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Joe De Maio, Aeroflightdynamics Directorate, U.S. Army Aviation and Troop Command,
Ames Research Center, Moffett Field, California
Curtis Becker, Monterey Technologies, Inc., Carmel California



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**Ames Research Center**
Moffett Field, California 94035-1000

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# Aided Targeting System Simulation Evaluation

JOE DE MAIO* AND CURTIS BECKER†

*Ames Research Center*

## Summary

Simulation research was conducted at the Crew Station Research and Development Facility on the effectiveness and ease of use of three targeting systems. A manual system required the aviator to scan a target array area with a simulated second generation forward looking infrared (FLIR) sensor, locate and categorize targets and construct a target hand-off list. The interface between the aviator and the system was like that of an advanced scout helicopter (manual mode). Two aided systems detected and categorized targets automatically. One system used only the FLIR sensor, and the second used FLIR fused with Longbow radar. The interface for both was like that of an advanced scout helicopter aided mode. Exposure time while performing the task was reduced substantially with the aided systems, with no loss of target hand-off list accuracy. The fused sensor system showed lower time to construct the target hand-off list and a slightly lower false alarm rate then the other systems. A number of issues regarding system sensitivity and criterion, and operator interface design are discussed.

## 1. Introduction

The purpose of the simulation was to demonstrate and evaluate the potential performance benefits that might be achieved through the use of an aided target processing capability. The immediate issue was the relative effect of system sensitivity and detection criterion on total accuracy, execution timeline, and operator acceptance. Two generic systems were investigated, a fused sensor system combining forward-looking infrared (FLIR) and radar sensors and a single sensor, FLIR system.

We focused on two design parameters of aided targeting systems, sensitivity (d') and criterion (b). Sensitivity is of interest because it is a parameter which is substantially improved when two sensors operating in different spectral bands are fused by the aided targeting system. Criterion is of interest because the relative frequency of false alarms can greatly affect the usability and user acceptance of a detection system.

The sensitivity of a fused sensor system exceeds that of a single sensor system both because the radar provides more accurate range data and because the fused sensor system uses multiple data sources. A single sensor system operates using only coarse, target range data obtained either by lasing to the center of a FLIR frame or by triangulation. These relatively poor range data can lead to template matching ambiguities. Radar range data for individual target objects can eliminate many potentially erroneous template matches. Further ambiguity reduction comes because voting schemes can take advantage of correlations in the data from the two sensors.

An important reason for increasing a system's sensitivity is to reduce the rate or absolute number of false alarms it produces. False alarms by the aided system increase operator workload, and they also lower performance by impairing the operator's vigilance. For any system the probability of detection must be traded off against the false alarm rate to provide the greatest possible number of detections without impairing operator performance.

Another factor of interest in the test was the density of target objects in the environment. More target objects mean more detections. More detections increase operator tasking, and they may alter the way in which the system presents detections to the operator. Our concern was to determine simply whether target object density is a concern in evaluating aided targeting systems.

While we understand that systems such as those evaluated here are intended for use on a wide variety of tasks performed under a broad range of conditions, we did not perform a parametric evaluation of aided targeting systems over their full range of application. Rather we selected a likely combination of task and environment which would be amenable to performing an evaluation in simulation. The characteristics of the test environment included high thermal contrast (high $\Delta$ T), giving a high quality FLIR image, and stationary targets. These conditions permitted good performance by both the aviator and the system and an adequate level of experimental control.

*U.S. Army Aeroflightdynamics Directorate, Crew Station Research and Development Facility, Moffett Field, CA 94035-1000.

†Monterey Technologies, Inc., Carmel, CA 93922.

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## 2. Method

### Experimental Design

The simulation was designed to highlight the effects of automation on target detection and categorization performance. Two aided systems were studied. One was a multi-spectral system using passive forward-looking infrared (FLIR) and active radar. The other was a single sensor system using only FLIR. The actual systems would differ in a number of performance characteristics. These characteristics include detection sensitivity, ability to categorize targets, ability to provide accurate range data, susceptibility to environmental effects, and signature magnitude. The present study focused only on detection sensitivity and target categorization.

### Targeting System Modeling

The end-to-end performance of a detector is determined by its sensitivity and by its signal detection criterion, and both factors must be considered in evaluating systems. The P(d) is the probability that a given target is detected on a given scan. For a specified system sensitivity, P(d) is determined only by the detection criterion. A high criterion leads to a low P(d). In effect desired P(d) defines the criterion for each system. When the criterion has been set to achieve a desired P(d), sensitivity determines FAR. A lower sensitivity system produces more false alarms for a given P(d) than does a higher sensitivity system. A notional illustration of the relationship between the sensitivity of the detector (d'), P(d) and FAR is presented in the receiver operating characteristic (ROC) shown in figure 2-1. The ROC relates the P(d) of a detector to its FAR. Since these two parameters vary with criterion, a sufficiently high criterion will result in no detections and no false alarms and a sufficiently low criterion will result in a P(d) of 1.0 and a probability of false alarm given no target of 1.0. Between these extremes, detections and false alarms will vary to produce the monotonic function shown in figure 2-1. The degree of curvature of the ROC is proportional to d'.

In the present study, two levels of correct detection performance were set. The probability of detection (P(d)) determined criterion based on system sensitivity, and a corresponding false alarm rate was determined. Thus system sensitivity and signal detection criterion were covaried to yield four representative combinations of correct detections and false alarms, specified on a per scan basis. With a scan field of regard (FOR) of 6° × 45° centered 2° below the horizon, the correct detection and false alarm rates (FAR) shown in table 2-1 obtain. "Target objects" were placed in the data base to be detected, with the number of target objects varied across vignettes (see table 2-4 in Operator Interface section). "Non-target objects" were placed in the data base to yield the false alarm rates per scan shown in table 2-1. FAR is a function of system sensitivity and detection criterion.

The P(d) shown in table 2-1 is an average over all targets (target and non-target objects are treated identically by the targeting system). The P(d) for an individual object was determined by a function of $P(d)_M$ (see eq. 2-1), the

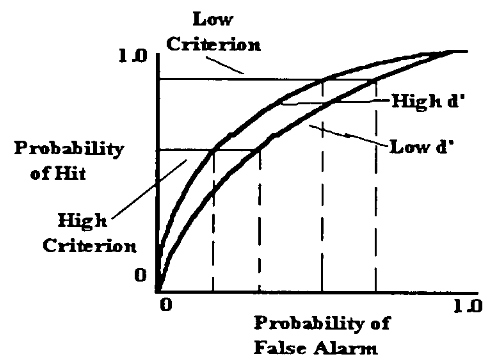



*Figure 2-1. Sample receiver operating characteristic.*

Table 2-1. Targeting system configurations

| | | High sensitivity | Low sensitivity |
|---|---|---|---|
| High criterion | | P(d) = 0.6 | P(d) = 0.6 |
| | | FAR = 0.6 | FAR = 3.6 |
| Low criterion | | P(d) = 0.9 | P(d) = 0.9 |
| | | FAR = 4.5 | FAR = 19.8 |

average P(d), range and a detectability factor (three levels). Tanks had a detectability factor of 0.02. APCs and tracked ADUs had a detectability factor of 0.0. Wheeled vehicles had a detectability factor of –0.02. Similarly non-target objects had a detectability factor, 0.02 for living (cow), 0.0 for man-made (dead vehicles), –0.02 for non-living (rocks and dead trees). The range scale factor was 0.08 at minimum range (about 1 km) and 0.0 at 2 km. Individual probability of detection was the sum of the average P(d), detectability, and range scalar. The range of individual P(d) was 0.5 to 0.7 for the high criterion conditions and 0.8 to 1.0 for the low criterion conditions. Detectability factors associated with each type of target object and non-target object are shown in table 2-2. Objects were placed in the data base to give an average detectability factor across all objects of 0. This scheme allows variation in P(d) independent of average P(d). Eighty percent of the variation in P(d) within a scan results from range effects, while 20% results from variation in the targets. The P(d) of object$_i$ was given by the following formula:

$$P(d)_i = P(d)_M + d + r \qquad (2\text{-}1)$$

where

$d = \{-0.02, 0.0, +0.02\}$

$r = -0.08 + \{0.16 * [(range_i - range_{min}) / (range_{max} - range_{min})]\}$

The sensor model was intended to provide a qualitatively correct rendering of the effects of target type and range. The target detection systems were modeled through a simple Monte Carlo process. Each target in the system FOR was detected through an independent stochastic process using P(d) determined by equation 2-1. Target objects and non-target objects were detected according to

Table 2-2. Experimental targets

| Target type | Classification type | Recognition type | Detectability factor |
|---|---|---|---|
| M1 | Tracked | Tank | 0.02 |
| M60 | Tracked | Tank | 0.02 |
| M3 | Tracked | APC | 0.0 |
| M113 | Tracked | APC | 0.0 |
| HUMMV | Wheeled | Truck | –0.02 |
| T72 | Tracked | Tank | 0.02 |
| BTR | Wheeled | Truck | –0.02 |
| BMP | Tracked | APC | 0.0 |
| ZSU | Tracked | ADU | 0.0 |
| SA9 | Wheeled | ADU | –0.02 |
| Zil | Wheeled | Truck | –0.02 |
| Rock | – | – | –0.02 |
| Rock | – | – | –0.02 |
| Rock | – | – | –0.02 |
| Dead truck | – | – | 0.0 |
| Dead tree | – | – | –0.02 |
| Dead hind | – | – | 0.0 |
| Dead tank | – | – | 0.0 |
| Cow | – | – | 0.02 |

the same stochastic process. Appropriate FARs were obtained by varying the number of non-target objects placed in the data base. In the experimental context the differences in individual P(d) provided a basis for target prioritization as well as the detection performance of the systems. If a target were detected, the individual P(d) would be used for target prioritization, with higher P(d) targets presented first.

The aided targeting systems provided information about target type. The single sensor system indicated target classification. The fused sensor system provided recognition information. The target labels used are shown in table 2-3. The probability of correct categorization conditional on target detection was 0.6 for both systems.

Table 2-3. Aided system categorization output

| Single sensor classification | Multi-sensor recognition |
|---|---|
| Tracked | Tank |
| Wheeled | Truck |
| Unknown | ADU |
| | APC |
| | Unknown |

A manual targeting system was included as a baseline for comparison against the aided systems. The manual system used the same FLIR and laser ranging system as the single sensor aided system, but these subsystems were under manual control. The FLIR sensor had a selectable field of view (FOV) of $1.5° \times 2°$ (narrow) or $6° \times 8°$ (medium). The laser range finder was triggered manually to obtain a range for each target included in the target hand-off list. Since the manual system detected no targets and generated no false alarms, there could be no specified FAR, but we assumed that in the worst condition the aided system detected every possible non-target object in the environment. Therefore, the non-target object count for single sensor, low criterion condition was used for the manual condition.

**Target environment**– Real targets were computer generated models of the military vehicles listed in table 2-2. Objects were placed into correlated out-the-window (OTW) visual and FLIR data bases. The OTW scene was created on a General Electric Compu-scene IV image generator. The FLIR imagery was generated on a Silicon Graphics Reality Engine. Vehicles were stationary, and their placement conformed to tactics and doctrine as reflected in the Rotorcraft Pilot's Associate vignettes. There were four conditions of target environment, differing in the number of real targets placed in the environment. A target-free condition contained no target objects, and the only detections reported by the aided systems were non-target objects. A low target density condition corresponded to a combat reconnaissance platoon. This condition contained six targets. A medium density condition, corresponding to a regimental reconnaissance company, contained 10 targets. The high target density condition contained 14 targets. This condition corresponded to an advanced guard.

The experimental design is shown in table 2-4. Two factors in the table taken together define the aided targeting system. The P(d) identically determines the hit rate, and it plus the number of non-target objects define the false alarm rate (number of non-target objects detected on a scan). A second environmental factor, number of target objects, defined the operational environment of the test. Four target object densities were presented.

### Operator Interface

**Targeting display page**– The targeting task was performed on a display page presented on the tactical situation display (TSD) of the CSRDF. The TSD consists of a 12 inch high-resolution, color CRT with an infrared touch screen. Subjects touched the area of the display showing the desired softkey control to activate the control. Touchscreen controls were of three types, instantaneous, on/off, and alternate action. In the following discussion controls are indicated by **BOLD CAPITAL** letters.

The targeting display page consisted of a system control area along with imagery and controls specific to the targeting system. The system control area for targeting systems is shown in figure 2-2. This area would allow for selection of manual sensor scan and aided scan if this function were supported. Top level controls were continuously displayed around the side of the targeting display page. Imagery and lower level controls were displayed in the center. Labeling controls were displayed at the bottom. For the purposes of the present test, manual and aided scan modes were mutually exclusive. Therefore the controls for selecting one or the other were active only if that test condition were available. Since switching between modes was not an issue, highlighting of available modes was not provided.

**Manual system controls**–The **MANUAL FLIR** softkey activated the sensor slewing control for manual mode targeting. Two sensor fields of view (FOV) were selectable by a toggling softkey, **MEDIUM** (6° × 8°) and **NARROW** (1.5° × 2°). The right side hand controller allowed the aviator to slew the sensor line of sight left and right and up and down over a range of ±110° in azimuth and +20°/–60° in elevation. An arrow in the lower left corner indicated the sensor line of sight in azimuth relative to the armament datum line (ADL). The aviator selected a target by touching the image on the sensor image display, and the system responded by placing a complete box around the target with the label "UNK" (unknown, fig. 2-3) and bringing up first level (classification) **LABELING** controls (fig. 2-4). The aviator could label the target at this level or select **REC**(ognition) or **ID**(entification). The aviator selected a label from the set shown in figure 2-4. Previously accepted targets that were not currently selected were indicated by a broken box.

Table 2-4. Experimental conditions

| Sensor/ criterion[a] | Target density | P(d) | Average targets detected (hits) | Average number false alarms | Number real targets | Number false targets | Number total targets |
|---|---|---|---|---|---|---|---|
| F/H | None | 0.6 | 0 | 0.6 | 0 | 1 | 1 |
| F/H | Low | 0.6 | 3.6 | 0.6 | 6 | 1 | 7 |
| F/H | Medium | 0.6 | 6 | 0.6 | 10 | 1 | 11 |
| F/H | High | 0.6 | 8.4 | 0.6 | 14 | 1 | 15 |
| F/L | None | 0.9 | 0 | 4.5 | 0 | 5 | 5 |
| F/L | Low | 0.9 | 5.4 | 4.5 | 6 | 5 | 11 |
| F/L | Medium | 0.9 | 9 | 4.5 | 10 | 5 | 15 |
| F/L | High | 0.9 | 12.6 | 4.5 | 14 | 5 | 19 |
| S/H | None | 0.6 | 0 | 3.6 | 0 | 6 | 6 |
| S/H | Low | 0.6 | 3.6 | 3.6 | 6 | 6 | 12 |
| S/H | Medium | 0.6 | 6 | 3.6 | 10 | 6 | 16 |
| S/H | High | 0.6 | 8.4 | 3.6 | 14 | 6 | 20 |
| S/L | None | 0.9 | 0 | 19.8 | 0 | 22 | 22 |
| S/L | Low | 0.9 | 5.4 | 19.8 | 6 | 22 | 28 |
| S/L | Medium | 0.9 | 9 | 19.8 | 10 | 22 | 32 |
| S/L | High | 0.9 | 12.6 | 19.8 | 14 | 22 | 36 |
| MAN | None | n/a | n/a | n/a | 0 | 22 | 22 |
| MAN | Low | n/a | n/a | n/a | 6 | 22 | 28 |
| MAN | Medium | n/a | n/a | n/a | 10 | 22 | 32 |
| MAN | High | n/a | n/a | n/a | 14 | 22 | 36 |

[a]"F" and "S" refer to fused sensor and single sensor aided systems. "MAN" refers to the manual targeting system. "H" and "L" refer to high and low detection criteria.

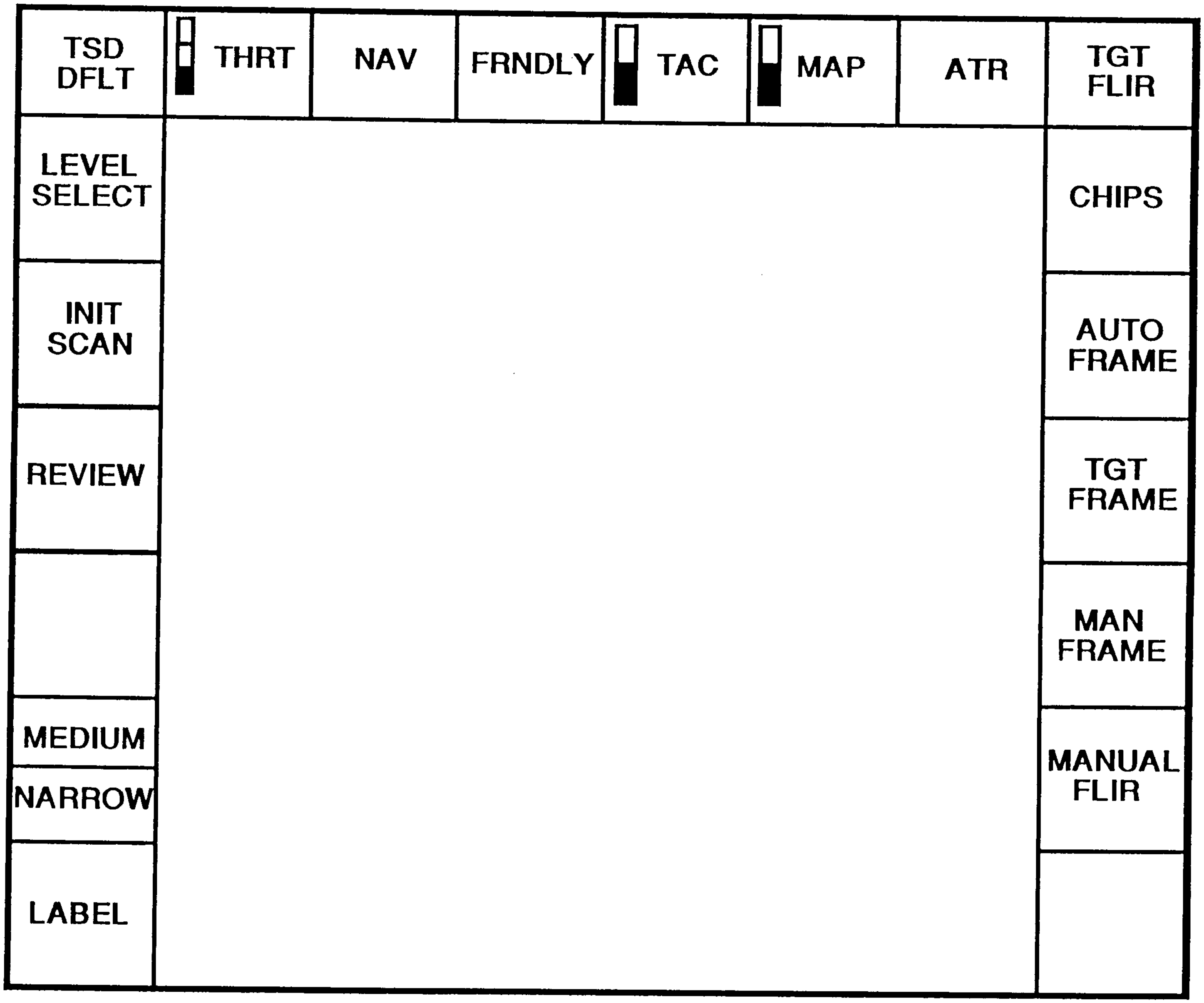



*Figure 2-2. System control area of targeting display page.*

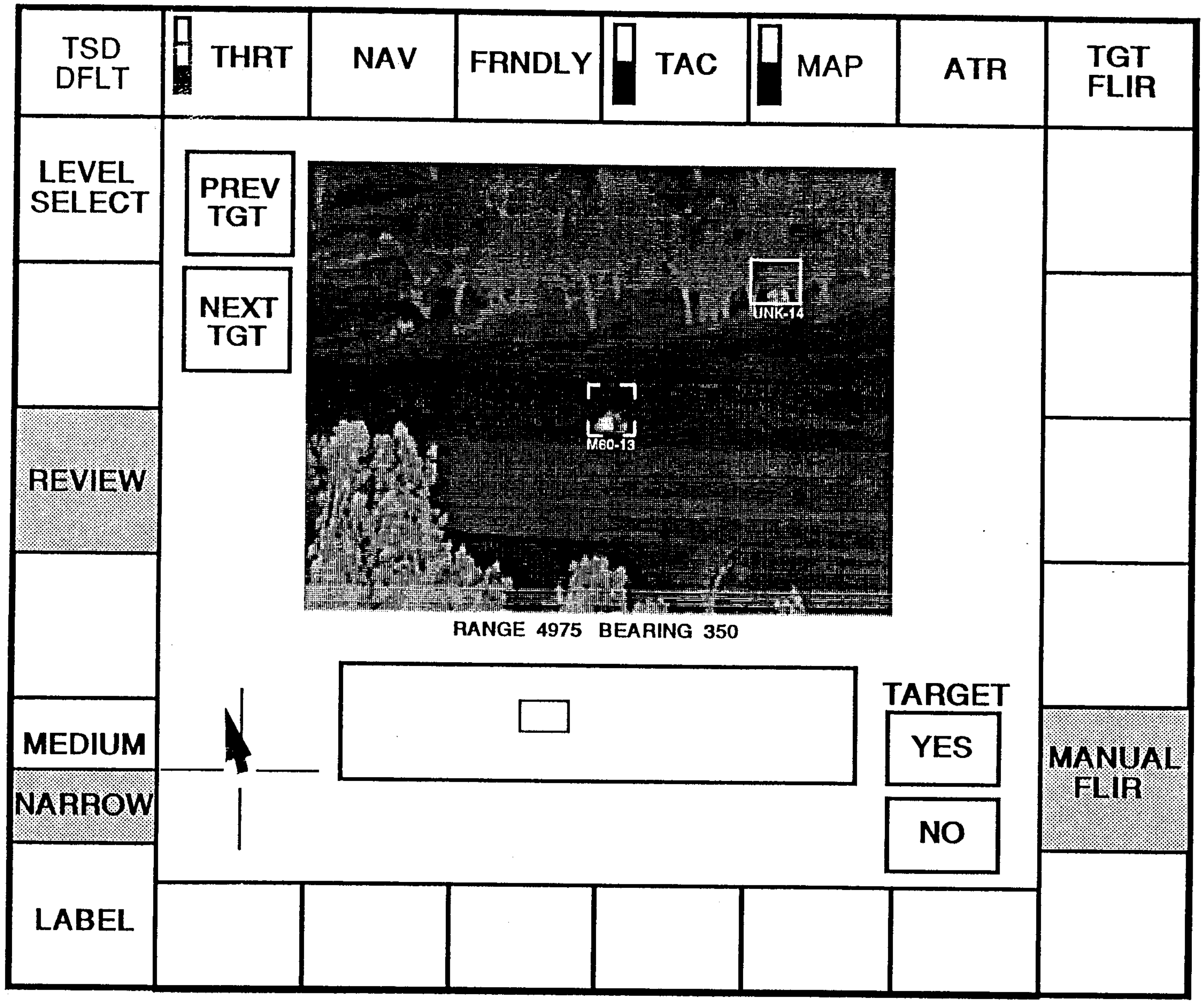



Figure 2-3. Manual system targeting display page.

**Aided system control and display**– The base control page contained softkeys for operating the aided targeting systems. **INIT SCAN** caused the system to execute a two pass scan (near and far bar). For the present test the area scanned was always 22.5° left and right of the ADL and 1° above/5° below it, so no scan limit controls were provided.

Following scan completion, the **REVIEW** softkey allowed the aviator to review the system detections. Four review mode controls were available on the right side of the page. **CHIPS** allowed the aviator to view up to 18 detections, presented in groups of six (fig. 2-5). The P(d) of each was used to prioritize detections, with highest priority (highest P(d)) shown in chip number one. Detections with priority of 19 or below were not presented in chips mode. Three frames modes allowed the aviator to view each of the 92 FLIR frames produced by the scans, with detections highlighted (fig. 2-6). **AUTO FRAME** first presented the frame in the upper left. At 20 second intervals the system automatically stepped one frame, moving left to right and down. Any input by the aviator reset the interval counter. **TGT FRAME** performed similar stepping but only between frames containing detections, beginning with the upper, left-most frame containing a detection. **MAN FRAME** did not step automatically, but the aviator could step manually using the **UP**, **DOWN**, **LEFT**, and **RIGHT** softkeys. These keys were also active in the automatic stepping modes. A grid displayed below the sensor imagery showed the frames array. The currently displayed frame was filled. Frames containing detections were stippled.

**Target selection and labeling**– A target chip could be selected by touching the chip, after which **YES** or **NO** would accept or reject the detection. Alternatively **YES** or **NO** could be touched to select and accept or reject simultaneously. Label controls and a system-determined categorization became available when a detection was accepted. The initial level of categorization was classification for the single sensor system and recognition for the fused sensor system.

In frames mode the bottom corners of a box indicated a system detection, a broken box indicated a detection that had been accepted, and a complete box indicated the selected target. A bullet (•) indicated an object that the aviator had rejected as a target. A target object could be selected by touching it whether the system had detected it or not. If the system had detected it or it had previously been accepted, it could also be selected using the **PREV TGT** and **NEXT TGT** softkeys. Label controls were the same as for chips mode.

**Target hand-off list**– Objects labeled by the aviator as target objects or non-target objects were automatically placed in a target hand-off list. This list was displayed on a 6 inch CRT located on the right side of the cockpit. For each object in the list the display presented a sequence number, the object label, and the object location (in Universal Transverse Mercator coordinates). Up to five target entries could be displayed at one time. **PAGE UP** and **PAGE DN** moved the display up and down the list in groups of five. "∧" and "∨" moved up and down the list one object at a time. The **SEND** softkey terminated the experimental trial.

### Experimental Task

The task presented to the experimental subjects was to reconnoiter a target area for which they have no prior intelligence and to formulate and transmit a target hand-off list. An experimental trial began at a point along the ingress route to the target area. The terminal phase on the ingress (about one minute) was prerecorded, and the experimental aircraft flew the subject to the designated observation point. The subject wore the fiber-optic helmet mounted display (FOHMD) to provide out-the-window cues for orientation to the task environment. At the end of the ingress, he called for an unmask, and the aircraft executed a prerecorded unmask to a hover. The aircraft was oriented with the target area directly in front of it. The subject executed his targeting task. In the aided conditions this activity consisted of initiating the scan. The subject then commanded a remask when the scan was completed, after which he constructed and transmitted the target list. The process of constructing the list consisted of reviewing the output of the aided system, accepting or rejecting each detection and providing categorization to the highest level possible. The trial ended at message transmission. In the manual condition the subject slewed the FLIR sensor and entered target data and transmitted the target hand-off list. The trial ended with message transmission.

### Subjects

Fourteen aviators participated in the experiment. Two test pilots were supplied by the Night Vision and Electronic Sensors Directorate (NVESD). These two aviators served from 07 SEP to 11 SEP 94. Their primary role was to support final debug of simulation and procedures, and their data were not analyzed. Twelve subjects were operational AH-64 aviators. These aviators had no CSRDF experience, but they were experienced in the AH-64 combat mission simulator. These aviators served in three groups of four each. Each group spent one week at the CSRDF during the period from 12 SEP through 02 OCT 94. Experience of the 12 aviators is shown in table 2-5.

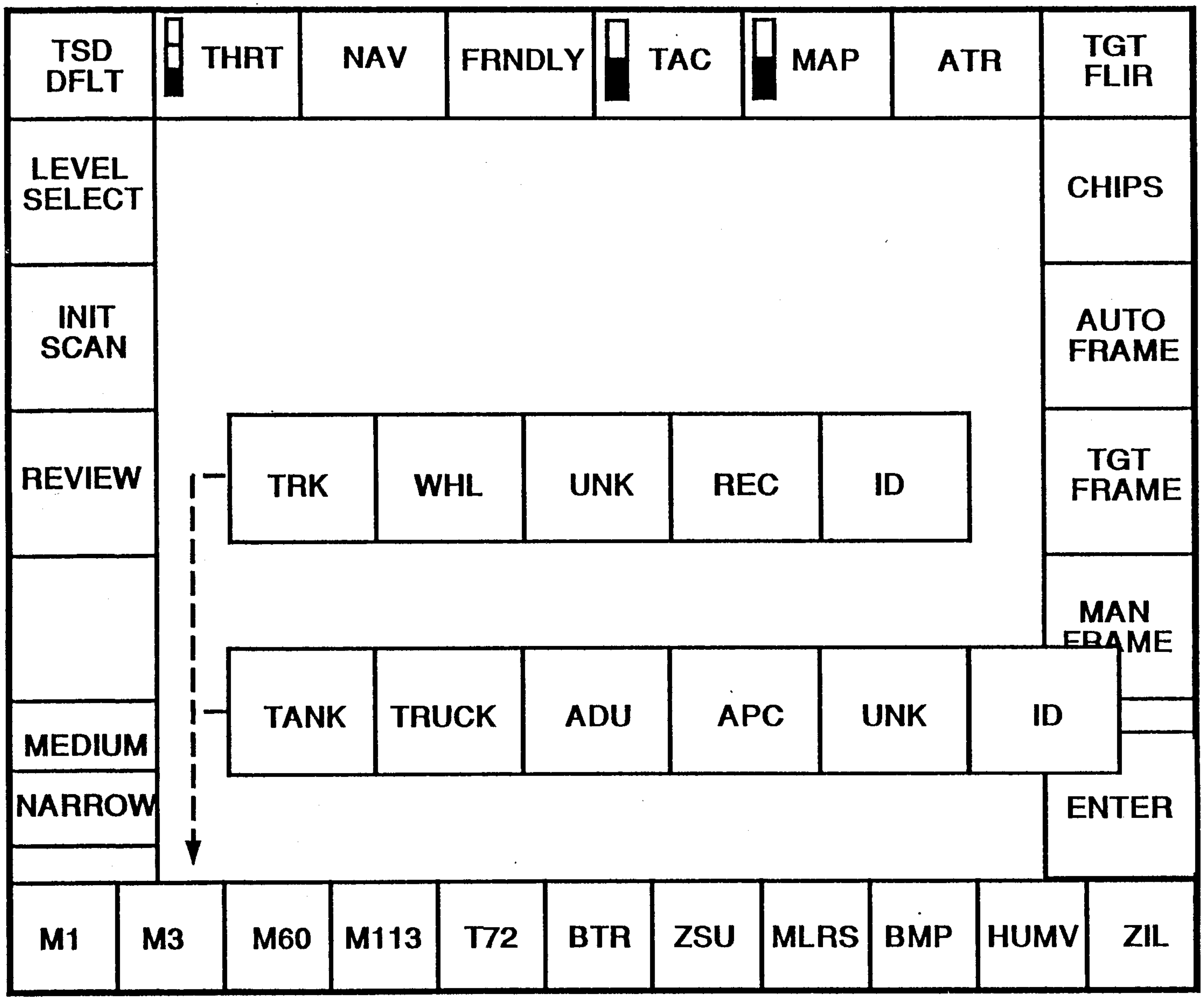



*Figure 2-4. Target object labeling controls.*

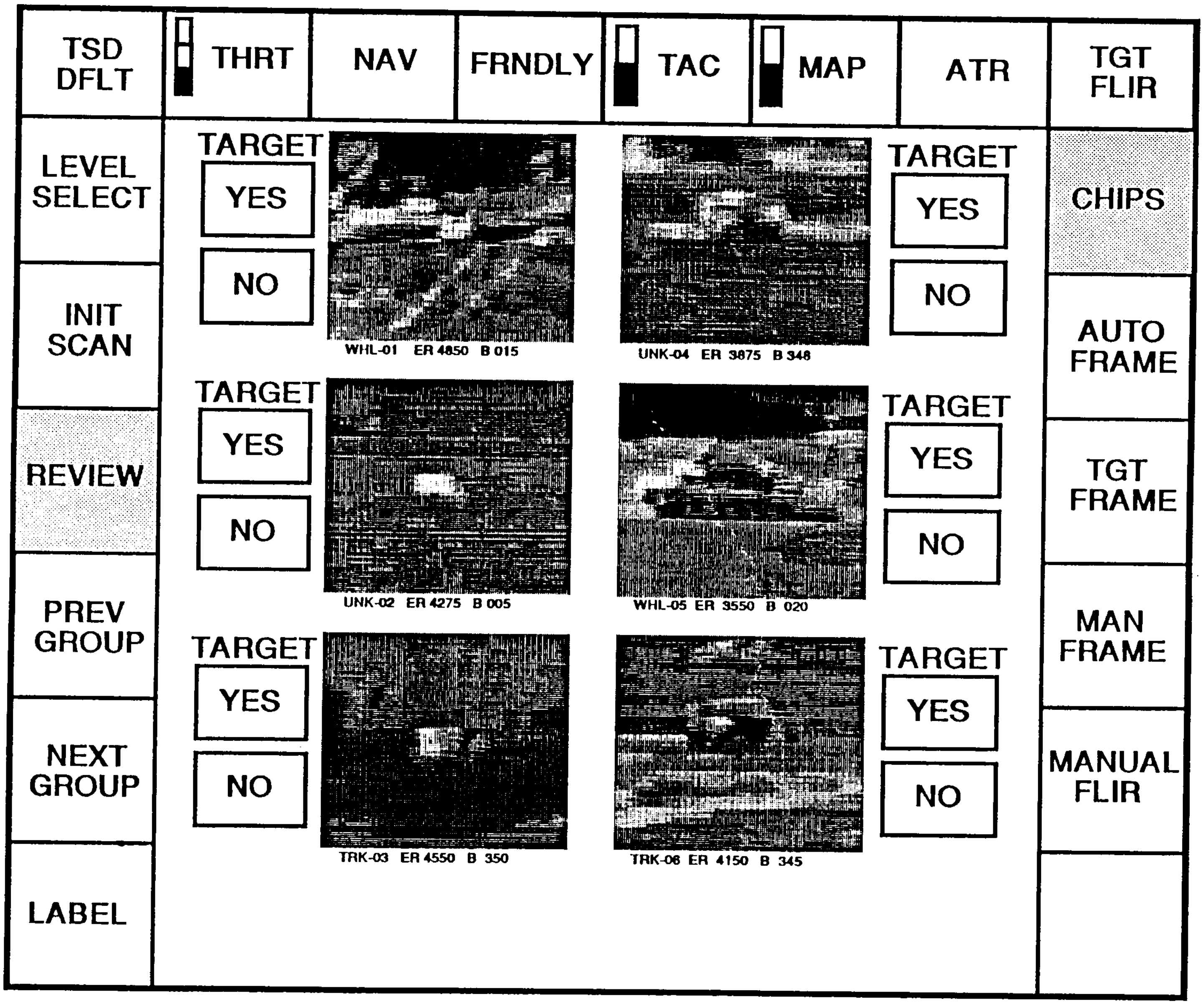



Figure 2-5. Chips mode display.

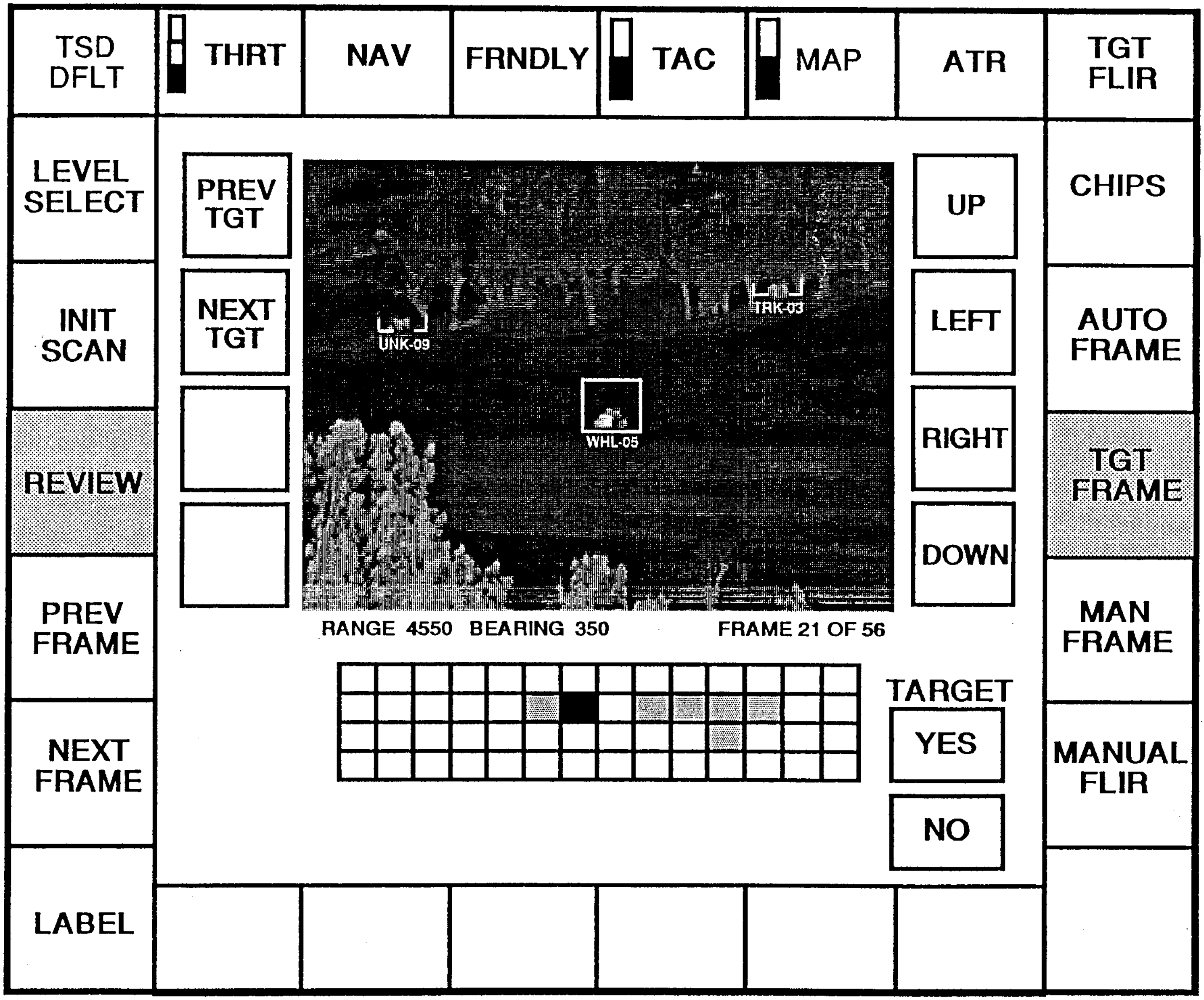



*Figure 2-6. Frames mode display.*

Table 2-5. Experimental aviator operational experience

| Aviator ID | AH-64 front seat time (hr) | AH-64 back seat time (hr) | Attack helicopter time (hr) | Total helicopter time (hr) |
|---|---|---|---|---|
| 1 | 200 | 150 | 600 | 750 |
| 2 | 160 | 40 | 500 | 580 |
| 3 | 300 | 70 | 450 | 700 |
| 4 | 300 | 300 | 2000 | 3500 |
| 5 | 250 | 400 | 1500 | 1700 |
| 6 | 200 | 50 | 300 | 350 |
| 7 | 150 | 20 | 170 | 350 |
| 8 | 150 | 30 | 300 | 465 |
| 9 | 150 | 50 | 475 | 550 |
| 10 | 50 | 50 | 1600 | 2000 |
| 11 | 85 | 40 | 500 | 700 |
| 12 | 170 | 20 | 190 | 350 |

**Procedure**

Data collection took place over three days for each group of aviators. Each aviator performed two data collections per day (roughly two hours total), being exposed once to each system X target density condition. Prior to starting the data collection, the aviators received training in the operation of the simulated targeting systems, and they were fitted with a custom liner for the FOHMD. Aviators were trained in the operation of the targeting systems as well as in recognition of the CSRDF FLIR imagery of target ground vehicles. Aviators were trained until they and the test administrator agreed that they were proficient.

Data collection took place on Tuesday, Wednesday and Thursday of each week. Two aviators were scheduled each morning session, and two were scheduled each afternoon. Each session consisted of two one-hour blocks per subject. Each subject completed two replications of each condition.

Each one-hour block consisted of 10 data collection runs with the order of experimental conditions randomized. On each run the simulated aircraft was initialized a short distance from the observation point (OP). The targeting system was correctly configured, and the appropriate display page was presented on the back seat displays. The right hand display contained the target list display. The center display contained the sensor system display. The left hand display contained the map. The aviator also wore the FOHMD to aid in orienting to the tactical environment, but neither the OTW scene nor helmet displayed symbology was used in the targeting task. When the aviator signaled that he was ready, the pre-recorded run-in to the OP was executed. Data collection began when the aircraft achieved a masked position at the OP. The aviator signaled readiness to begin the targeting task. A prerecorded unmask to a hover was executed. The prerecorded flight sequence was frozen for as long as the aviator needed to complete his task, and then the sequence resumed with a remask. The aviator completed the targeting task and transmitted the target list. Data recording terminated with transmission of the target list, and the aviator provided a subjective evaluation of the targeting system (see appendix A). A final debriefing gave aviators an opportunity to comment on all aspects of the evaluation.

**Data Collection and Analysis**

Real time objective measures of performance were collected along with the subjective questionnaire data. Data on correct detections (hits), misses, false alarms, correct rejections and categorization accuracy came from the target hand-off list. An explicit action to reject each non-target object detection (system false alarm) was required in order to support data collection. In addition objective measures of timing were determined. These included the following:

Time to accept or reject each target
Total time to target hand-off
Exposure time
Scanning sequence

## 3. Results

The objective of the simulation was to examine how system/configuration changes in an aided targeting system might affect the utility of that system. In order to address this issue, we have decomposed the issue into three component questions. These questions are (1) how does aiding affect the performance of the aviator on the targeting task, (2) how do changes in the performance of the aiding system affect aviator performance, and (3) what factors affect the interaction of the aviator with the system. These questions were addressed by way of analyses of variance on several dependent measures. A 2 × 2 repeated measures ANOVA looked at aided system and criterion effects. A three-way repeated measures ANOVA looked at aided versus manual system. A 2 × 2 × 4 repeated measures ANOVA looked at effects of target density on aided system performance. ANOVA tables are presented in appendix B. Significant effects are shown in **bold** for objective measures (B1–B13). Only significant effects are shown for subjective evaluations (B14–B18).

The presentation of results is organized as follows. First we discuss the effect of aiding. Second we discuss how sensitivity of the aided systems affect the quality of performance and speed. Next we look at the effects of variation in criterion. We finish with a discussion of the effects of target density. A review of the aviators' subjective evaluations supplements the analysis of the objective data.

### Effects of Aiding

The major effect that could be attributed to aiding, per se, was a substantial reduction in exposure time (fig. 3-1). For this analysis exposure time was defined to be the period of time during which there was an unobstructed line of sight from the ownship to a vehicle in the target array being scanned. Exposure time with aiding was determined by the time required to enter a stable hover above the masking obstruction, to initiate the sensor scan manually, to complete the automated scanning process, and to descend below the obstruction. Exposure time in the manual condition was determined by the transition times as above plus the time required to scan, identify targets, and build the target hand-off list. Mean exposure time was 258 seconds for manual targeting. Exposure time was 37 to 61 seconds for the aided system, a reduction of over 75%. There was no difference between aided system configurations.

Detection performance was measured by comparing the target hand-off list generated by the aviator with ground truth represented in the simulation data base. Detection performance was generally very good, since the FLIR simulation represented optimal viewing conditions. Overall the rate of correct detection was over 98%, that is, of 3095 target objects only 42 were missed. There were no differences in hit or miss rates for the various systems (fig. 3-2). The fused sensor system did show a slightly lower acceptance rate for false alarms than the single sensor and manual systems (fig. 3-3). Most of the false alarms were non-target vehicles that were most easily confused with target objects (fig. 3-4). The labeling of a non-target object as a target by the aiding system did not bias the aviator's response to the non-target objects that were not visually confusable.

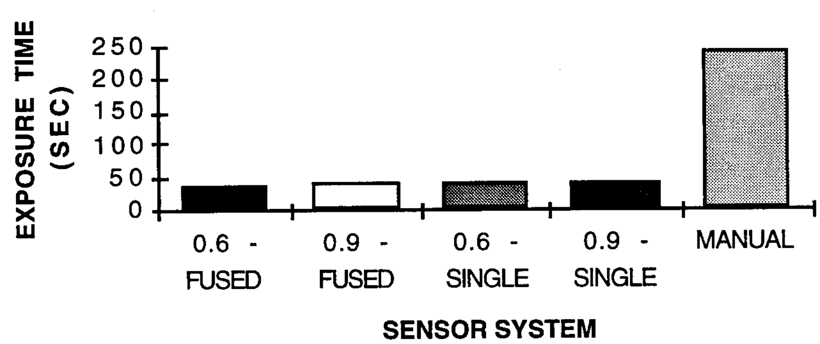



*Figure 3-1. Exposure time for each targeting system.*

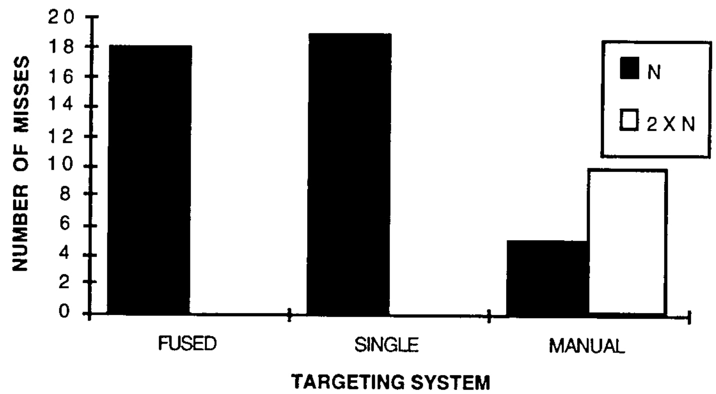



*Figure 3-2. Number of targets not included in target hand-off list. For manual condition 2 × N number is comparable to aided systems since manual sample is one-half as large.*

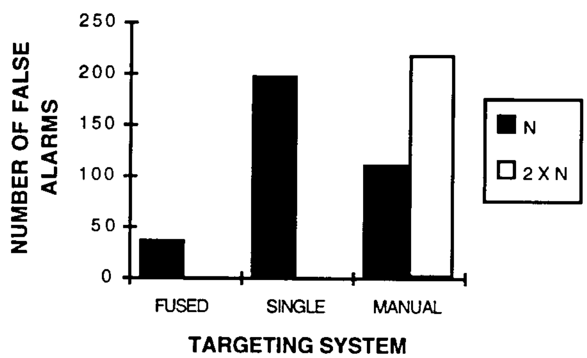



*Figure 3-3. Number of false alarms included in target hand-off list.*

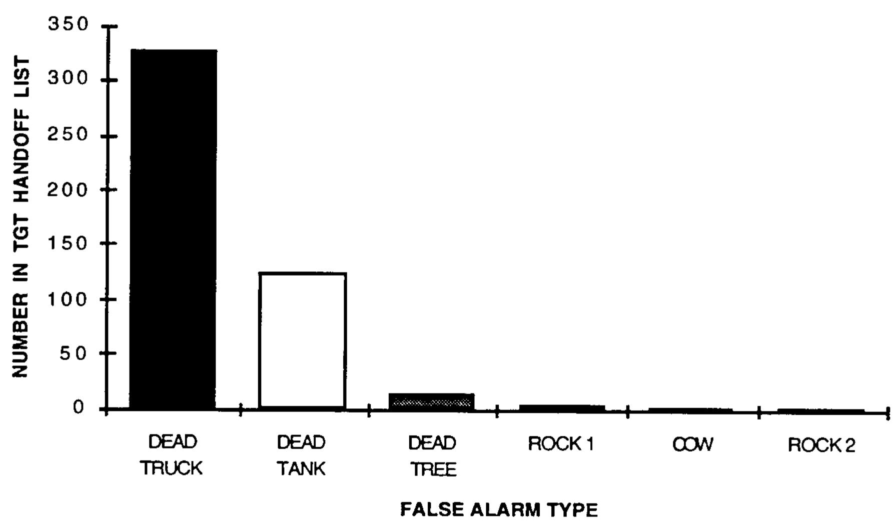



*Figure 3-4. Number of non-target objects included in target hand-off list.*

There was a difference in the reason for missed targets in the aided conditions as compared to the manual condition. In a number of cases, target objects were missed because they were not displayed to the aviator by the aided systems. More than one-half of the target objects missed with the aided systems were never presented to the aviator (fig. 3-5). Using the manual system, the aviator was presented every target object in the scene. Appendix C shows a typical range of scan fields for the aided and manual systems.

The presentation of the manual scans in appendix C uses a denser pattern of dots to represent the narrow field of view (FOV) and a sparser pattern of dots to represent the medium FOV. When scanning manually, the aviators tended to concentrate on the main body of target objects or confusable non-target objects using the narrow FOV. They searched for the main body in the medium FOV, and they also used this FOV to search for outlying target objects after finishing the main body. This pattern of use is reflected in the small area of dense stippling surrounded by sparse stippling shown in the sample scans. Between narrow and medium FOV the sample scans cover an area between 150 square degrees and more than 400 square degrees. The assigned area was 270 square degrees.

The presentation of the aided scans indicates target objects by a "+," target objects displayed in chips mode by a superimposed circle ("o"), and displayed frames by a stippled area. Uncircled target objects in an unfilled area were not presented to the aviator. All three examples of an aided scan contain undisplayed target objects.

The sequence of operation with the aided systems was different than that used with the manual system. The aviators began by verifying all the detections presented in chips mode. If there were more than 18 detections, they verified the remaining detections in target frame mode. The aviators proceeded to subsequent targets by stepping sequentially left, right, up and down. They added any target objects missed by the system that they encountered during this search process. After completing the detections, they made a search for outlying undetected target objects. This search was restricted to a small area around the main body of target objects, owing to the slowness and heavy manual involvement of stepping through frames. The sample scans cover an area between 48 square degrees and slightly over 100 square degrees.

**Effects of Aided Systems**

Differences between and within aided systems showed their effects in the time needed to perform targeting operations. There were performance time differences resulting from differing sensitivity as well as differences arising from the type of operations performed by the aviator.

On the whole the fused system supported much faster completion of the target hand-off list than did either the single sensor system or the manual system, which did not differ from each other. Time required to construct the target hand-off list (target hand-off time) was over 50 seconds less with the fused system than with the other systems. This represents about a 20% reduction (fig. 3-6). For the aided systems, target hand-off time included time to process the chips array and the target objects presented in frames plus the time to search for outlying target objects plus the time to verify the target hand-off list. The process began as soon as the system presented a detected object to the aviator. Presentation of chips began during the scan, while the aircraft was still unmasked, but most

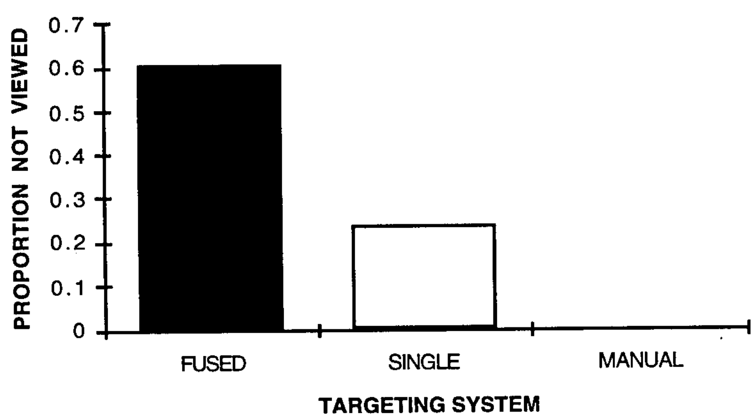



*Figure 3-5. Proportion of missed target objects not presented to aviator.*

of the time was spent after remask. By contrast the aviator performed the scanning in the manual condition, so the target hand-off time is equal to the exposure time.

The differences in target hand-off time are interesting because they reflect not simply aiding but how well the aiding is done. The effectiveness of aiding depends on how the aviator must act on the data presented by the aiding system. The target hand-off time was shorter for the fused system even though the average time to process an individual detection was shorter for the single sensor system (fig. 3-7). This seeming paradox exists because the average time to process a detection masks important individual differences between detections. The time required to process each detection is determined by two factors, object type and presentation mode. Non-target objects are processed faster than target objects, because they require no labeling of target type, and chips presentations are processed faster than frames presentations (fig. 3-8).

When the (single sensor) aided system produces more false alarms, the aviator must reject more non-target objects. Since this is the relatively faster process, the average time per object decreases. If, however, these objects were not detected, they would not be processed at all. Therefore the total time to accomplish the task increases by the amount required to process the added detections.

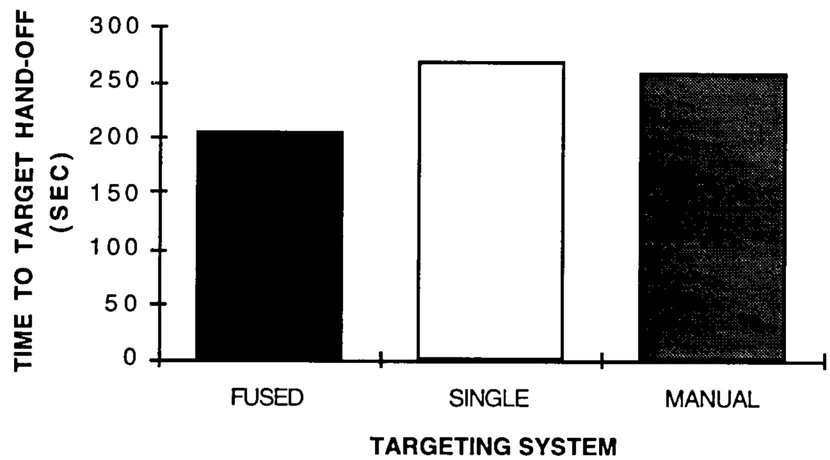



*Figure 3-6. Time to construct and send target hand-off list.*

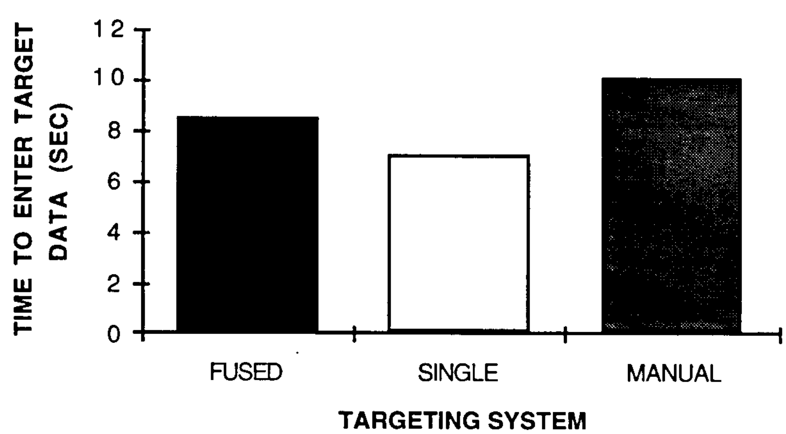



*Figure 3-7. Time to enter individual target data.*

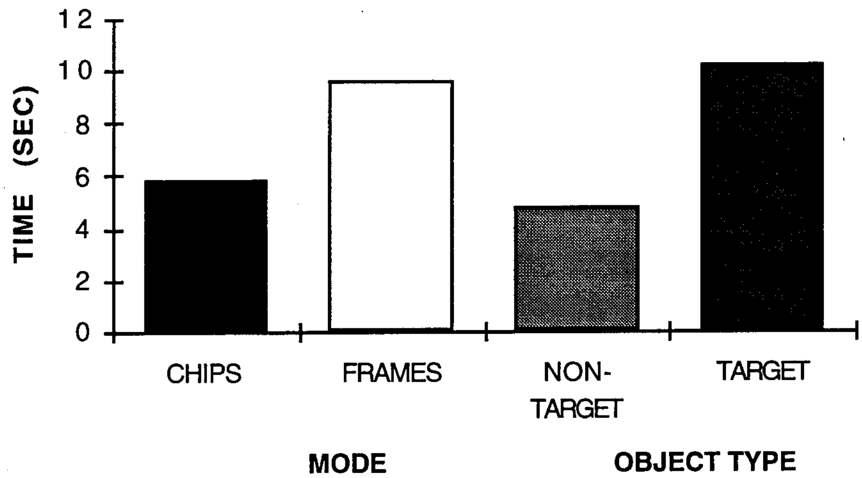



*Figure 3-8. Time to enter individual target data by system mode and by target type.*

Increasing the number of false alarms also increases the total number of detections. When there are more than 18 total detections, some are presented only in frames mode. Frames mode processing is slower than chips mode processing. Detected target objects displaced to frames mode presentation take longer to process, so the total time to perform the task increases.

Chips mode processing is faster than frames mode processing because the former allows rapid selection of detections for processing while the latter requires a cumbersome search sequence. In chips mode up to six detections are presented as a group. The aviator can select by touching the imagery or the "yes" or "no" softkeys. The softkey is preferred because it required fewer actions. A single softkey touch brings up the next group of detections. In target frames mode the aviator finds detection number 19 and processes it. The aviator then steps one frame up or over. If there were a detection, he would select it and process it. If there were more he would select and process them; otherwise, he would step to another frame. This process is time consuming for several reasons. It requires a large amount of manual interaction with the system, it requires examination of a number of frames containing no detections, and it requires searching the frames to locate detections.

An additional factor affecting processing time in frames mode is that missed target objects must be located in this mode. This task is essentially the same as the manual task, which is somewhat slower than processing detected objects. While this effect inflates our estimate of frames mode processing time slightly, it is still the case that the extra work associated with frames mode makes it substantially slower than chips mode for processing detections.

### Crew–System Interaction

Crew–system interaction is generally considered to be an issue of physical interface design. Type and position of controls, display formats, operational sequences, and organization of data all affect usability and effectiveness. We did not vary the operator interface, but implemented that of the Comanche ATD/C. This design has not been fielded nor fully tested. We identified some difficulties in operating the aided systems using this interface. These are reported along with suggested improvements.

A second crew–system interface issue for aided targeting systems is the criterion for target detection. For a given system the criterion determines the ratio of correct detections to false alarms. This ratio must be optimized for any given system sensitivity. The present study was not intended to optimize criterion. Rather it was intended to determine what aspects of performance are affected by criterion and how criterion interacts with other system design factors.

Since criterion affects the ratio of correct detections to false alarms, we might expect it to affect performance time. In fact we see the same pattern of performance time effects for criterion that we saw for the difference in aided system sensitivity. That is, the lower criterion led to a longer time to perform the target hand-off task (fig. 3-9) even though the mean time to process an individual detection was shorter (fig. 3-10). This pattern occurs because the lower criterion generates more false alarms (fig. 3-11). These are processed more rapidly than are correct detections, but because they increase the total number of detections to be processed, they lead to a longer total time to perform the task. The lower criterion was not unequivocally bad, however. Its benefit lay in reducing the number of targets that were missed because they were never presented to the aviator (fig. 3-12). As stated above target objects were not presented when the system failed to detect them and the aviator failed to select the appropriate frame during his stepwise search. In some sense the lower criterion compensates for the cumbersome frames mode interaction by obviating the need to find missed target objects. The cost of this compensation is a large increase in the time required to perform the target hand-off. This is a substantial cost, and the operator interface should be optimized to reduce the likelihood of failing to present target objects prior to optimizing criterion. Possible alternatives for optimizing the operator interface are discussed below.

The effect of target density also turns out to be related to the aviator-system interaction. Increasing the number of target objects in the environment increases the target hand-off time, and this increase with target density is greatest for the lower criterion (fig. 3-13). The interaction between criterion and target density does not arise simply from there being more detections to process, since neither the single sensor nor the fused sensor system shows a sensitivity to target density relative to the manual system (fig. 3-14). Rather it is an effect of the operator interface design. As mentioned above, detections are processed more quickly in chips mode than they are in frames mode.

Thus the time required to perform the hand-off increases when there are enough detections to result in some being presented only in frames mode. Table 3-1 shows the expected number of detections presented only in frames mode. All four target density conditions result in frames mode presentations for the single sensor, low criterion configuration. The highest target density condition results in frames mode presentation for the fused sensor, low criterion configuration and the single sensor, high criterion condition. All of these conditions show an elevated target hand-off time (fig. 3-15) except the no-target object, single sensor condition and the single sensor, high criterion condition.

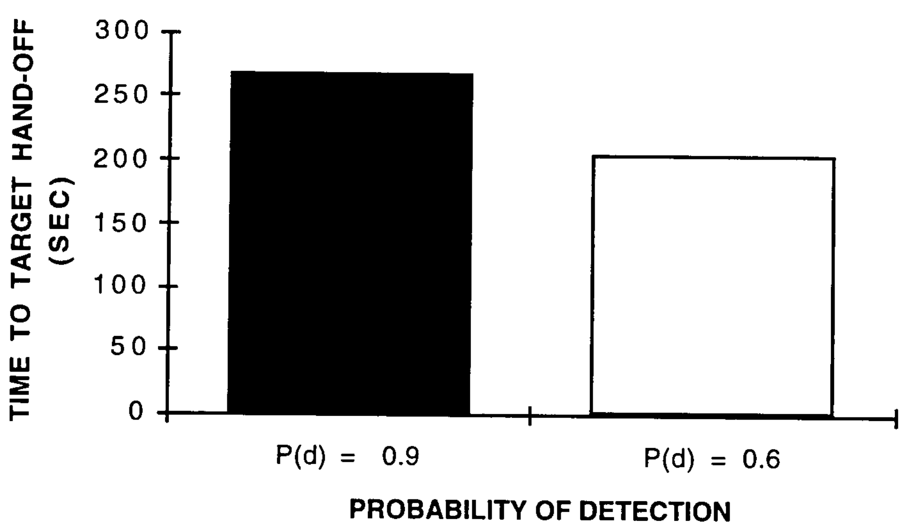



*Figure 3-9. Time to target hand-off by criterion (P(d) = 0.9 is low criterion).*

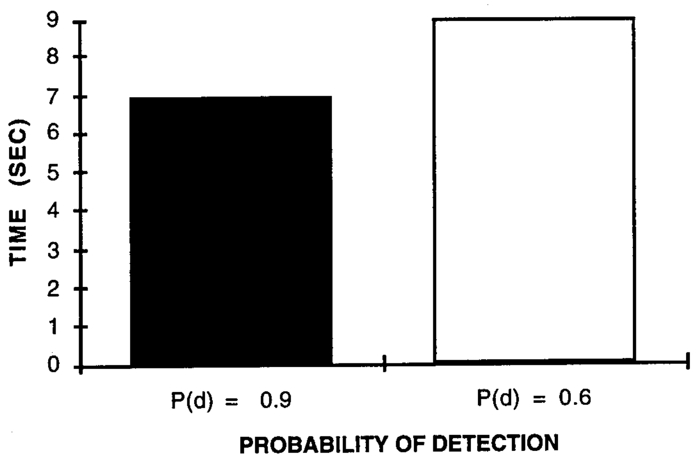



*Figure 3-10. Time to process individual detections by criterion (P(d) = 0.9 is low criterion).*

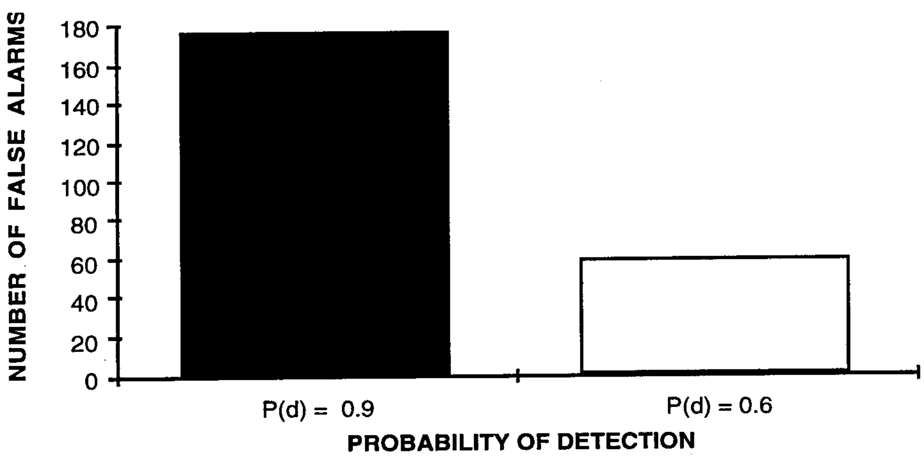



*Figure 3-11. Number of false alarms by criterion (P(d) = 0.9 is low criterion).*

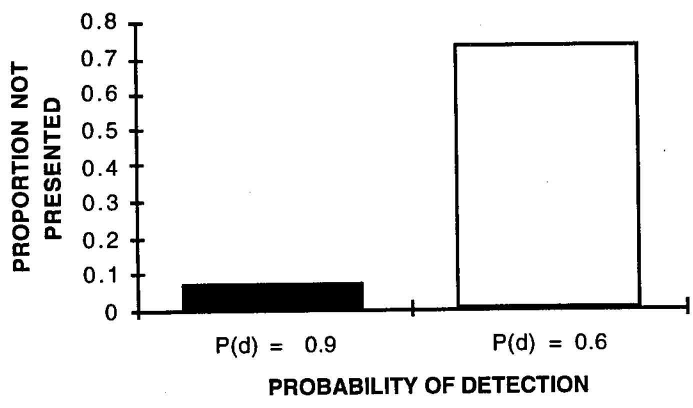



*Figure 3-12. Proportion of missed target objects not presented by criterion (P(d) = 0.9 is low criterion).*

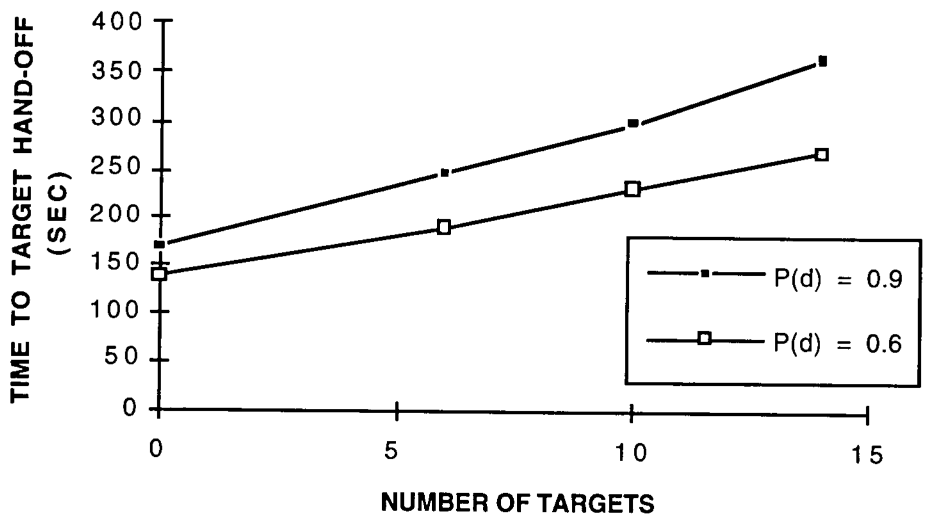



*Figure 3-13. Target hand-off time: interaction between criterion and target density.*

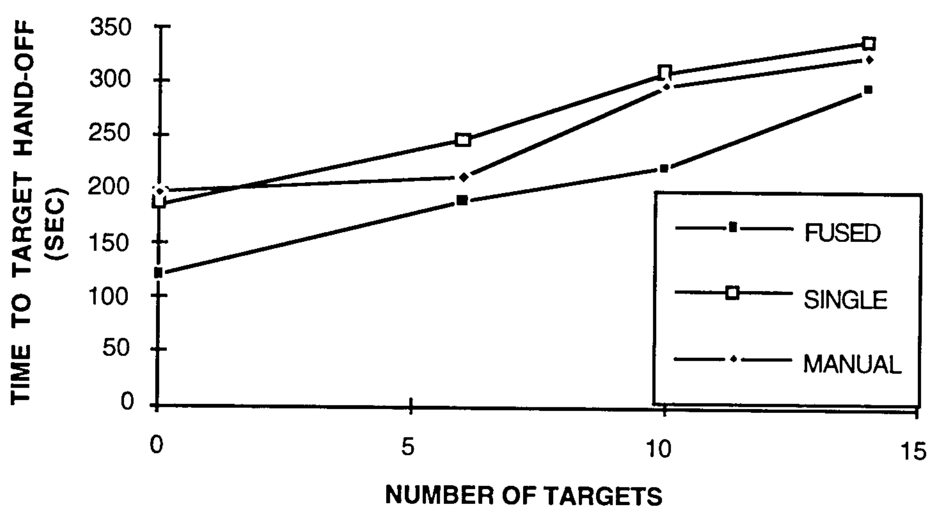



*Figure 3-14. Effect of target density on target hand-off time for each sensor system.*

Table 3-1. Number of detections presented in frames mode

| System configuration | Number of target objects | Number of non-target objects | Expected number of detections | Number presented in frames mode |
|---|---|---|---|---|
| Fused, P(d) = 0.6 | 0 | 1 | 0.6 | 0 |
| Fused, P(d) = 0.6 | 6 | 1 | 4.2 | 0 |
| Fused, P(d) = 0.6 | 10 | 1 | 6.6 | 0 |
| Fused, P(d) = 0.6 | 14 | 1 | 9.2 | 0 |
| Fused, P(d) = 0.9 | 0 | 5 | 4.5 | 0 |
| Fused, P(d) = 0.9 | 6 | 5 | 9.9 | 0 |
| Fused, P(d) = 0.9 | 10 | 5 | 13.4 | 0 |
| Fused, P(d) = 0.9 | 14 | 5 | 17.1 | 0–1 |
| Single, P(d) = 0.6 | 0 | 6 | 3.6 | 0 |
| Single, P(d) = 0.6 | 6 | 6 | 7.2 | 0 |
| Single, P(d) = 0.6 | 10 | 6 | 9.6 | 0 |
| Single, P(d) = 0.6 | 14 | 6 | 12.0 | 0–2 |
| Single, P(d) = 0.9 | 0 | 22 | 19.8 | 0–4 |
| Single, P(d) = 0.9 | 6 | 22 | 25.2 | 0–10 |
| Single, P(d) = 0.9 | 10 | 22 | 18.8 | 0–14 |
| Single, P(d) = 0.9 | 14 | 22 | 32.4 | 0–18 |

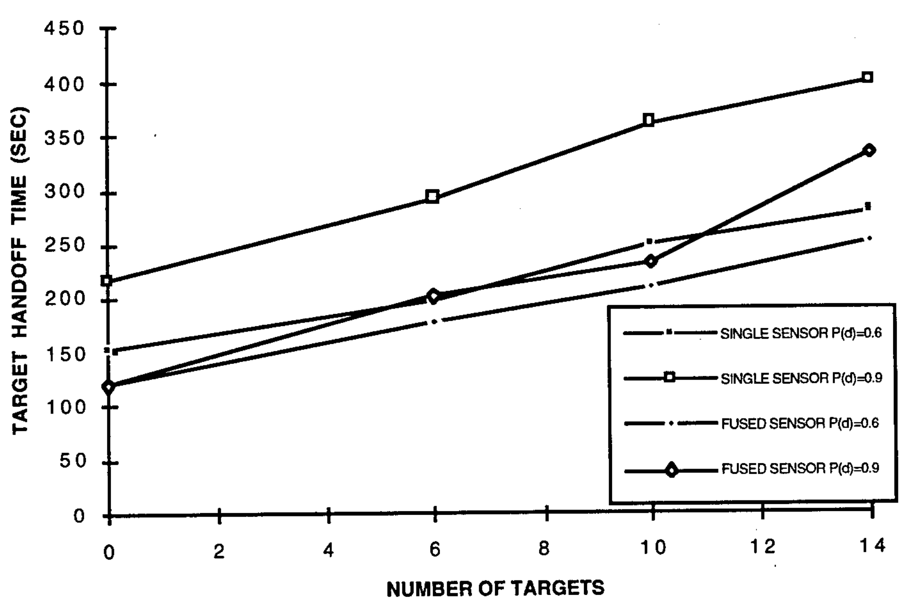



*Figure 3-15. Target hand-off time: interaction between system configuration and target density.*

The frames mode effect is more apparent when the data are segregated by criterion than when they are segregated by system because all of the configurations in which detections are presented in frames are low criterion configurations while only four out of five of these are single sensor configurations. The effect is likely due to the frames mode operator interaction, not to the aided system.

A further indication of the ineffectiveness of frames mode is the relatively large amount of time required to process target objects. Even though the aviators spent over twice as much time in frames mode as in chips mode (fig. 3-16), they processed fewer targets (fig. 3-17) in frames mode. It is true that area clearing and target list verification may inflate the time spent in frames mode by as much as 70 seconds, which is the mean time from the penultimate target acceptance to sending the list. Even accounting for this activity as much time, or more, is spent in frames mode to detect fewer targets.

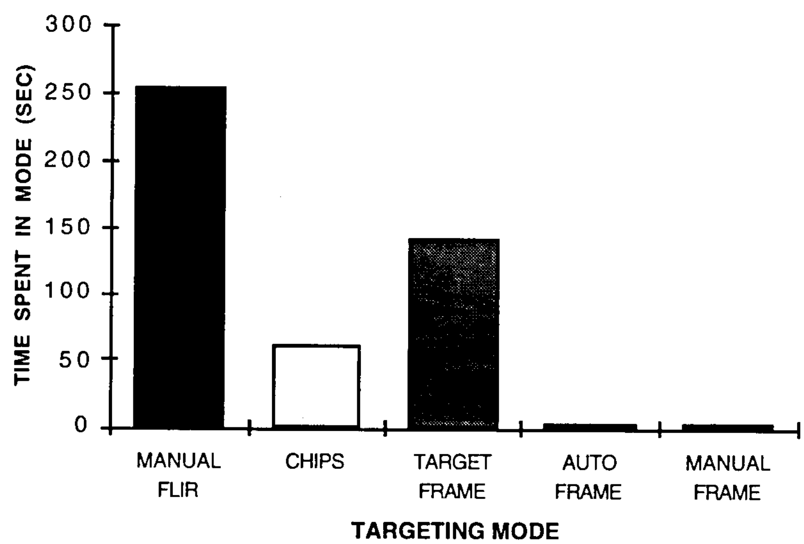



*Figure 3-16. Time spent in each system mode.*

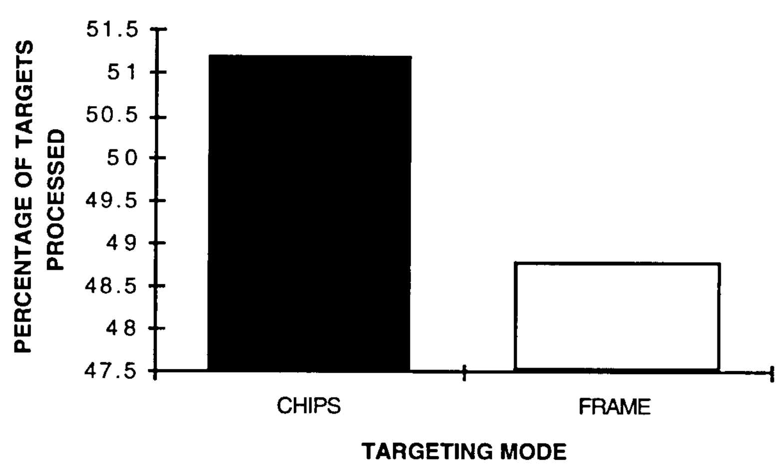



*Figure 3-17. Percentage of targets processed in each system mode.*

### Aviator Subjective Evaluation

In general the aviators' subjective evaluation of the systems was less sensitive to differences between the systems than was the objective data, but their evaluation paralleled the objective evaluation (table 3-2). They felt that the aided systems provided a substantial improvement in exposure time, although this improvement led to a perceived improvement in tactical value only for the fused sensor system. They felt that the fused system gave a shorter target hand-off time than either the single sensor system or the manual system and that the workload associated with the fused system was lower than with the manual system. They perceived the superior detection and categorization data provided by the aided systems, but, correctly, they did not feel that these resulted in better overall performance.

Table 3-2. Aviator subjective evaluation[a]

| Evaluation factor | Fused sensor system | Single sensor system | Manual system |
|---|---|---|---|
| Exposure time | 6.6 | 6.6 | 2.5 |
| System detection | 5.4 | 4.6 | 2.0 |
| System categorization | 3.8 | 3.2 | 1.8 |
| Target hand-off time | 5.3 | 4.6 | 4.1 |
| Workload | 5.7 | 5.1 | 4.8 |
| Tactical value | 5.8 | 5.3 | 4.9 |

[a]Shows mean ratings. Seven represents the best rating and one represents the worst.

## 4. Discussion

### Effects of Aiding

The targeting system evaluation has demonstrated a clear advantage of aided systems over a manual system having the same FLIR sensing capability. The greatest benefit of the aided systems was the reduction in exposure time. This benefit had been anticipated, and in fact the exposure time for the aided systems was largely defined by the scan time of the system. The relative unknown was the exposure time for the manual system. At an average of over six minutes, the exposure time obtained is longer than would be considered tactically sound under actual combat conditions, but it is an accurate measure of the time needed to perform the complete targeting task. Tactical considerations might force segmentation of the task to reduce exposure time. Such segmentation could greatly increase the duration of a manual targeting task. Therefore the benefit derived from aiding might be substantially greater under combat conditions than under the conditions in the present test.

A significant concern about aided systems is that the improvement in exposure time might be purchased at the expense of poorer performance. This was definitely not the case. Overall the aided systems gave performance comparable to the manual system in accuracy with less risk due to exposure to ground threats. The fused sensor system actually allowed quicker construction of the target hand-off list, by about 50 seconds, than either the single sensor system or the manual system. The design of the test mitigated against finding accuracy improvements with the aided systems, since the high thermal contrast (high $\Delta$ T) image made the aviator's visual discrimination task easy. Aiding could enhance accuracy under poor thermal contrast (low $\Delta$ T) conditions. We might expect the greatest benefit from the fused sensor system, since the Longbow would provide it information to compensate for the poor FLIR data.

### Crewstation Interface

**Chips mode**– The chips mode interface was highly effective in allowing the aviators to process detections quickly. A large number of individual detections could be processed in this mode. It was also useful for verifying the target hand-off list. Its limitation was that only 18 detections could be presented in this mode. This limitation was caused by processing and memory in available, flight qualified hardware, that should not limit future systems.

Chips mode should be expanded to cover all system detections. Chips-like review modes would also be useful for verification of the target hand-off list. One such mode would include all accepted targets, whether detected by the system or by the crew. This mode would enable the aviator to verify the accuracy of the targets he has included in the target hand-off list. A second mode would present only detections not accepted by the crew as targets. This mode would facilitate the aviator's checking his own editing.

Chips mode presents only individual targets detected by the system. A substantial part of the reconnaissance task requires frames mode. Frames mode supports detection of target objects missed by the system. It also allows the aviator to view global relationships between target objects.

**Frames mode**– The aviators were no more likely to miss target objects with the aided systems than with the manual system, and in fact the miss rate was very low across the board. There was, however, a negative effect in that a number of misses with the aided systems resulted from the target object never having been displayed to the aviator. This situation occurred when the system failed to detect the object and the aviator failed to select the frame containing the object during his search for system misses. This problem was symptomatic of a design flaw in the operator interface, which has not yet been fielded nor fully tested. This flaw is the cumbersome process of sorting through a large number of sensor frames (92 for the 6° × 45° scan). The aviators found this process time consuming and monotonous. In addition, the rate of non-displayed system misses indicates that it is somewhat error prone.

Further potential problems exist with the frames mode interface that were not directly apparent in the present evaluation. One is the possibility of missing outlying target objects due to failure of the aviator to view the entire search zone. Appendix C shows that the aviators reduced the area they actually viewed with the aided systems. Another potential problem is that relationships between targets in the scanned formation may be less apparent when the area is viewed in small frames. The present evaluation did not test this sort of situation awareness, but the aviators commented that they felt the fragmented view to be less than satisfactory.

Aviators used the medium field of view in the manual mode to provide a big picture view. Having found possible target objects in the medium FOV, they switched to narrow FOV to gain adequate resolution for their decision. Frames mode should provide a comparable capability. Pixel expanded medium and wide FOV modes would allow the crew to search quickly and thoroughly, getting a global perspective. Narrow frames would provide a detailed image, and the chips-like modes would support review of the final product of the reconnaissance activity.

### Crew–System Interaction

We have addressed crew–system interaction as a criterion issue. Detection criterion affects how the aviator has to act on the information provided to him by the system. As criterion varies, the aviator has to deal with varying numbers of hits and false alarms. We have seen that the system's judgment does little to bias the aviator, at least under the high thermal contrast conditions of the present evaluation. The principal effect of criterion variation is to change the amount of frames mode interaction. Frames mode can lead to failure to present target objects when criterion is high. When criterion is low, frames mode increases the time needed to perform the reconnaissance. Both of these effects stem from the design problems cited above. A definitive judgment regarding criterion values must await optimization of system modes.

Another interaction factor linked to the criterion issue is the crew's response to detected non-target objects. We required an explicit response for data collection. This response slowed processing of detected non-target objects. A "no-target" default would speed the task and would likely have no adverse effect on accuracy. This change should be included in an operator interface refinement and evaluation program.

## 5. Conclusions

1. Aided targeting systems provide a substantial reduction (over 81%) in exposure to ground based threats.

2. The fused sensor system provides a considerable reduction in time to construct the target hand-off list.

3. The benefits of aiding are obtained with no loss of accuracy. The fused sensor system actually showed slightly lower false alarm rates than the other systems.

4. Aiding may improve accuracy under poor FLIR viewing conditions (low $\Delta$ T), particularly with the fused sensor system.

5. Battlefield conditions, which lead to greater time stress, may magnify the benefits obtained under the present, relatively benign test conditions.

6. Operator interface/system mode refinement and evaluation should be an integral part of system design to address problem areas identified in the present test.

# 6. Appendices

# A. Aviator Subjective Evaluation Form

Targeting System Evaluation Questionnaire

Name:______________________________ Run number:______

1. Rate the ease of use of each targeting system.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Manual | 1 very hard | 2 | 3 | 4 | 5 | 6 | 7 very easy |
| Single-Sensor | 1 very hard | 2 | 3 | 4 | 5 | 6 | 7 very easy |
| Multi-Sensor | 1 very hard | 2 | 3 | 4 | 5 | 6 | 7 very easy |

2. Rate the accuracy of each targeting system.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Manual | 1 very poor | 2 | 3 | 4 | 5 | 6 | 7 very good |
| Single-Sensor | 1 very poor | 2 | 3 | 4 | 5 | 6 | 7 very good |
| Multi-Sensor | 1 very poor | 2 | 3 | 4 | 5 | 6 | 7 very good |

3. Rate your accuracy using each targeting system.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Manual | 1 very poor | 2 | 3 | 4 | 5 | 6 | 7 very good |
| Single-Sensor | 1 very poor | 2 | 3 | 4 | 5 | 6 | 7 very good |
| Multi-Sensor | 1 very poor | 2 | 3 | 4 | 5 | 6 | 7 very good |

4. Rate exposure time with each targeting system.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Manual | 1 very long | 2 | 3 | 4 | 5 | 6 | 7 very short |
| Single-Sensor | 1 very long | 2 | 3 | 4 | 5 | 6 | 7 very short |
| Multi-Sensor | 1 very long | 2 | 3 | 4 | 5 | 6 | 7 very short |

5. Rate total time to perform targeting task.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Manual | 1 very long | 2 | 3 | 4 | 5 | 6 | 7 very short |
| Single-Sensor | 1 very long | 2 | 3 | 4 | 5 | 6 | 7 very short |
| Multi-Sensor | 1 very long | 2 | 3 | 4 | 5 | 6 | 7 very short |

6. Rate the tactical value of each system.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Manual | 1 very low | 2 | 3 | 4 | 5 | 6 | 7 very high |
| Single-Sensor | 1 very low | 2 | 3 | 4 | 5 | 6 | 7 very high |
| Multi-Sensor | 1 very low | 2 | 3 | 4 | 5 | 6 | 7 very high |

## B. Analysis of Variance Tables

Number of observations in data set = 422
Dependent Variable: EXPSD Total Time Aircraft was Exposed (seconds)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 14 | 3227380.10541434 | 230527.15038674 | 88.87 | 0.0001 |
| Error | 407 | 1055726.26571824 | 2593.92202879 | | |
| Corrected Total | 421 | 4283106.37113258 | | | |

| R-Square | C.V. | Root MSE | EXPSD Mean |
|---|---|---|---|
| 0.753514 | 56.66843 | 50.93056085 | 89.87465599 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **PILOT** | **10** | **83536.94273476** | **8353.69427348** | **3.22** | **0.0005** |
| **TGT_M** | **4** | **3133994.89815930** | **783498.72453983** | **302.05** | **0.0001** |

*B1. ANOVA—Exposure Time.*

Number of observations in data set = 422
Dependent Variable: N_R_N_D Number Real Targets NOT Detected

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 121 | 13.66991075 | 0.11297447 | 0.66 | 0.9936 |
| Error | 190 | 32.67624310 | 0.17198023 | | |
| Corrected Total | 311 | 46.34615385 | | | |

| R-Square | C.V. | Root MSE | N_R_N_D Mean |
|---|---|---|---|
| 0.294952 | 308.0666 | 0.41470499 | 0.13461538 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| PILOT | 10 | 1.28089976 | 0.12808998 | 0.74 | 0.6816 |
| RUN | 39 | 4.01890639 | 0.10304888 | 0.60 | 0.9703 |
| TGT_M_J3 | 2 | 0.11084093 | 0.05542047 | 0.32 | 0.7249 |
| RUN*TGT_M_J3 | 70 | 7.50981624 | 0.10728309 | 0.62 | 0.9881 |

*B2. ANOVA—Misses by Targeting System.*

Number of observations in data set = 422

NOTE: Due to missing values, only 421 observations can be used in this analysis.

Dependent Variable: N_F_ACC Number False Targets Accepted as Real

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 126 | 692.54453316 | 5.49638518 | 4.16 | 0.0001 |
| Error | 294 | 388.37233145 | 1.32099432 | | |
| Corrected Total | 420 | 1080.91686461 | | | |

| R-Square | C.V. | Root MSE | N_F_ACC Mean |
|---|---|---|---|
| 0.640701 | 140.6611 | 1.14934517 | 0.81710214 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **PILOT** | **10** | **220.81298601** | **22.08129860** | **16.72** | **0.0001** |
| **RUN** | **39** | **105.03549591** | **2.69321784** | **2.04** | **0.0005** |
| **TGT_M_J3** | **2** | **90.94249257** | **45.47124628** | **34.42** | **0.0001** |
| **RUN*TGT_M_J3** | **75** | **147.18956166** | **1.96252749** | **1.49** | **0.0113** |

*B3. ANOVA—False Alarms.*

Number of observations in data set = 422

Dependent Variable: PROP_OF_MISSED_TARGETS_NOT_PRESENTED

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 12 | 0.33071382 | 0.02755949 | 0.85 | 0.5949 |
| Error | 409 | 13.20483120 | 0.03228565 | | |
| Corrected Total | 421 | 13.53554502 | | | |

| R-Square | C.V. | Root MSE | PROP_M Mean |
|---|---|---|---|
| 0.024433 | 541.6131 | 0.17968208 | 0.0331753 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| PILOT | 10 | 0.09808461 | 0.00980846 | 0.30 | 0.9801 |
| **TGT_M_J3** | **2** | **0.22915471** | **0.11457735** | **3.55** | **0.0296** |

*B4. ANOVA—Number of Missed Target Objects not Presented.*

Number of observations in data set = 422

Dependent Variable: TTH Time To Target Hand-off (seconds)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 12 | 1242489.51191388 | 103540.79265949 | 11.16 | 0.0001 |
| Error | 409 | 3793218.76751411 | 9274.37351470 | | |
| Corrected Total | 421 | 5035708.27942799 | | | |

| R-Square | C.V. | Root MSE | TTH Mean |
|---|---|---|---|
| 0.246736 | 39.92129 | 96.30354882 | 241.23358899 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **PILOT** | **10** | **864300.21394836** | **86430.02139484** | **9.32** | **0.0001** |
| **TGT_M_J3** | **2** | **363255.23426774** | **181627.61713387** | **19.58** | **0.0001** |

*B5. ANOVA—Time to Target Hand-off.*

Number of observations in data set = 422

Dependent Variable: TIME Time Required For Target Determination

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 12 | 24760.95770457 | 2063.41314205 | 51.17 | 0.0001 |
| Error | 5614 | 226377.83178860 | 40.32380331 | | |
| Corrected Total | 5626 | 251138.78949317 | | | |

| R-Square | C.V. | Root MSE | TIME Mean |
|---|---|---|---|
| 0.098595 | 80.28132 | 6.35010262 | 7.90981300 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **PILOT** | **10** | **17898.76238181** | **1789.87623818** | **44.39** | **0.0001** |
| **TGT_M_J3** | **2** | **6187.06434307** | **3093.53217154** | **76.72** | **0.0001** |

*B6. ANOVA—Time to Process an Individual Target.*

Number of observations in data set = 422

Dependent Variable: TIME Time Required For Target Determination

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 15 | 65090.45764067 | 4339.36384271 | 130.87 | 0.0001 |
| Error | 5611 | 186048.33185249 | 33.15778504 | | |
| Corrected Total | 5626 | 251138.78949317 | | | |

| R-Square | C.V. | Root MSE | TIME Mean |
|---|---|---|---|
| 0.259181 | 72.79919 | 5.75827969 | 7.90981300 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **PILOT** | **10** | **13804.11564181** | **1380.41156418** | **41.63** | **0.0001** |
| **REAL** | **1** | **8193.69244699** | **8193.69244699** | **247.11** | **0.0001** |
| **MODE** | **2** | **9630.56492595** | **4815.28246297** | **145.22** | **0.0001** |
| **MODE*REAL** | **2** | **3517.53880691** | **1758.76940345** | **53.04** | **0.0001** |

*B7. ANOVA—Time to Enter Individual Target Data.*

Number of observations in data set = 422

Dependent Variable: TTH Time To Target Hand-off (seconds)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 13 | 1399191.52145124 | 107630.11703471 | 13.03 | 0.0001 |
| Error | 321 | 2650511.78737057 | 8257.04606657 | | |
| Corrected Total | 334 | 4049703.30882181 | | | |

| R-Square | C.V. | Root MSE | TTH Mean |
|---|---|---|---|
| 0.345505 | 38.38302 | 90.86828966 | 236.74083826 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **PILOT** | **10** | **618816.03621018** | **61881.60362102** | **7.49** | **0.0001** |
| **ATM_C** | **1** | **324094.27126135** | **324094.27126135** | **39.25** | **0.0001** |
| **ATM_S** | **1** | **333486.26219446** | **333486.26219446** | **40.39** | **0.0001** |
| **ATM_C*ATM_S** | **1** | **89049.35866618** | **89049.35866618** | **10.78** | **0.0011** |

*B8. ANOVA—Time to Target Hand-off by Criterion.*

Number of observations in data set = 422

Dependent Variable: TIME Time Required For Target Determination

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 14 | 53336.69941862 | 3809.76424419 | 115.34 | 0.0001 |
| Error | 4819 | 159179.00186784 | 33.03154220 | | |
| Corrected Total | 4833 | 212515.70128646 | | | |

| R-Square | C.V. | Root MSE | TIME Mean |
|---|---|---|---|
| 0.250978 | 76.17454 | 5.74730739 | 7.54491857 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **PILOT** | **10** | **18655.61402806** | **1865.56140281** | **56.48** | **0.0001** |
| TM_C | 1 | 18.40346889 | 18.40346889 | 0.56 | 0.4554 |
| ATM_S | 1 | 48.27414799 | 48.27414799 | 1.46 | 0.2268 |
| **ATM_C*ATM_S** | **1** | **103.59856558** | **103.59856558** | **3.14** | **0.0766** |
| **REAL** | **1** | **29092.16932434** | **29092.16932434** | **880.74** | **0.0001** |

*B9. ANOVA—Time to Process Detections by System and Criterion.*

Number of observations in data set = 422

Dependent Variable: N_F_ACC Number False Targets Accepted as Real

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 52 | 375.81741717 | 7.22725802 | 6.51 | 0.0001 |
| Error | 281 | 311.83827146 | 1.10974474 | | |
| Corrected Total | 333 | 687.65568862 | | | |

| R-Square | C.V. | Root MSE | N_F_ACC Mean |
|---|---|---|---|
| 0.546520 | 149.7236 | 1.05344423 | 0.70359281 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **PILOT** | **10** | **163.22601576** | **16.32260158** | **14.71** | **0.0001** |
| **RUN** | **39** | **70.73831310** | **1.81380290** | **1.63** | **0.0133** |
| **ATM_C** | **1** | **30.80365069** | **30.80365069** | **27.76** | **0.0001** |
| **ATM_S** | **1** | **79.53399499** | **79.53399499** | **71.67** | **0.0001** |
| **ATM_C*ATM_S** | **1** | **8.91574605** | **8.91574605** | **8.03** | **0.0049** |

*B10. ANOVA—False Alarms by System and Criterion.*

Number of observations in data set = 422

Dependent Variable: TTH Time To Target Hand-off (seconds)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 21 | 2776553.81415053 | 132216.84829288 | 23.41 | 0.0001 |
| Error | 400 | 2259154.46527746 | 5647.88616319 | | |
| Corrected Total | 421 | 5035708.27942799 | | | |

| R-Square | C.V. | Root MSE | TTH Mean |
|---|---|---|---|
| 0.551373 | 31.15338 | 75.15241954 | 241.23358899 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **PILOT** | **10** | **897691.12591794** | **89769.11259179** | **15.89** | **0.0001** |
| **TGT_DENS** | **3** | **1306729.71218274** | **435576.57072758** | **77.12** | **0.0001** |
| **TGT_M_J3** | **2** | **339009.91596192** | **169504.95798096** | **30.01** | **0.0001** |
| TGT_M_J3 *TGT_DENS | 6 | 52553.68400731 | 8758.94733455 | 1.55 | 0.1603 |

*B11. ANOVA—Effect of Target Density.*

Number of observations in data set = 422

Dependent Variable: TTH Time To Target Hand-off (seconds)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 25 | 2726648.50579628 | 109065.94023185 | 25.47 | 0.0001 |
| Error | 309 | 1323054.80302553 | 4281.73075413 | | |
| Corrected Total | 334 | 4049703.30882181 | | | |

| R-Square | C.V. | Root MSE | TTH Mean |
|---|---|---|---|
| 0.673296 | 27.63990 | 65.43493527 | 236.74083826 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **PILOT** | **10** | **646497.28869393** | **64649.72886939** | **15.10** | **0.0001** |
| **TGT_DENS** | **3** | **1248183.65886381** | **416061.21962127** | **97.17** | **0.0001** |
| **TGT_M** | **3** | **741285.86665516** | **247095.28888505** | **57.71** | **0.0001** |
| TGT_M*TGT_DENS | 9 | 72619.05200043 | 8068.78355560 | 1.88 | 0.0537 |

*B12. ANOVA—Effect of Target Density by Aided System Configuration.*

Number of observations in data set = 422

Dependent Variable: TIMEM Time Spent In Mode (seconds)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 34 | 10170726.80218550 | 299139.02359369 | 169.65 | 0.0001 |
| Error | 2060 | 3632420.40672497 | 763.31087705 | | |
| Corrected Total | 2094 | 13803147.20891050 | | | |

| R-Square | C.V. | Root MSE | TIMEM Mean |
|---|---|---|---|
| 0.736841 | 96.04019 | 41.99179535 | 43.72314849 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **PILOT** | **10** | **153765.38166671** | **15376.53816667** | **8.72** | **0.0001** |
| **MODE** | **4** | **3489486.42048208** | **872371.60512052** | **494.73** | **0.0001** |
| **TGT_M** | **4** | **158064.56859834** | **39516.14214958** | **22.41** | **0.0001** |
| **MODE*TGT_M** | **16** | **6377055.47521187** | **398565.96720074** | **226.03** | **0.0001** |

*B13. ANOVA—Time Spent in Mode.*

| Source | SS | df | MS | F | P |
|---|---|---|---|---|---|
| Between Blocks | 9.0626 | 11 | | | |
| Within Blocks | 147.8172 | 24 | | | |
| SENSOR | 130.0482 | 2 | 65.0241 | 80.507 | 0.0000 |
| Error | 17.7690 | 22 | 0.8077 | | |
| Total | 156.8798 | 35 | | | |

*B14. ANOVA—Subjective Evaluation of Exposure Time.*

| Source | SS | df | MS | F | P |
|---|---|---|---|---|---|
| Between Blocks | 24.0024 | 11 | | | |
| Within Blocks | 117.2898 | 24 | | | |
| SENSOR | 77.4934 | 2 | 38.7467 | 21.420 | 0.0000 |
| Error | 17.7690 | 22 | 0.8077 | | |
| Total | 141.2922 | 35 | | | |

*B15. ANOVA—Subjective Evaluation of System Detection.*

| Source | SS | df | MS | F | P |
|---|---|---|---|---|---|
| Between Blocks | 18.4040 | 11 | | | |
| Within Blocks | 57.4687 | 24 | | | |
| SENSOR | 23.6204 | 2 | 11.8102 | 7.676 | 0.0033 |
| Error | 33.8483 | 22 | 1.5386 | | |
| Total | 75.8727 | 35 | | | |

*B16. ANOVA—Subjective Evaluation of System Categorization.*

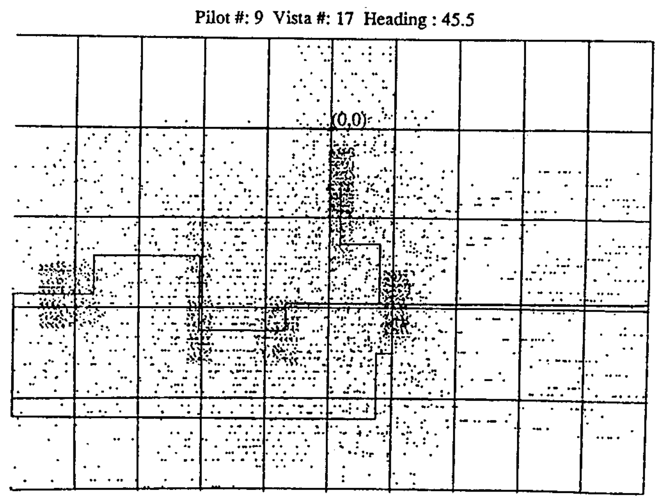
| Source | SS | df | MS | F | P |
|---|---|---|---|---|---|
| Between Blocks | 20.4431 | 11 | | | |
| Within Blocks | 14.2856 | 24 | | | |
| SENSOR | 4.2539 | 2 | 2.1264 | 4.663 | 0.0202 |
| Error | 10.0327 | 22 | 0.4560 | | |
| Total | 34.7286 | 35 | | | |

*B17. ANOVA—Subjective Evaluation of Workload.*

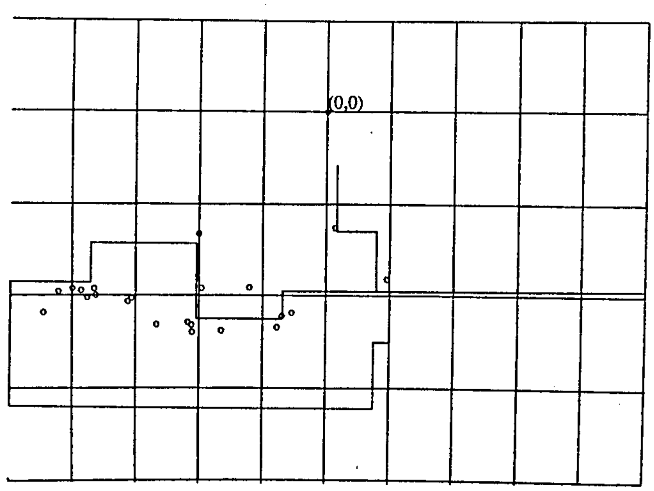
| Source | SS | df | MS | F | P |
|---|---|---|---|---|---|
| Between Blocks | 18.3413 | 11 | | | |
| Within Blocks | 15.8502 | 24 | | | |
| SENSOR | 5.0052 | 2 | 2.5026 | 5.077 | 0.0152 |
| Error | 10.8450 | 22 | 0.4930 | | |
| Total | 34.1915 | 35 | | | |

*B18. ANOVA—Subjective Evaluation of Tactical Value.*

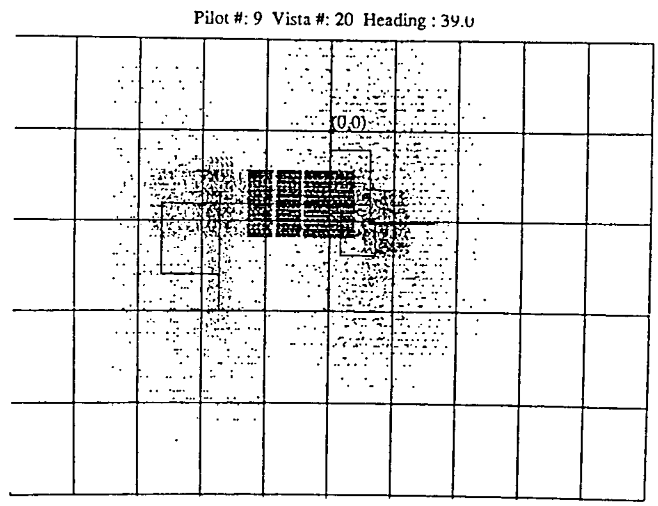
## C. Sample Sensor Scans



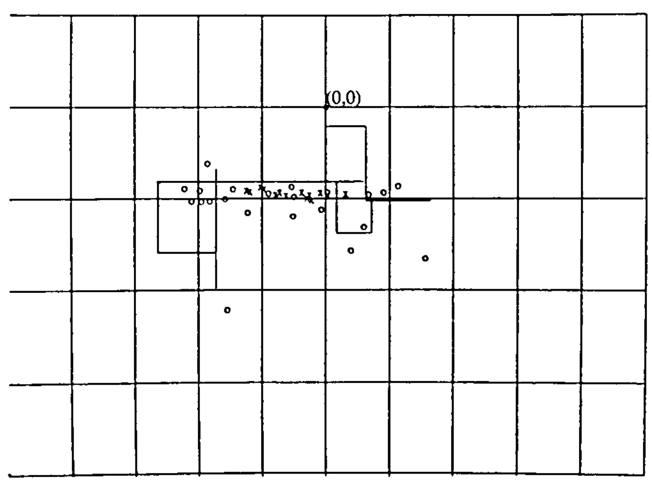

*C.1.A. Manual Sensor Scan. Grid Units—5° in AZ, 2° in EL.*



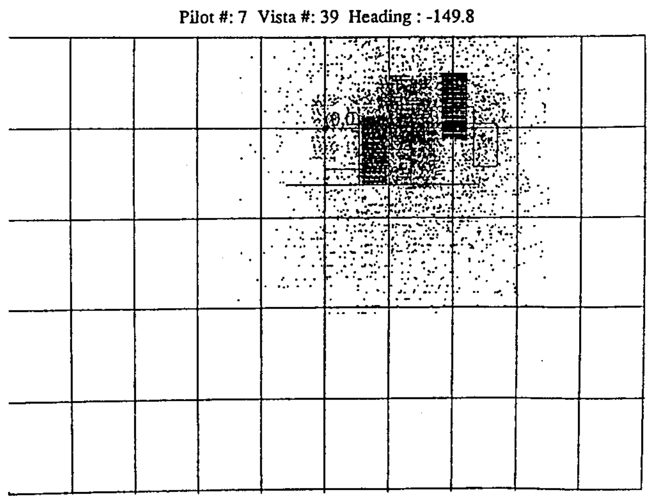

*C.1.B. Target Object Laydown.*



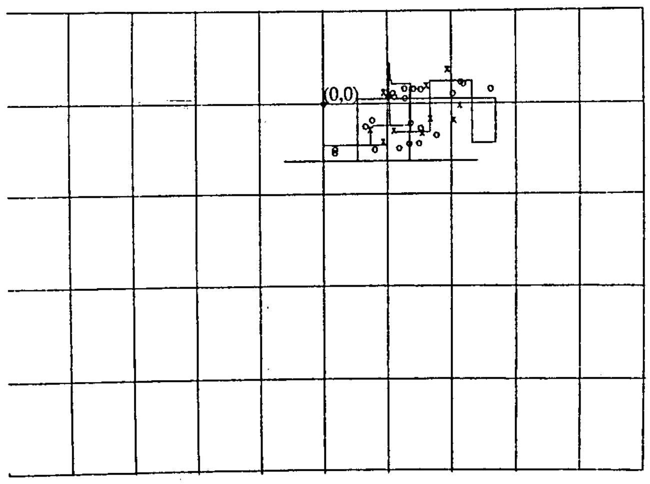

*C.2.A. Manual Sensor Scan. Grid Units—5° in AZ, 2° in EL.*




*C.2.B. Target Object Laydown.*

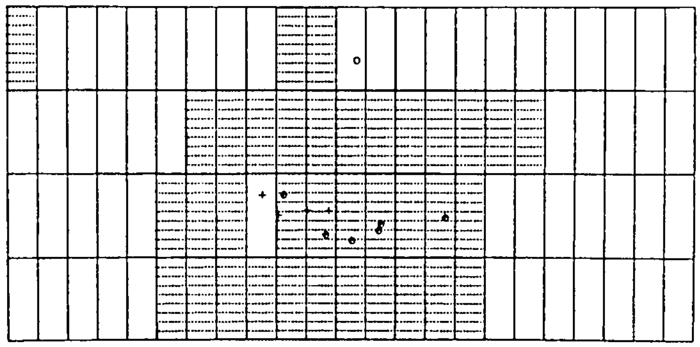



*C.3.A. Manual Sensor Scan. Grid Units—5° in AZ, 2° in EL.*



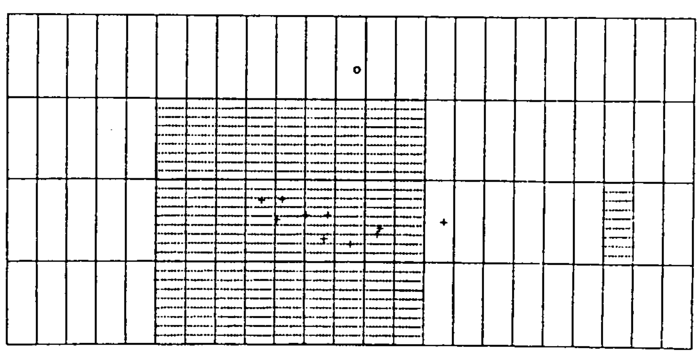

*C.3.B. Target Object Laydown.*

Vista #: 11 Heading : 295.5



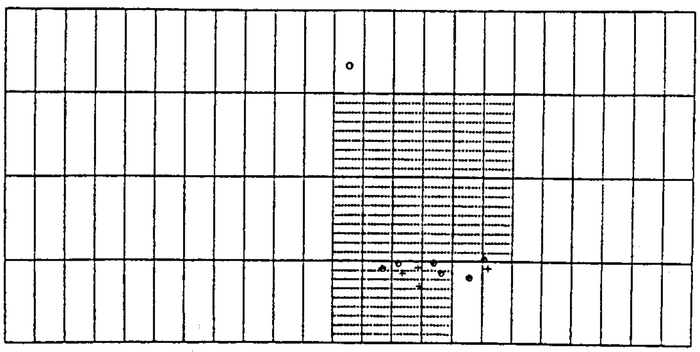
*C.4. Aided Sensor Scan. Grid Units—2° in AZ, 1.5° in EL.*

Vista #: 11 Heading : 295.5



*C.5. Aided Sensor Scan. Grid Units—2° in AZ, 1.5° in EL.*

Vista #: 3 Heading : 331.0



*C.6. Aided Sensor Scan. Grid Units—2° in AZ, 1.5° in EL.*

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(415) 604-6974

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**13. ABSTRACT *(Maximum 200 words)***

Simulation research was conducted at the Crew Station Research and Development Facility on the effectiveness and ease of use of three targeting systems. A manual system required the aviator to scan a target array area with a simulated second generation forward looking infrared (FLIR) sensor, locate and categorize targets and construct a target hand-off list. The interface between the aviator and the system was like that of an advanced scout helicopter (manual mode). Two aided systems detected and categorized targets automatically. One system used only the FLIR sensor, and the second used FLIR fused with Longbow radar. The interface for both was like that of an advanced scout helicopter aided mode. Exposure time while performing the task was reduced substantially with the aided systems, with no loss of target hand-off list accuracy. The fused sensor system showed lower time to construct the target hand-off list and a slightly lower false alarm rate then the other systems. A number of issues regarding system sensitivity and criterion, and operator interface design are discussed.

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