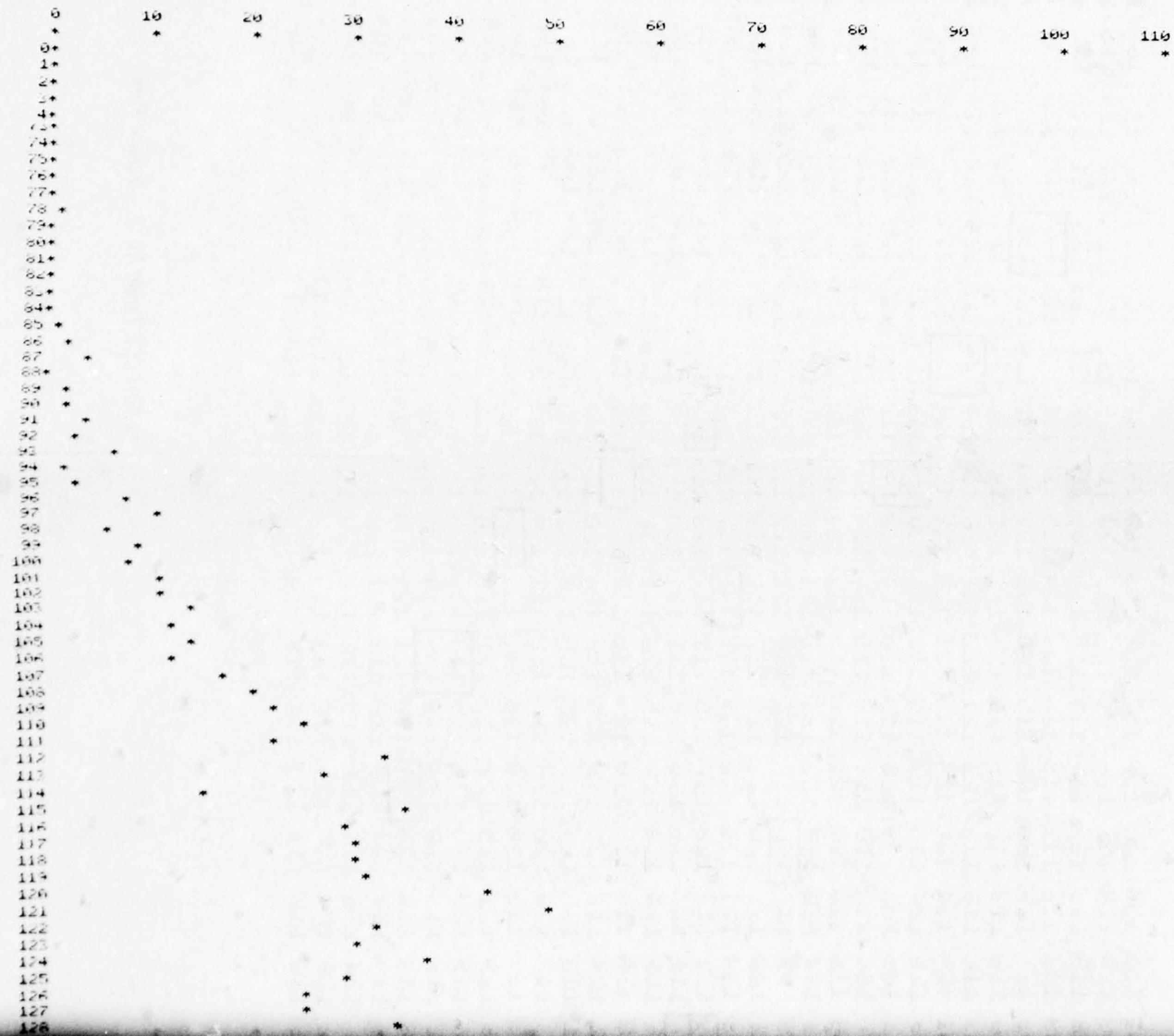
TAC/RECCE Target No. 2 – Vehicle Park

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

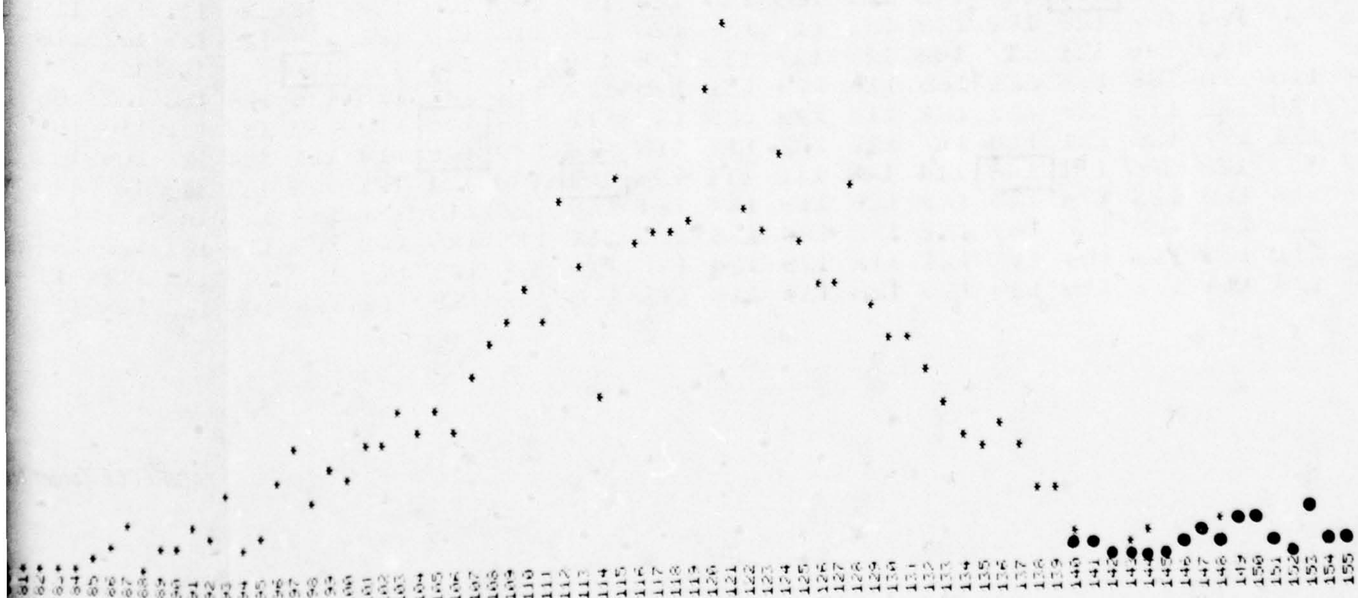
MAGNETIC TAPE USED -- ST0
FIRST RECORD -- 12322   LAST RECORD -- 12352
FIRST ELEMENT -- 143   LAST ELEMENT -- 173
NO. OF ELEMENTS/RECORD -- 384

AVERAGE = 118   VARIANCE = 0.1417E+03   STANDARD DEVIATION = 0.1191E+02

MAXIMUM VALUE = 49



2



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ALITY PRACTICABLE
TO DDC

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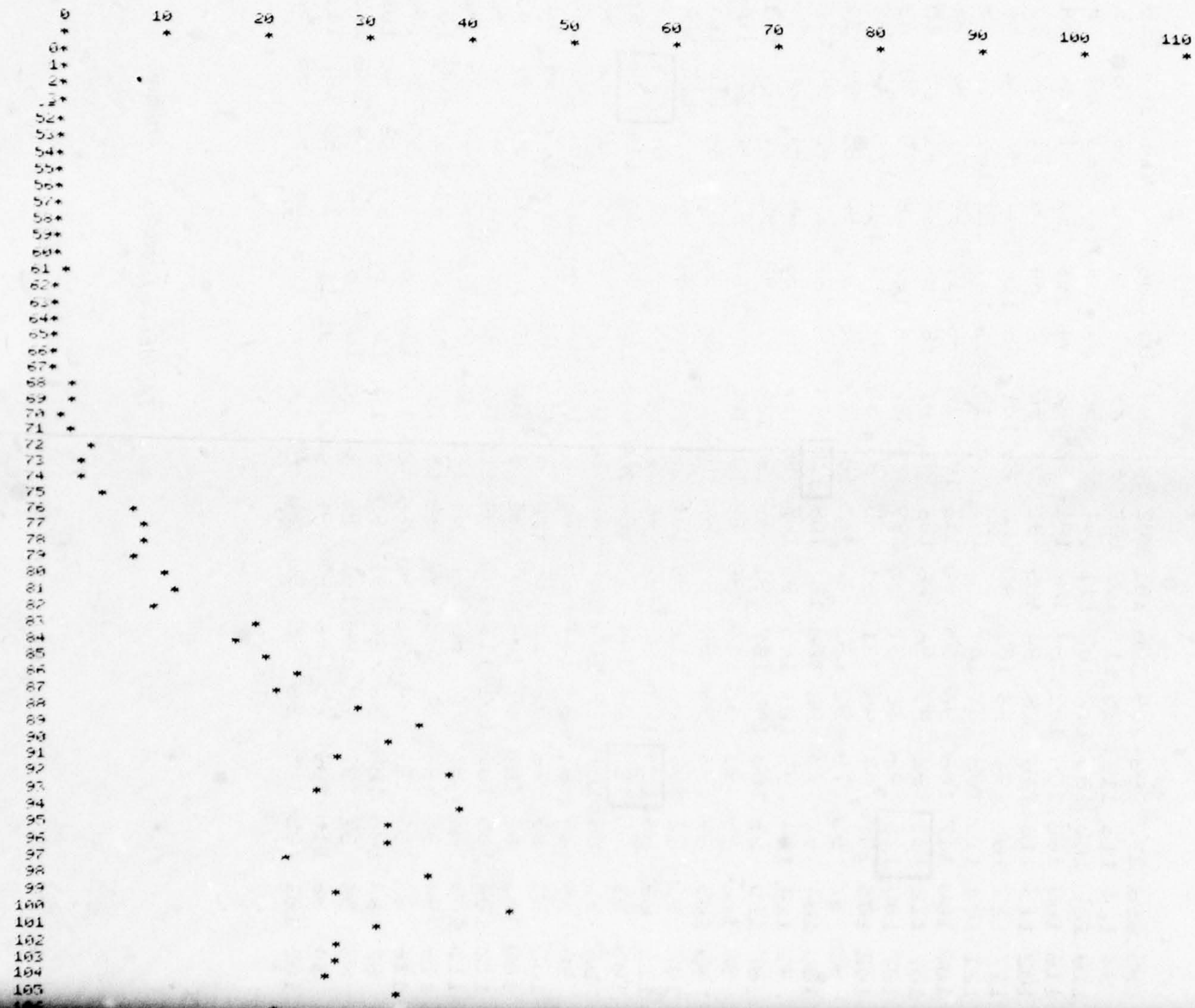
TAC/RECCE Target No. 3 – Artillery

MAGNETIC TAPE USED -- S70
FIRST RECORD -- 12861 LAST RECORD -- 12891
FIRST ELEMENT -- 265 LAST ELEMENT -- 315
NO. OF ELEMENTS/RECORD -- 384

AVERAGE = 97 VARIANCE = 0.1264E+03 STANDARD DEVIATION = 0.1124E+02

MAXIMUM VALUE = 45



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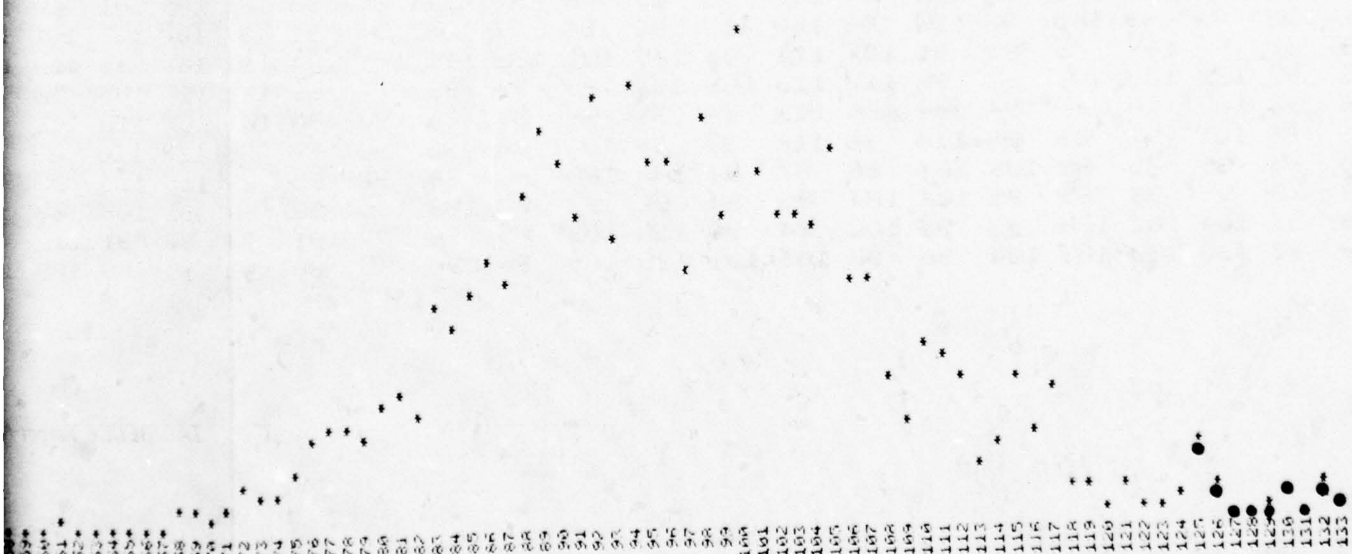

THIS PAGE IS BEST QUALITY PRACTICABLE
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TAC/RECCE

2

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TAC/RECCE Target No. 4 – AAA

```
MAGNETIC TAPE USED -- STØ
FIRST RECORD -- 13077      LAST RECORD -- 13187
FIRST ELEMENT --  260      LAST ELEMENT --  290
NO. OF ELEMENTS/RECORD --  384

AVERAGE =  108   VARIANCE = 0.1186E+03   STANDARD DEVIATION = 0.1089E+02

MAXIMUM VALUE =      44
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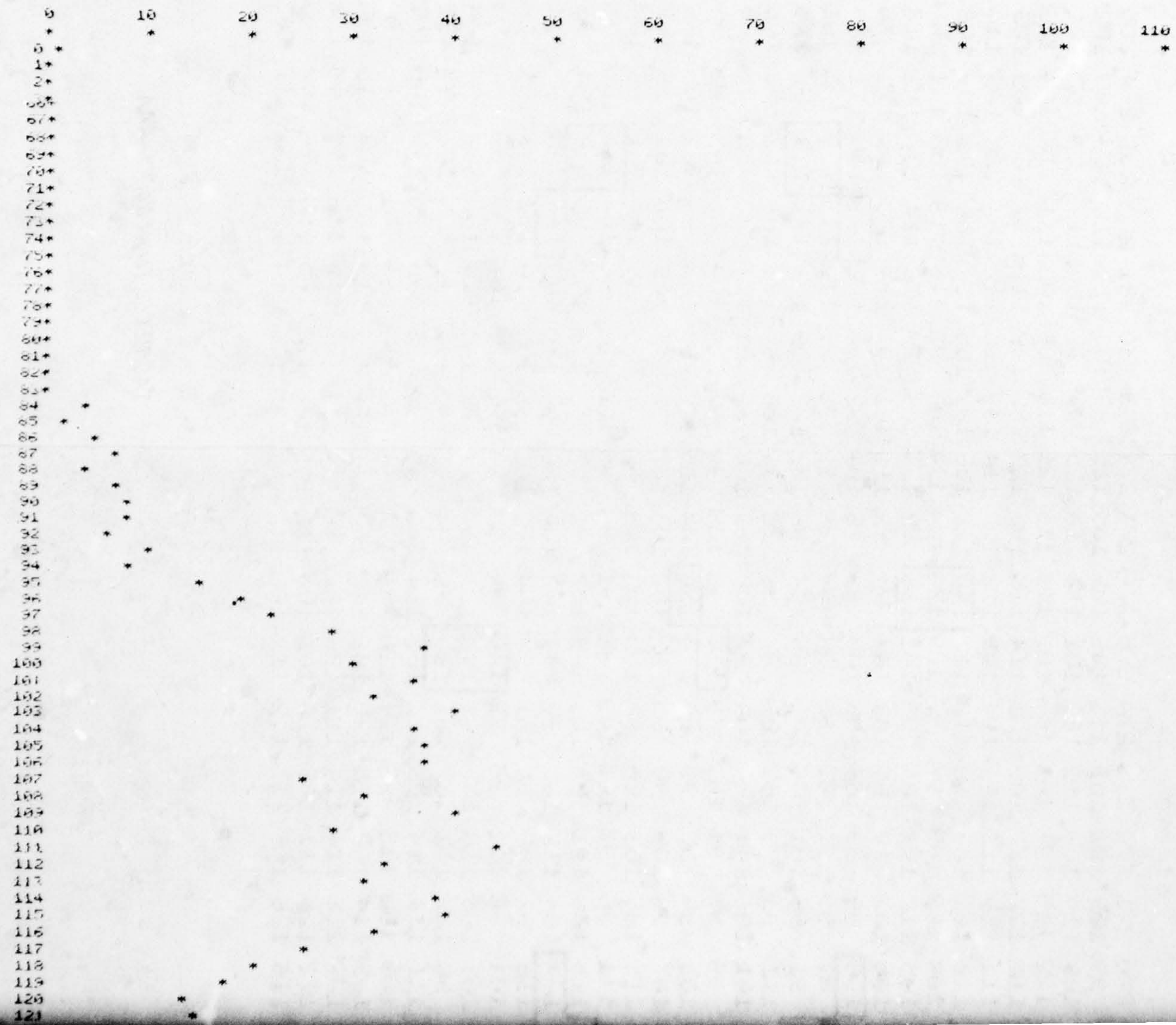

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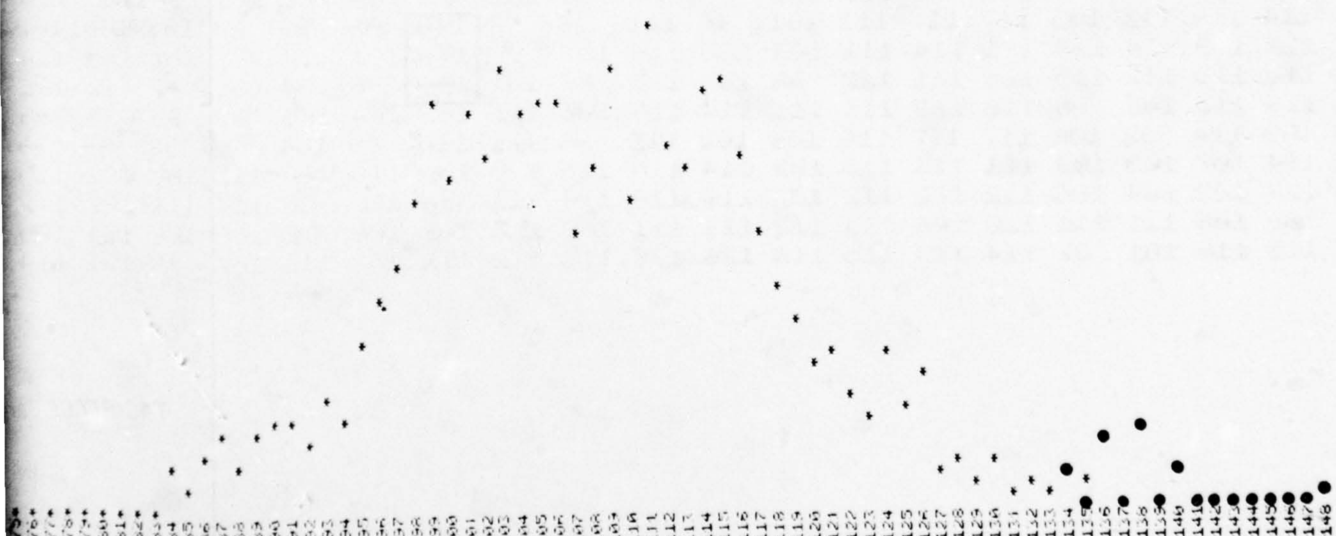

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TAC/RECCE Targ

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IS BEST QUALITY PRACTICABLE
URNISHED TO DDC

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

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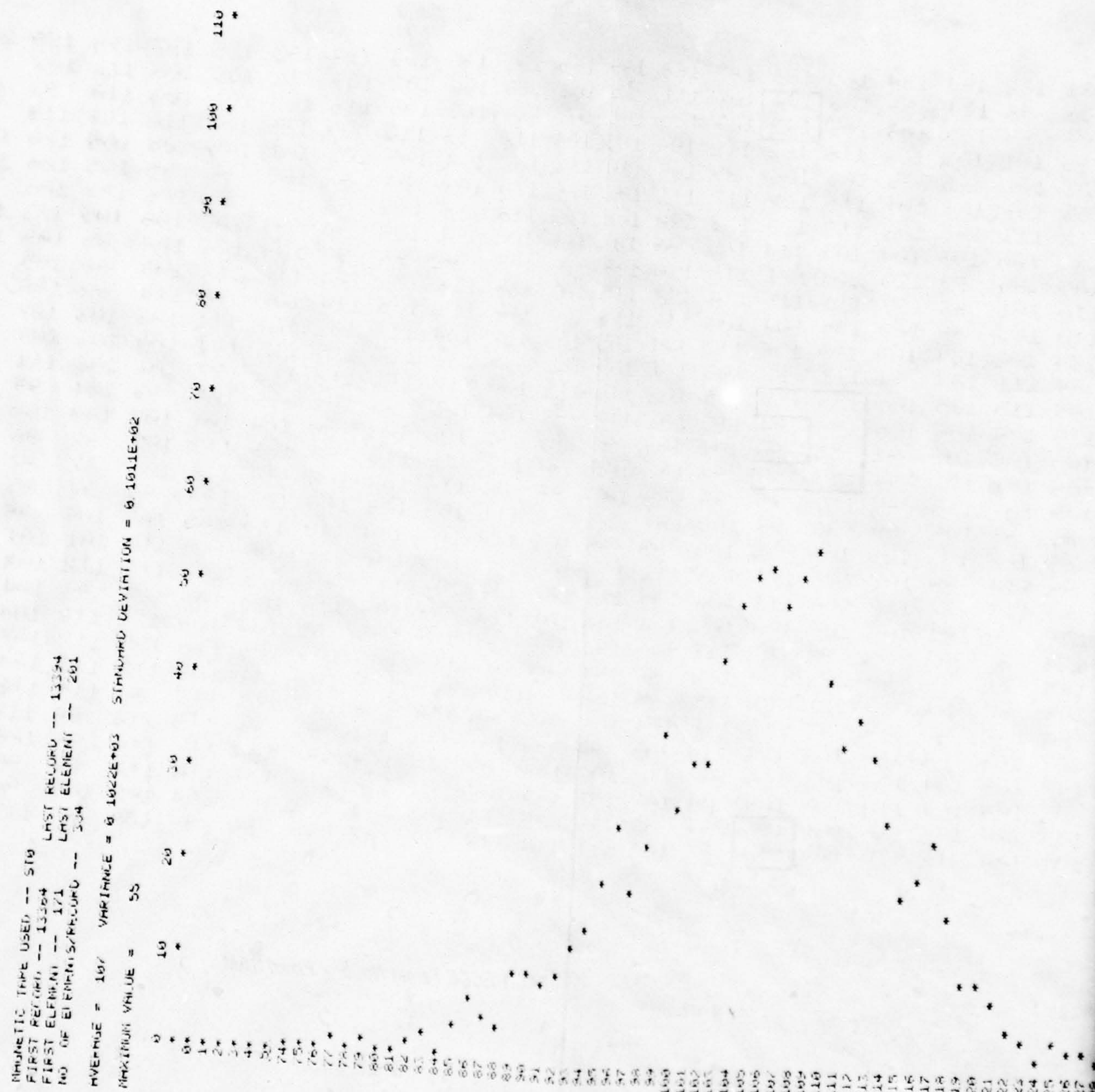
TAC/RECCE Target No. 5 – Fixed SAM


MAGNETIC TAPE USED -- STD
FIRST RECORD -- 13364   LAST RECORD -- 13394
FIRST ELEMENT -- 171   LAST ELEMENT -- 201
NO OF ELEMENTS/RECORD -- 304
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MAXIMUM VALUE = 55
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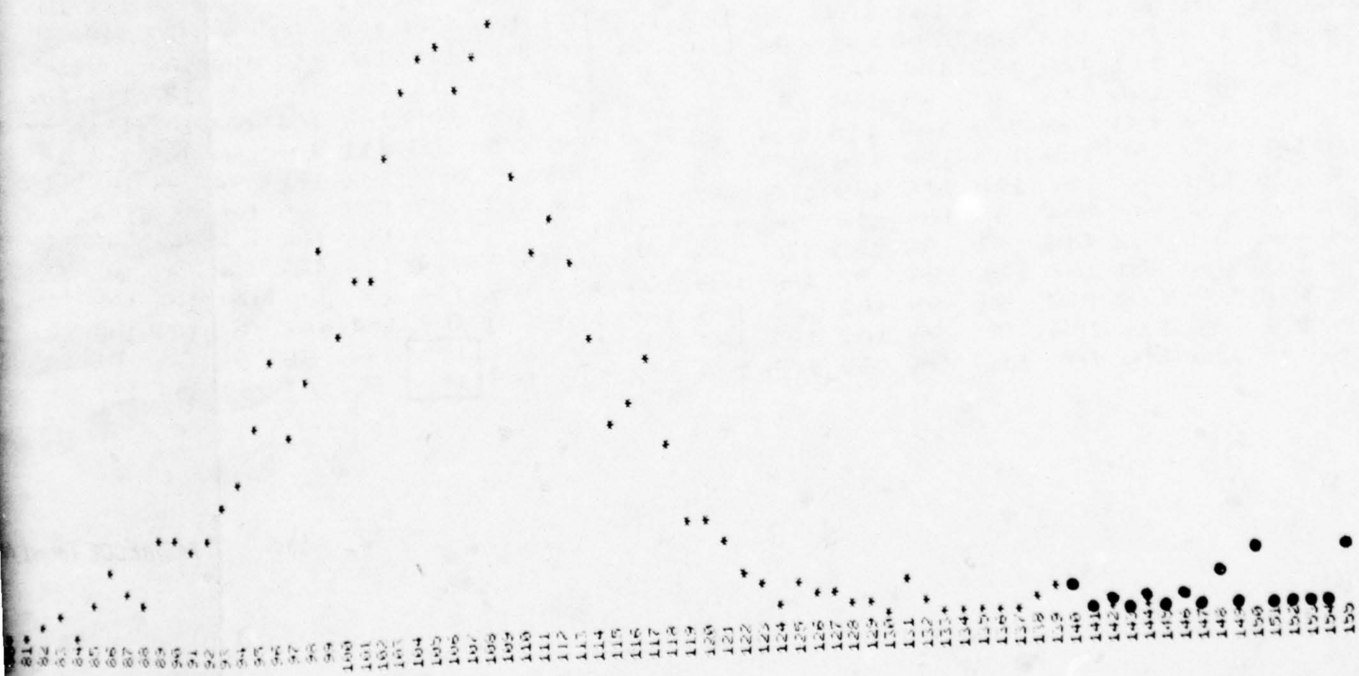
2



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TAC/RECCE T[…]

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TAC/RECCE Target No. 6 – SP Guns

MAGNETIC TAPE USED -- ST0
FIRST RECORD -- 13743 LAST RECORD -- 13773
FIRST ELEMENT -- 266 LAST ELEMENT -- 296
NO. OF ELEMENTS/RECORD -- 384

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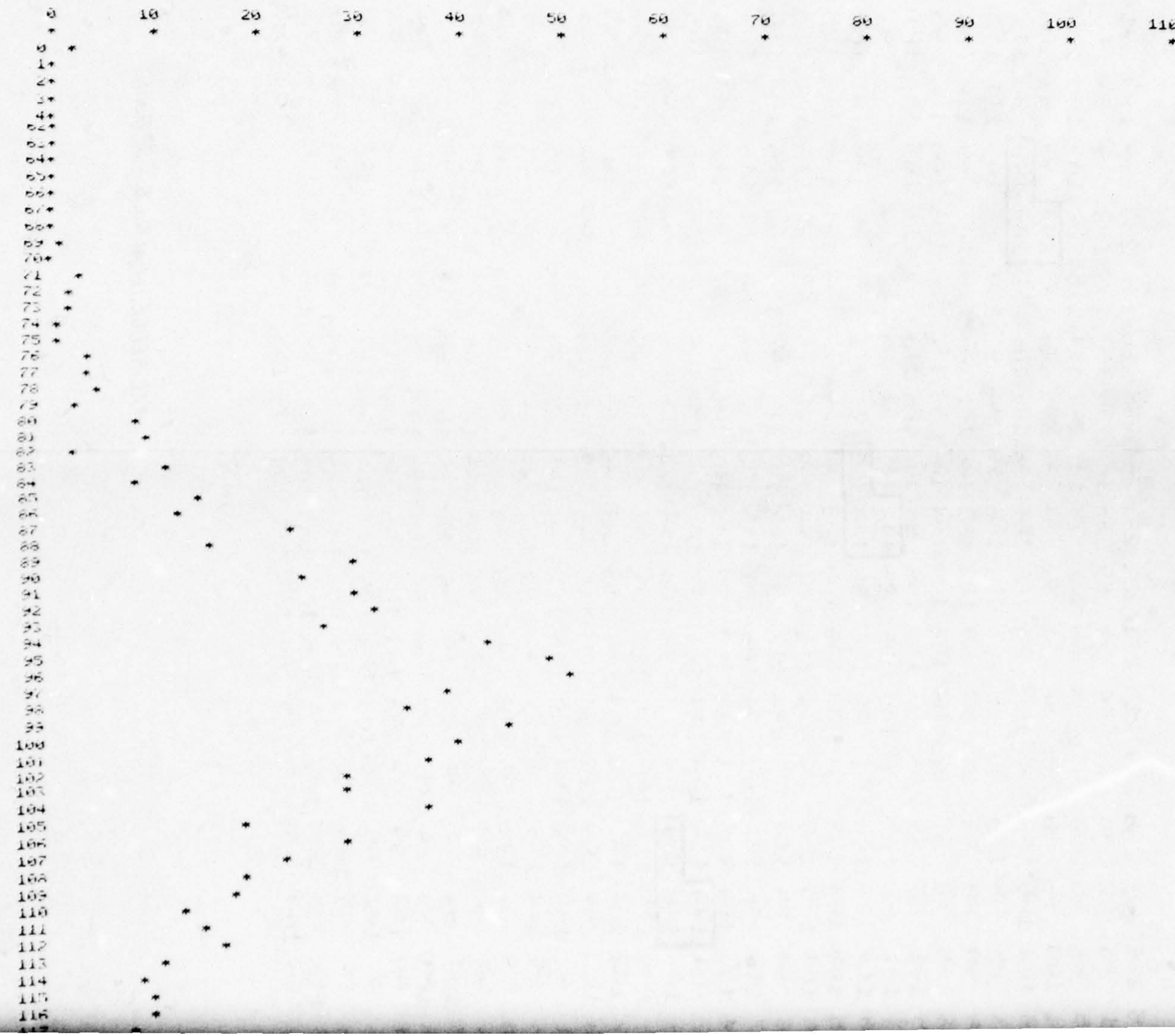

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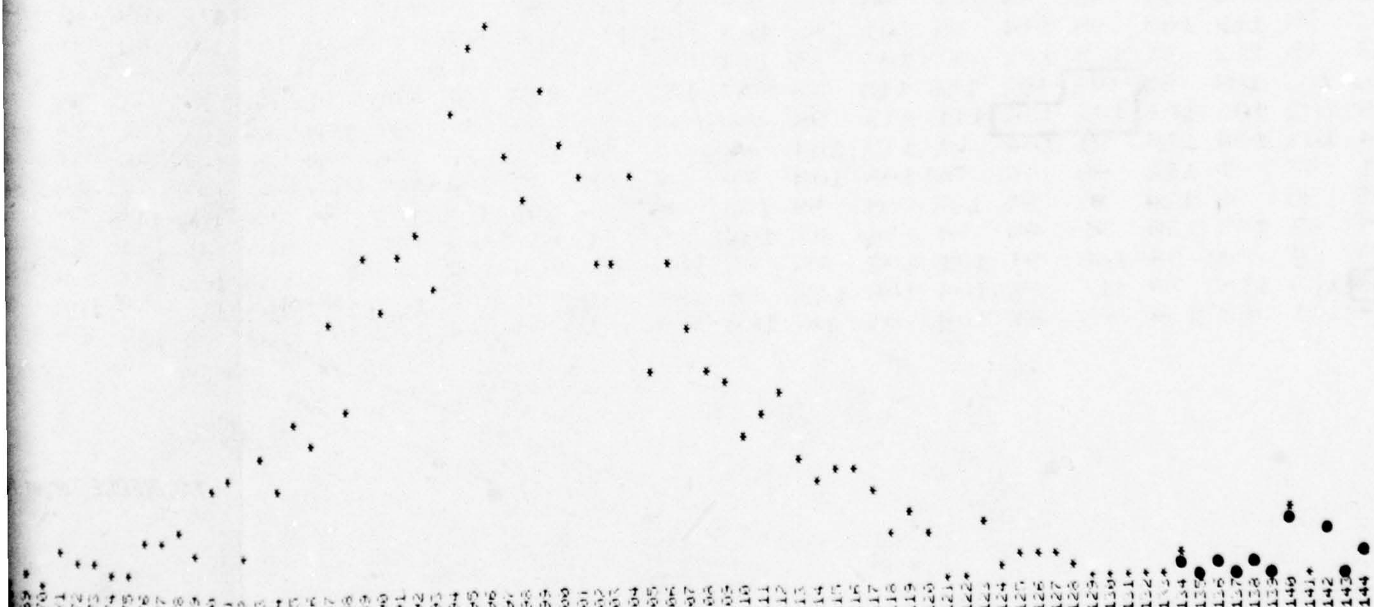

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TAC/RECCE Target No. 7 – Convoy

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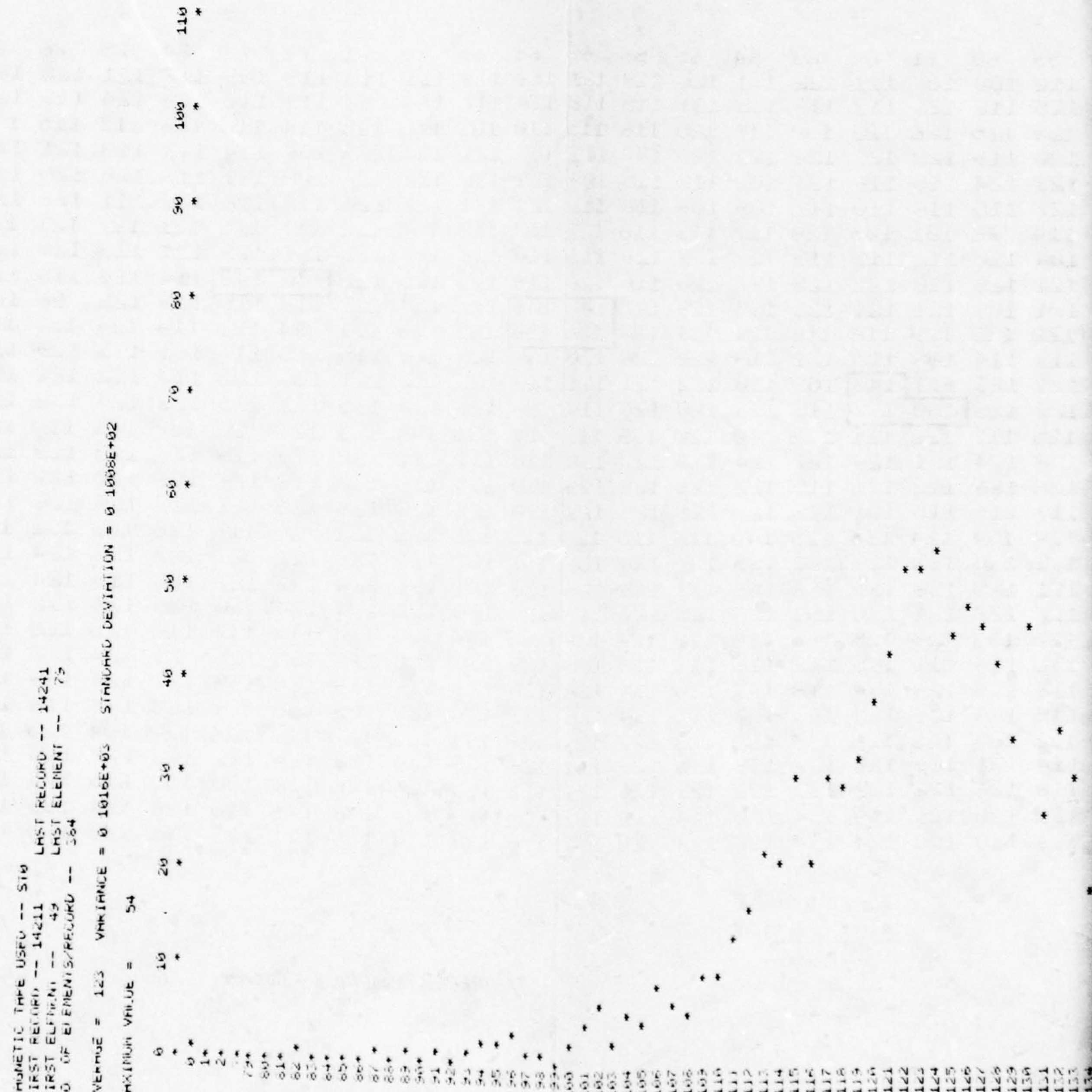

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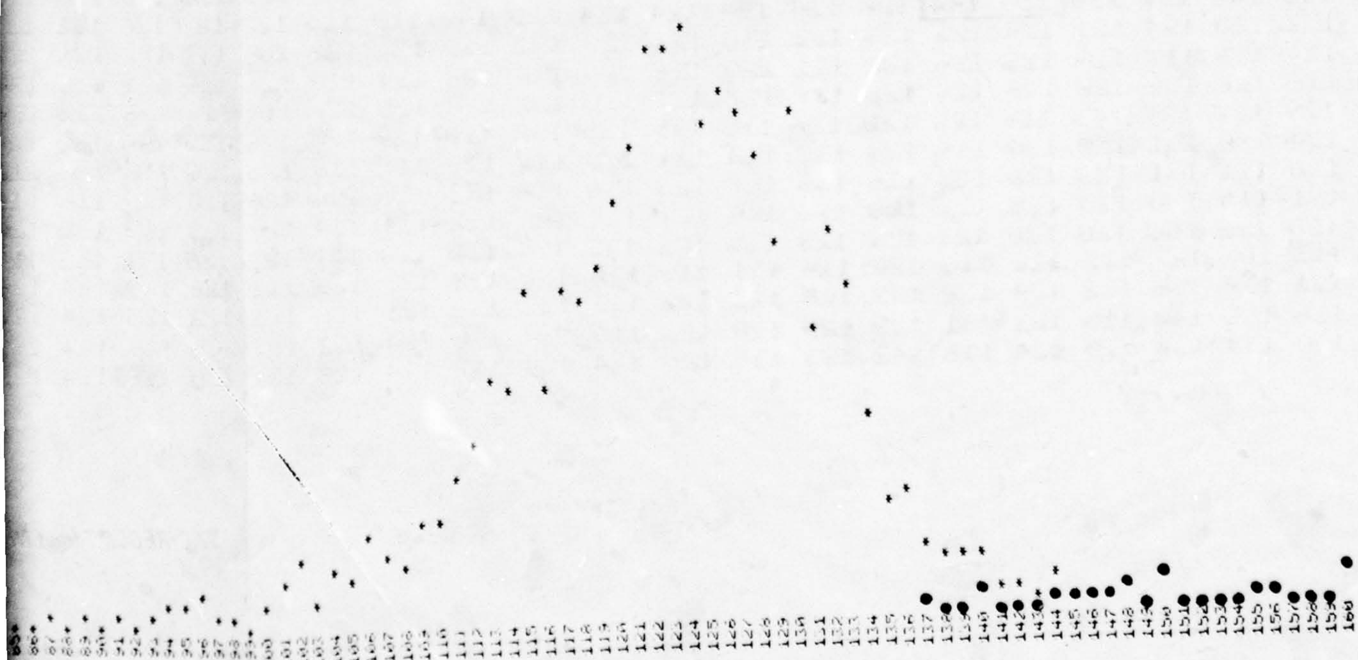

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TAC/RECCE Tar

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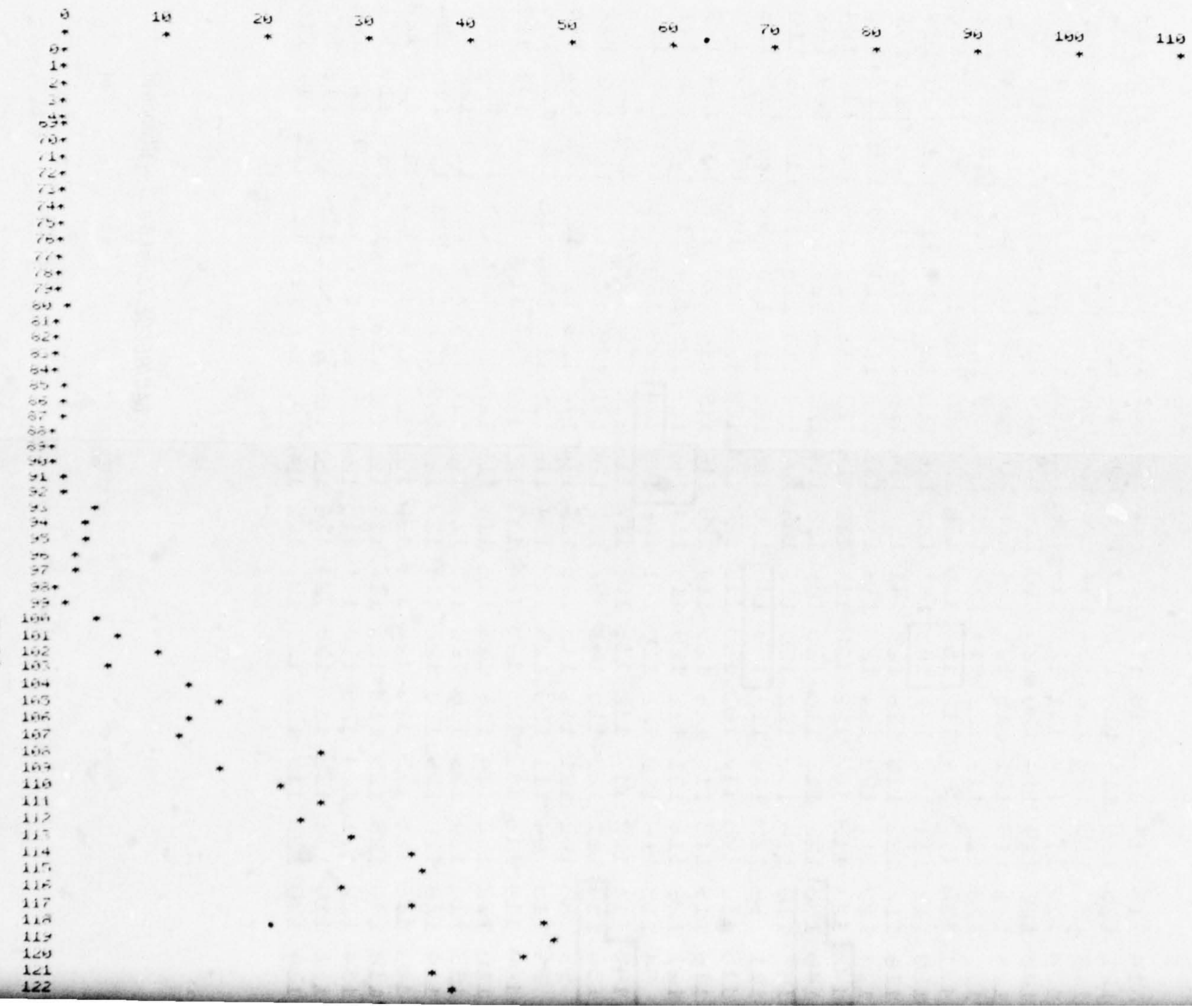
TAC/RECCE Target No. 8 – Chaparral

MAGNETIC TAPE USED -- STD
FIRST RECORD -- 14551 LAST RECORD -- 14561
FIRST ELEMENT -- 304 LAST ELEMENT -- 334
NO. OF ELEMENTS/RECORD -- 384

AVERAGE = 120 VARIANCE = 0.1014E+03 STANDARD DEVIATION = 0.1007E+02

MAXIMUM VALUE = 49



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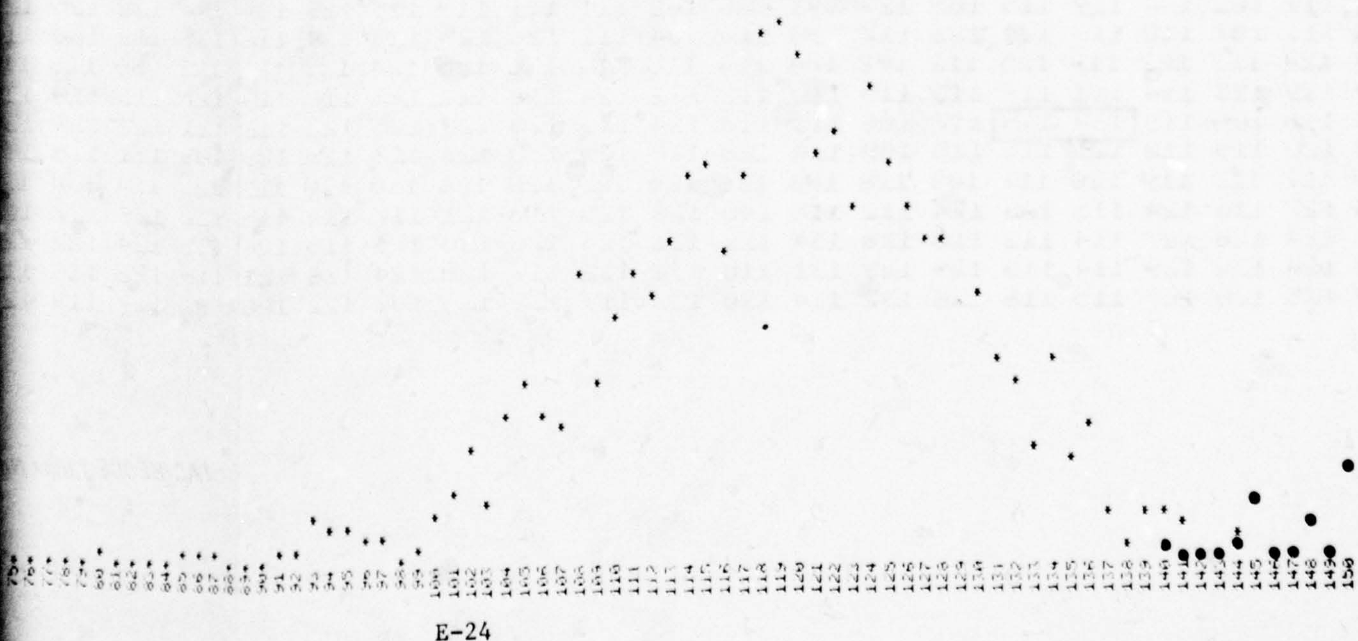

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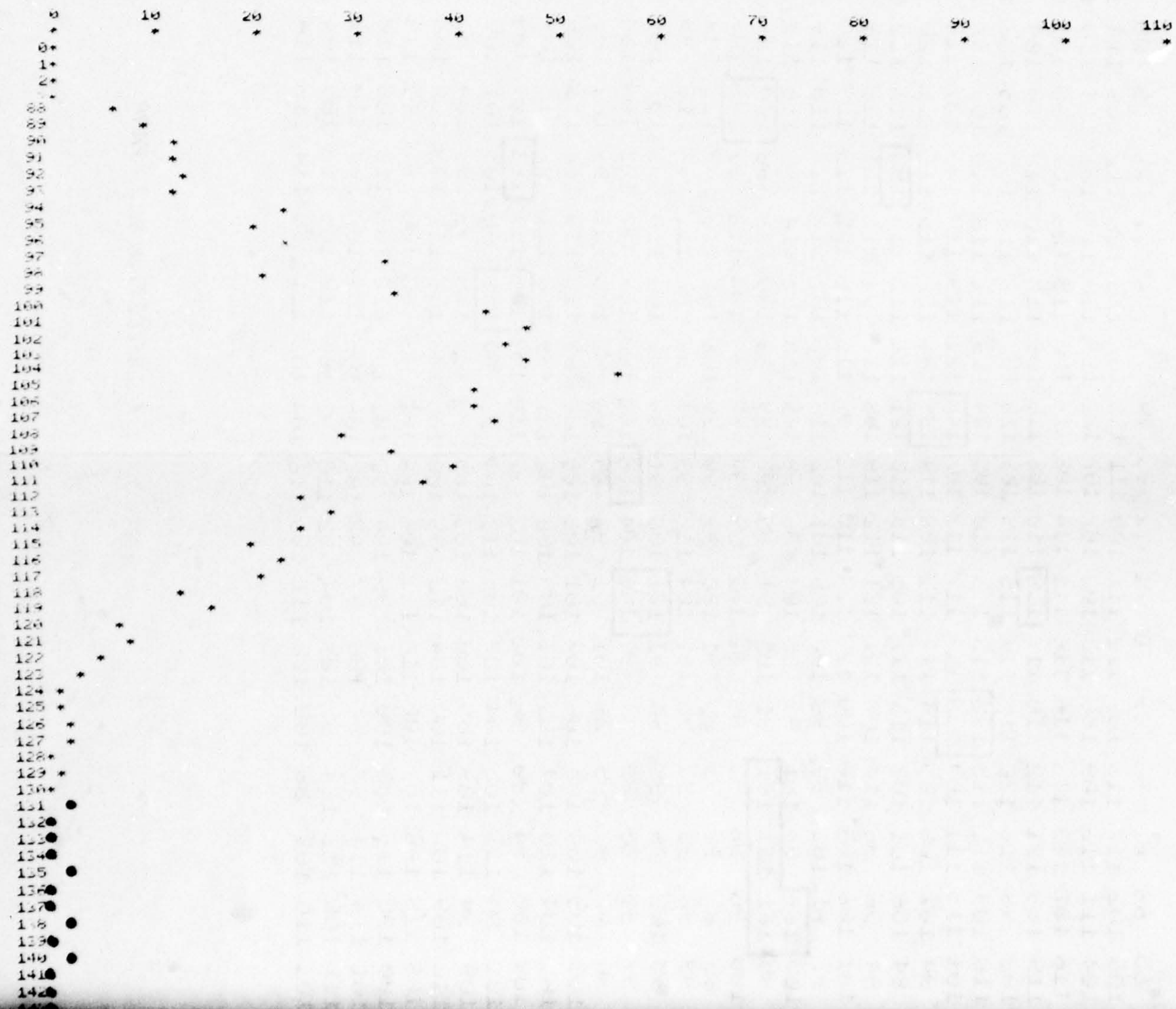
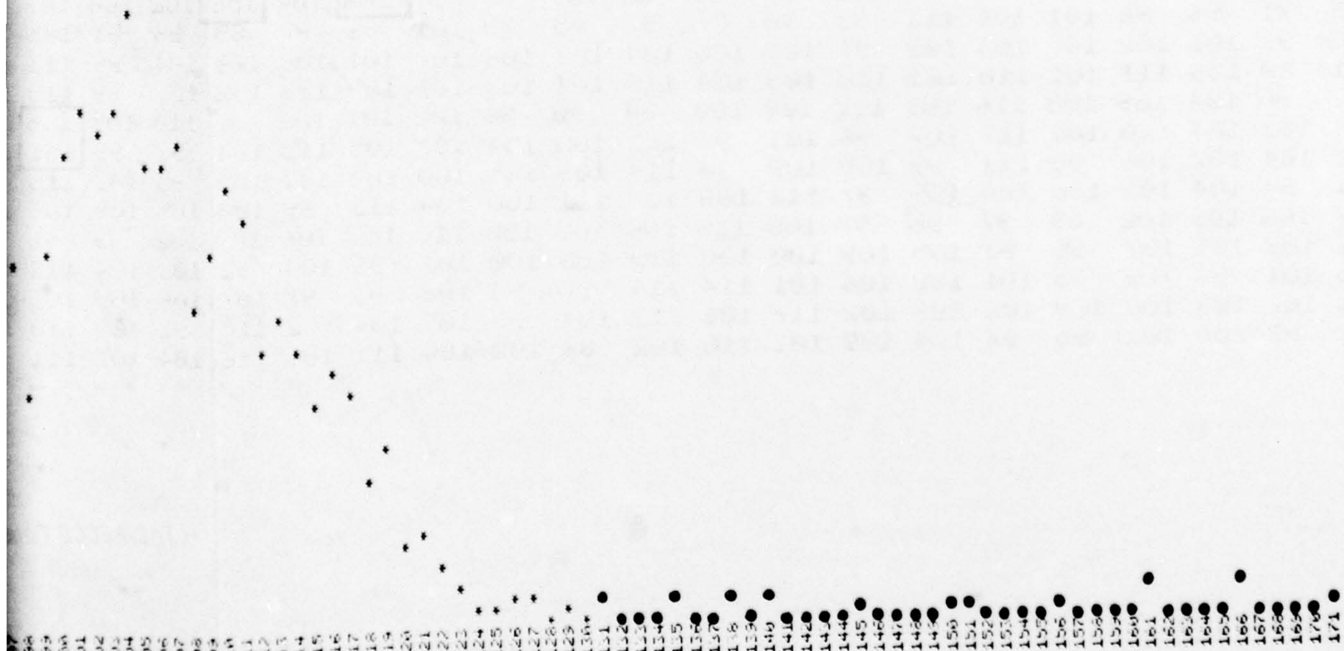
TAC/RECCE Target No. 9 – FARP

MAGNETIC TAPE USED -- 510
FIRST RECORD -- 14903   LAST RECORD -- 14933
FIRST ELEMENT -- 55   LAST ELEMENT -- 85
NO OF ELEMENTS/RECORD -- 394

AVERAGE = 106   VARIANCE = 0.1111E+03   STANDARD DEVIATION = 0.1054E+02

MAXIMUM VALUE = 56





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TAC/RECCE Targe

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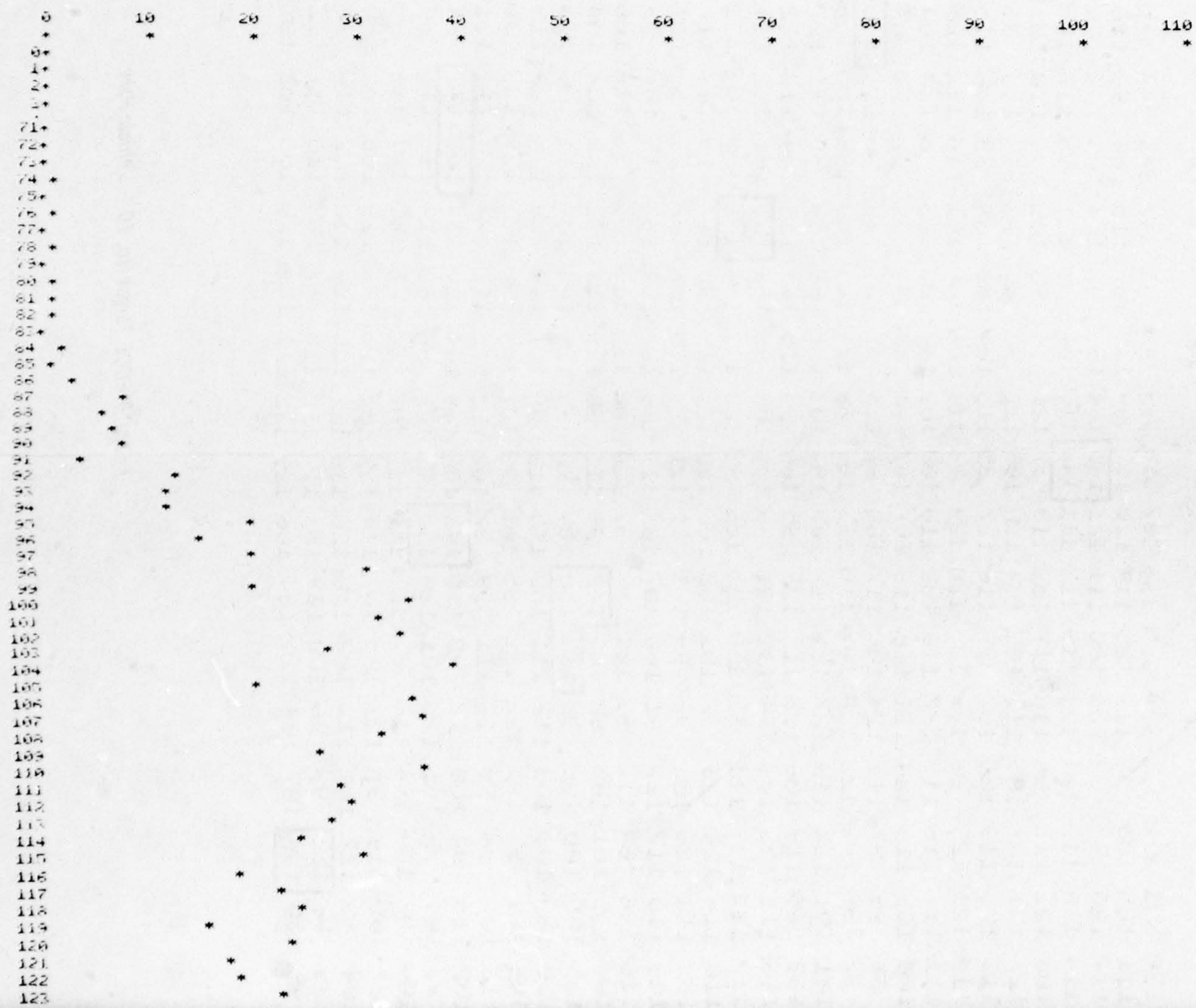
TAC/RECCE Target No. 10 – Vehicle Park

MAGNETIC TAPE USED -- STO
FIRST RECORD -- 15163 LAST RECORD -- 15193
FIRST ELEMENT -- 320 LAST ELEMENT -- 350
NO. OF ELEMENTS/RECORD -- 384

AVERAGE = 110 VARIANCE = 0.1519E+03 STANDARD DEVIATION = 0.1232E+02

MAXIMUM VALUE = 39



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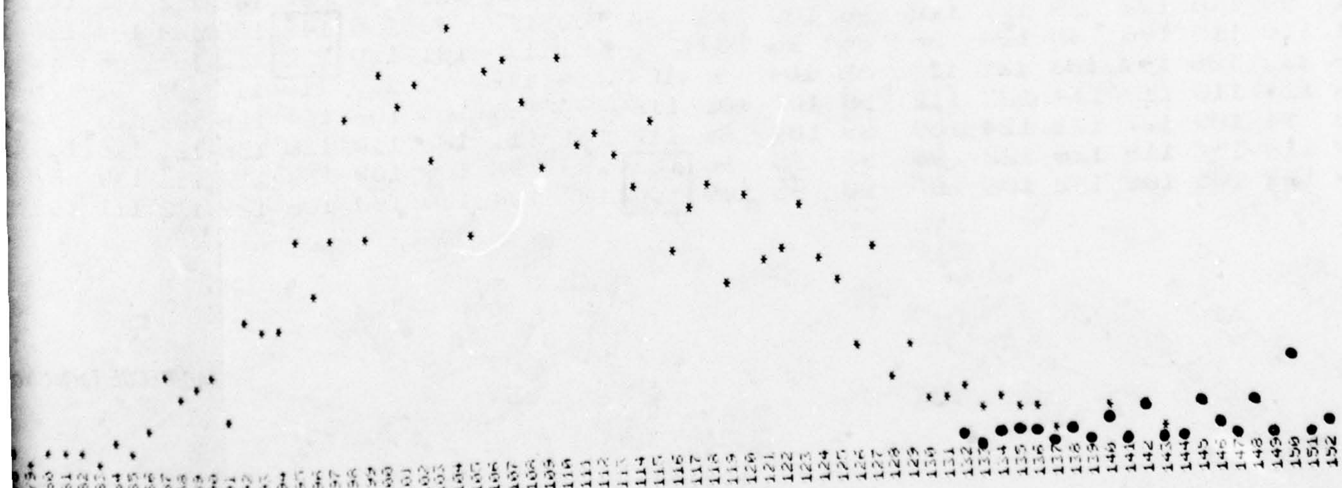

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TAC/RECCE Target No. 11 – AAA

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FIRST ELEMENT -- 336 LAST ELEMENT -- 366
NO. OF ELEMENTS/RECORD -- 364

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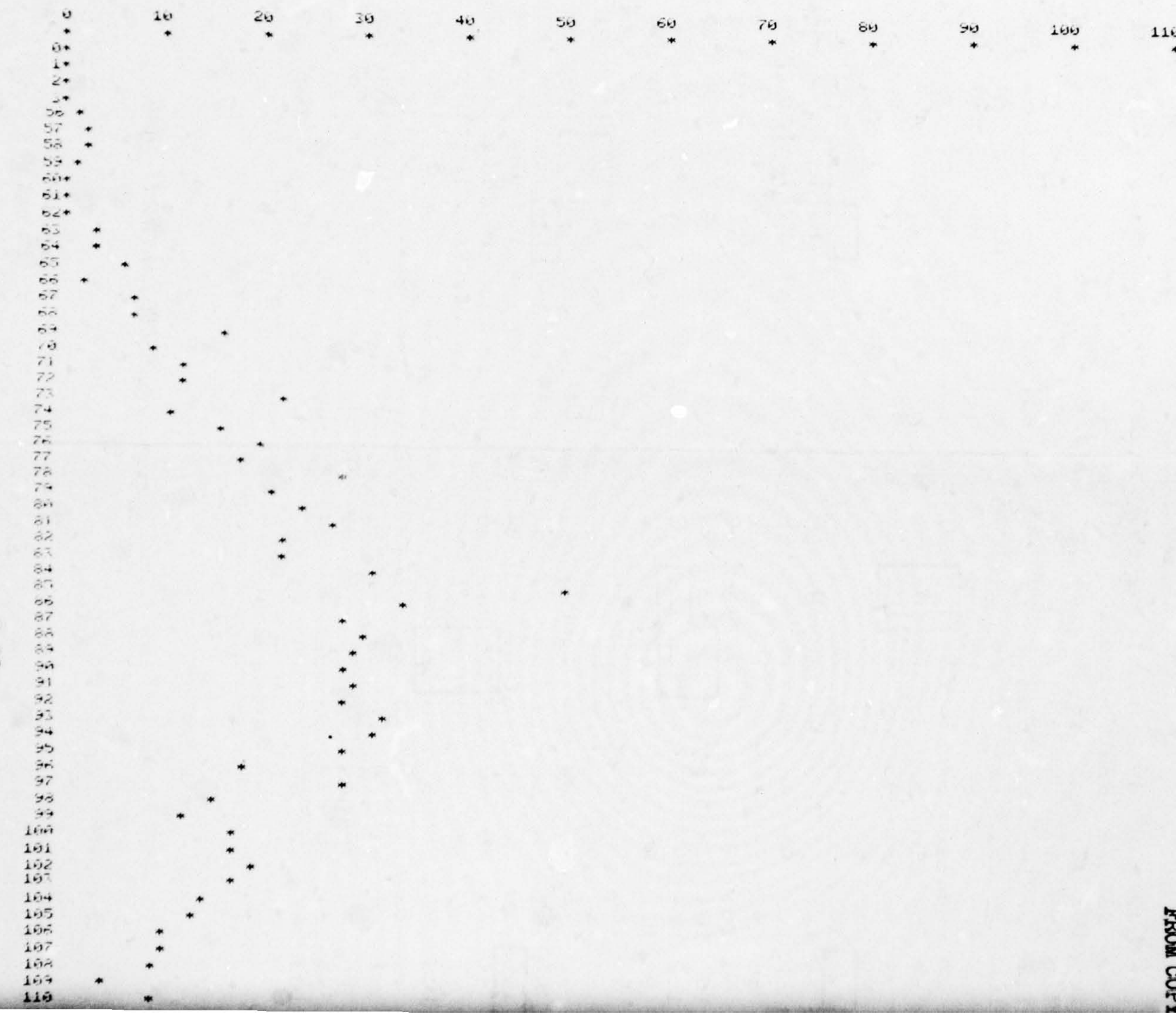

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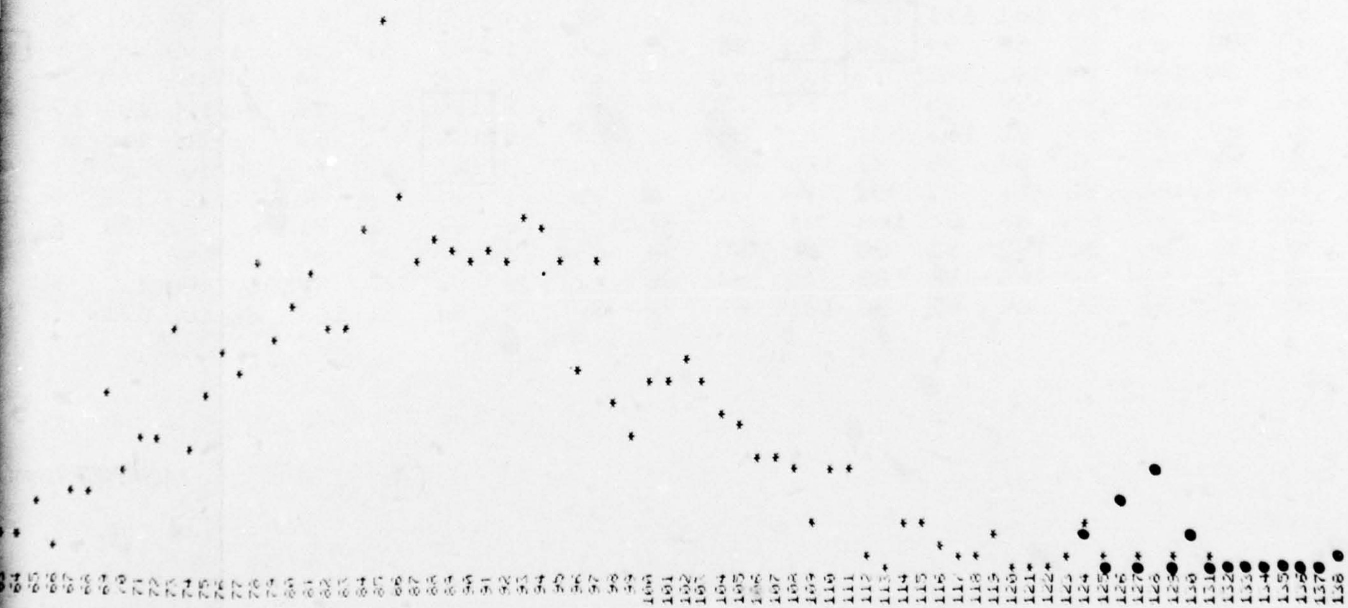

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TAC/RECCE Target No. 12 – Hawk

MAGNETIC TAPE USED -- ST0
FIRST RECORD -- 15948   LAST RECORD -- 15978
FIRST ELEMENT -- 310   LAST ELEMENT -- 340
NO. OF ELEMENTS/RECORD -- 384

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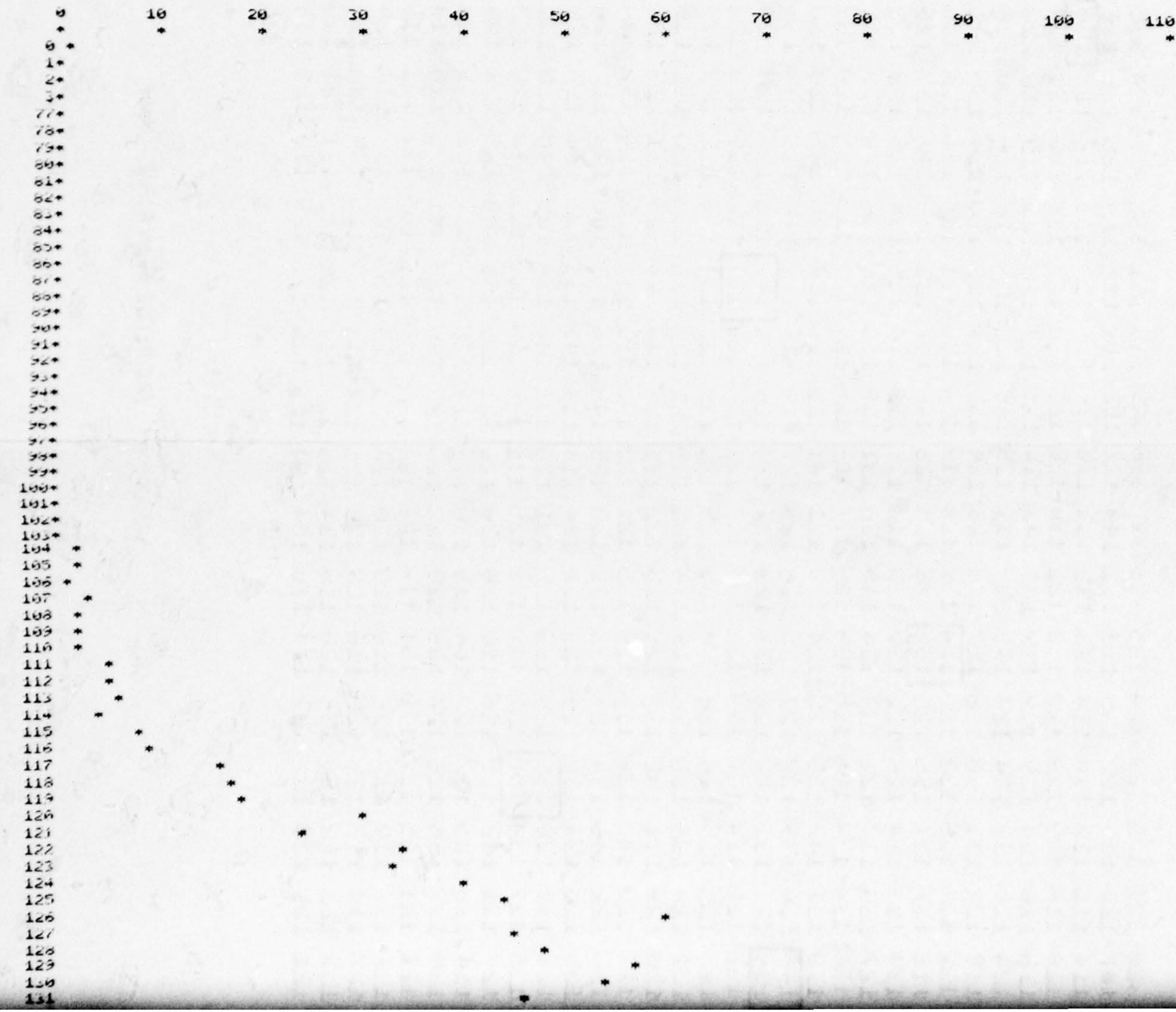
MAXIMUM VALUE = 60



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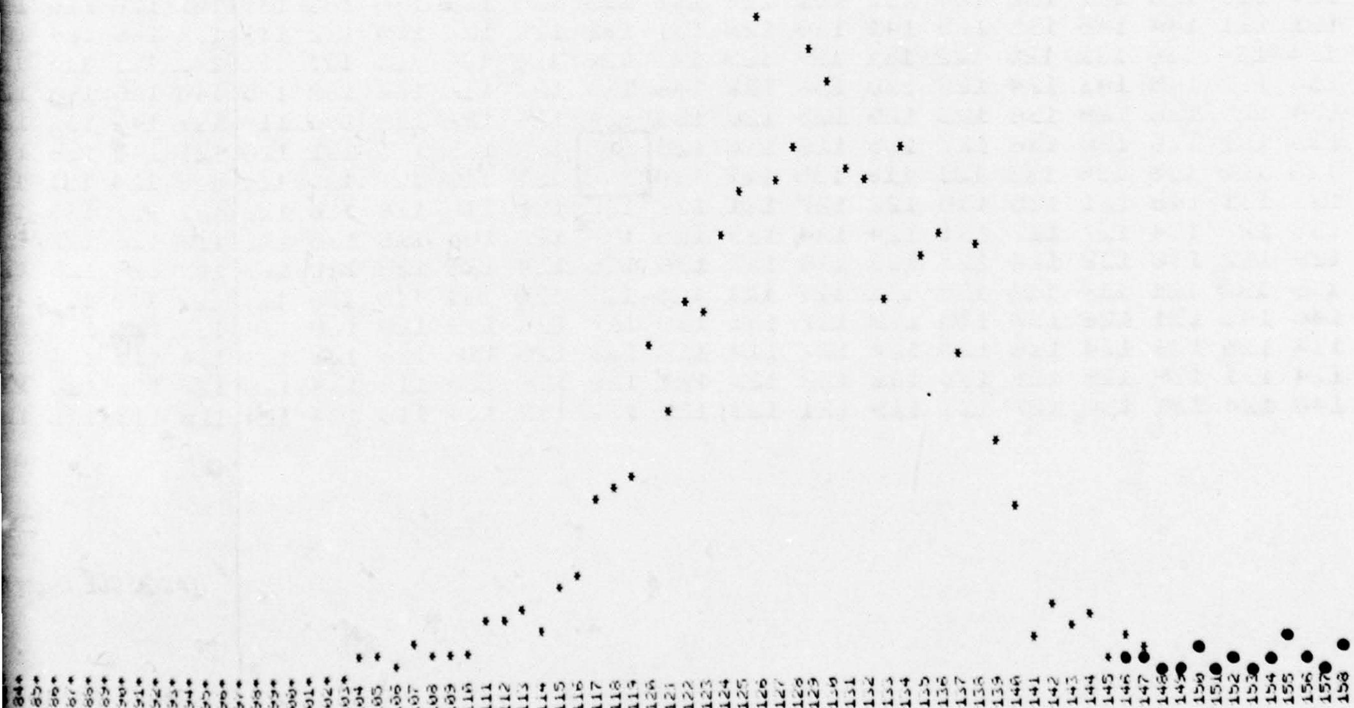

APPENDIX F

USE OF STATISTICAL TESTS IN ANALYZING HUMAN FACTORS STUDIES

In performing statistical analyses on human factors data, a test is employed to determine whether the performance scores of various groups or conditions differ by an amount which is too large to attribute to chance. When such a difference is found, the analyst can conclude that a significant statistical difference exists between (or among) the groups or conditions. Conversely, when the difference is too small (and therefore can be attributed to chance), the analyst concludes that there is no significant difference. Because scores from two groups usually overlap, it is typically impossible to state that a difference exists with 100-percent confidence. Hence, some threshold confidence level must be selected for making decisions of difference versus no difference. In the behavioral sciences, this level has typically been established at 95 percent. The experimenter is willing to accept a five-percent chance that his conclusion that a difference exists is incorrect. Usually, the experimenter concluding that there is either a difference or no difference will include a probability statement with his conclusion. A conclusion by an analyst that a difference exists is normally accompanied by one of two statements: (1) $p < 0.05$ (the probability that he is incorrect about stating there is a difference); or (2) 95-percent confidence level (he is 95-percent confident that there is a difference). Conversely, $p > 0.05$ accompanies a conclusion that no difference exists and means that he is less than 95-percent confident in stating that there is a difference, and so he states there is none.