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DD254; DA44-188-ARO-2

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# Ground Observer Ability to Detect and Estimate the Range of Jet Aircraft Flying Over Hilly Terrain.

by

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(15) DA-44-188-ARO-2

This Consulting Report has been prepared to provide information to the requesting agency on the results of technical advisory service. It has been issued by the Director of Research of HumRRO Division No. 5 (Air Defense). It has not been reviewed by, nor does it necessarily represent the official opinion or policy of the Director, Human Resources Research Office of the Department of the Army.

HumRRO Division No. 5
(Air Defense)
Fort Bliss, Texas

(11) Aug[redacted]68

(12) 99p.

Work Unit: TESTAID

## FOREWORD

This Consulting Report presents the results of tests conducted by The Human Resources Research Office, Division No. 5 in support of Joint Task Force Two (JTF-2) of the Joint Chiefs of Staff.

JTF-2 was organized by the Joint Chiefs of Staff to conduct a series of coordinated and integrated tests to determine the capabilities and vulnerabilities of offsensive and defensive weapons systems operating in the low altitude regime. Test 3.1/3.5 Nonfiring (NF) provided discrete operational and tactical data for the evlauation of visually sighted and radar controlled air defense weapons systems against low-flying, high speed tactical and strategical aircraft.

This report is concerned with the results of that portion of Test 3.1/3.5 (NF) which was conducted in the Oklahoma/Arkansas environment of Test 4.1, Visual Target Acquisition.

The data reduction and statement analysis for this test was provided to JTF-2 by Mr. Michael Carter of Sandia Laboratories, Albuquerque, New Mexico. The support of the Human Resources Research Office (HumRRO) was provided under authority of the Department of the Army in accordance with the HumRRO prime contract, DA 44-188-ARO-2.

ROBERT D. BALDWIN
Director of Research

## SUMMARY

1. (U) Joint Task Force Two Test 3.1/3.5, Surface Based Air Defense (NF), was designed as a series of coordinated test efforts to provide operational and technical data for the evaluation of the capabilities of surface based air defense systems against attacks by low-altitude high performance aircraft.

2. (U) The Oklahoma/Arkansas portion of Test 3.1/3.5 (NF) investigated the capabilities of ground observers to detect and estimate the range to aircraft flying attack missions against prebriefed ground targets. Observer performance was obtained for three aircraft flying three programmed speeds and two programmed altitudes.

3. (U) The test environment used was the same as that for Test 4.1, Visual Target Recognition. The Test 3.1/3.5 (NF) portion of the test was conducted by Human Resources Research Office (HumRRO), Divison No. 5 (Air Defense) on a cooperative noninterference basis. Instrumentation and data on event times as well as data on aircraft position, speed, and altitude were provided from that collected for Test 4.1.

4. (U) During the conduct of the test, considerable aircraft position data were lost due to faulty instrumentation and offcourse aircraft flight paths. During the data reduction portion, additional data losses accrued due to ambiguities in observer responses and missing visibility and unmask data. As a result, the original test objectives for Test 3.1/3.5 (NF) had to be considerably modified. Final objectives were to determine:

a. the relationship between the frequency of detection and the slant range to the aircraft,

b. the relationship between the frequency of detection and the apparent size of the aircraft,

c. the relative frequency with which the aircrew visually acquired the ground target before being detected by the observers,

d. the relationship between the frequency of visual detection and the distance to the aircraft for each of the ground targets separately, and

e. the accuracy with which ground observers judge engagement ranges of 400, 800, 1,500, and 2,500 meters under conditions different from those used in training.

5. (U) Sixteen observers were used in the test. They received training in range estimation at Fort Bliss, Texas, just prior to the test. During the test, they were deployed in groups of 4 at each of the 4 ground targets chosen for Test 3.1/3.5 (NF). Observers were systematically rotated from target to target. Observers were instructed to search a 180-degree sector for each trial, with early warning of an aircraft approach being provided for some trials. Observers were assigned a range to estimate for both inbound and outbound legs of the flights. Three real time events were recorded for each observer for each trial by means of an observer response box (ORB) connected with Test 4.1 instrumentation. These events were: time at detection, time when the aircraft was at the estimated inbound range, and time when the aircraft was at the estimated outbound range. In addition to the real time events, the observer completed a posttrial questionnaire for each trial. The questions pertained to whether or not smoke was seen at the time of detection, against what kind of background the aircraft was seen, and whether or not the aircraft was seen before it was heard.

6. (U) The test data were recorded on magnetic tape by the GSIP located at each target. These data were subsequently edited to remove ambiguities and time related to Test 4.1 position data. The resulting responses were edited further, and any data not considered plausible were removed. Further data reduction consisted of preparation of analysis tapes and the providing of descriptive statistics. The analysis consisted of a review of the descriptive statistics (histograms and scatter diagrams) for the purpose of formulating initial analysis of variance (ANOVA) and analysis of covariance (ANCOVA) models. These models were processed using the weighted regression analysis program (WRAP) and multiple analysis of variance (MANOVA) statistical analysis computer programs. The resulting series of analyses revealed that the test variables were strongly confounded. This confounding and the unbalance in the design largely precluded any meaningful results other than from descriptive statistics. A further series of examination revealed the individual flight profiles as the source of the confounding.

7. (C) The average distance of the aircraft at detection for all trials was approximately 6,200 meters. A cumulative percent detection curve as a function of slant range was obtained for all trials, and these data were compared with data from two previous detection studies. Considering that the three tests were not comparable with respect to aircraft, test environment, or instructions to observers, the range of differences in detection ranges for the three studies were not considered to be unusual.

8. (C) Cumulative percent detection as a function of slant range was obtained for each of the four ground targets separately. The average slant range at detection varied over targets between 5,300 and 7,700 meters. Differences between the targets were partially explainable in terms of differences in gross terrain and unmask characteristics of the four targets.

9. (C) A measure of aircraft apparent size (ASA) was found to be correlated with cumulative percent detection. The regression equation describing this



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relationship is presented. This equation is of particular interest since it relates aircraft characteristics and slant range to cumulative percent detection.

10. (C) Data from the posttrial questionnaire showed that smoke was noticed at the time of detection of F-4C aircraft a significantly greater percentage of the time than for the F-105D and A-6A aircraft. A majority of all detections (68 percent) occurred with either cloud or sky background, and the majority of aircraft (83 percent) were seen before they were heard.

11. (C) Ground observers detected the aircraft before the pilot acquired the ground target 60 percent of the time. The percentage of time the observer detected first varied from target to target. However, these differences were partially explainable in terms of gross differences between target visibilities and gross differences between terrain and unmask characteristics of the targets. Also, there were indications that the inflight behavior of the aircraft had a significant effect on whether the observer detected first or whether the pilot acquired first.

12. (C) The range estimation data indicated that observers can estimate the range of an outbound aircraft more accurately than an inbound aircraft.

13. (C) However, the magnitude of the errors made during the test were larger than those made at the conclusion of training. It was hypothesized that the change in aircraft type and test environment probably contributed to the greater errors made during the test. Also, the lack of feedback on the accuracy of estimates during the test was believed to be a factor.

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## SECTION 1

## INTRODUCTION

1. BACKGROUND.

a. Joint Task Force Two (JTF-2) Test 3.1/3.5 Nonfiring (NF), Surface Based Air Defense, was the third in a series of coordinated and integrated tests designed to obtain factual operational and technical data on low altitude offensive and defensive weapons system operation.

b. Tests 3.1 and 3.5 were combined tests. Test 3.1 was a test of the vulnerability of US aircraft flying at low altitude and high speed aircraft against Communist gun type weapons. Test 3.5 was a test of the effectiveness of US gun type weapons against low altitude, high speed Communist aircraft. Test 3.1/3.5 was originally planned to be conducted in two phases, a nonfiring and a firing phase. The disestablishment of JTF-2 has precluded the firing stage from being conducted.

c. The major portion of the test was conducted for JTF-2 by the US Army Combat Developments Command Experimentation Center (CDCEC), Fort Ord, California.

d. During the planning of the nonfiring (NF) phase of Test 3.1/3.5, Joint Task Force Two (JTF-2) recognized that data concerning the ability of ground observers to detect and estimate the range of low-flying high performance aircraft could be obtained using the aircraft and instrumentation established for JTF-2 Test 4.1, Visual Target Acquisition. This additional data would augment that obtained by JTF-2 during Test 3.1/3.5 (NF) which was conducted at Hunter Liggett Military Reservation (HLMR), a subpost of Fort Ord, California.

e. JTF-2 Test 4.1 was an air-to-ground visual target acquisition test conducted in the Oklahoma/Arkansas area in the general vicinity of Mena, Arkansas. One of the objectives of Test 4.1 was to determine the abilities of representative aircrews to visually acquire prebriefed ground installations consisting of simulated military targets such as surface-to-air missile and radar sites, landing strips, logistics supply points, and bridges. It was concluded that this air-to-ground target acquisition test would provide an environment for obtaining ground-to-air observations, such as visual detection and distance estimation judgments.

f. Test 4.1 was conducted under conditions that offered a unique environment for obtaining ground-to-air visual observation data and would supplement the very large amount of observer data obtained at HLMR.

(1) Although the aircrews participating in Test 4.1 received normal premission briefings concerning the location of the ground targets, each aircrew would participate in only one flight over each target. Consequently, it was expected that the crews would exhibit variability in their navigational and target acquisition ability. This variability in the performance of the aircrews would increase the uncertainty of the ground observers concerning the time of arrival at the target and the direction of "attack" by the aircraft. These conditions of uncertainty concerning the aircrafts' time of arrival and direction would be more representative of tactical ground-to-air defense than if the aircraft always flew the same flight path to each target.

(2) One measure of aircrew performance of interest to Test 4.1 was the time and distance at which the aircrew visually acquired the ground target. Since this pilot acquire event was recorded for each trial during Test 4.1, this event would be compared with the ground observer detection time and distance events to obtain data relevant to the following questions:

(a) Does the air defense gunner tend to detect the attacking aircraft before the aircraft locates the defended point?

(b) When the pilot acquires the target first, how much time elapses before the air defense gunner detects the aircraft?

(3) The instrumentation provided for Test 4.1 included distance measuring equipment (DME) for accurately locating the position of the aircraft; a radar line-of-sight system between aircraft and each ground target for determining the time at which the unmask and remask events occurred, and visibility recording equipment at each target site. The DME and electronic unmask instrumentation provided accurate data concerning the slant distance to the aircraft from the target when the visual detections occurred and permitted computation of unmask-to-detection time delays. Measurement (computation) of the unmask-to-detection time delay was a potentially important performance measures that could be used to evaluate the effects on visual detection of controlled (independent) test factors, such as variation in predetection altitude, aircraft speed, and the accuracy of the early warning provided to the ground observers.

2. PREVIOUS TESTS.

a. Visual Detection. A number of tests have been conducted in desert terrain concerning human ability to detect low-flying aircraft under various simulated tactical conditions.

(1) Tests conducted at Gila Bend, Arizona, by the US Army Human Engineering Laboratories (see reference 1) varied the size of the sector to be searched, but provided no temporal early warning (no information concerning probable time-on-target and time of arrival). When the search sector was 45 degrees, the mean distance of jet aircraft (T-33, F-86, and F-100) at detection was 2,750 meters. When the search sector was 90 degrees and 360 degrees, the average distances were approximately 2,585 and 1,985 meters, respectively.

(2) Tests with T-33 and F-100 aircraft conducted by White Sands Missile Range (WSMR), New Mexico (see reference 2), used 30-degree and 180-degree sectors and varied temporal early warning from less than 15 minutes to more than 90 minutes. The mean detection range of F-100 aircraft, for example, averaged over all search and early warning conditions was approximately 4,400 yards. However, detection range appeared to be influenced by aircraft heading angle, altitude, and speed as well as other factors. The affect of the lengthy alert intervals on detection range could not be evaluated.

(3) Tests were conducted by The Human Resources Research Office (HumRRO) in April 1965, using the same terrain used earlier for the WSMR tests. The HumRRO tests compared unaided versus binocular-aided detections using a 30-degree search sector and 1 to 5 minutes of early warning. Under these conditions, the average range at which jet aircraft (F-4C, F-100, and T-33) were detected was approximately 10,000 meters, when averaged over all viewing systems and observer offsets. The increase in detection range, as compared to earlier tests, was attributed to the increased accuracy of the early warning information provided the observers concerning the heading and expected time of arrival of the aircraft. When averaged over all aircraft, the optical aids did not reliably increase detection range.

(4) Tests were also conducted by HumRRO in June 1965, in conjunction with the JTF-2 Test 1.0, Minimum Terrain Clearance, at Tonopah, Nevada. Either 1 or 5 minutes of early warning was used, and the exact heading of the aircraft at the time of unmask was known. Both near and far terrain masking existed, and unaided and binocular-aided detection data were obtained. The mean detection range for F-4C and F-105D aircraft, averaged over all viewing conditions for the far terrain masking condition, exceeded 12,000 meters. Detection range was not increased by using either 6 x 30 or 7 x 50 binoculars, nor did the difference between 1 versus 5 minutes of temporal early warning have a reliable influence on detection range.

(5) In summary, the previous visual detection tests had been conducted under good visibility conditions in desert terrain. Most tests have occurred under far terrain masking conditions. The studies collectively indicated that increasing the precision of early warning information markedly increased detection range, and that detection range was influenced by aircraft altitude, aspect angle, size, and speed. However, the extent to which detection ranges experienced in the desert can be generalized to other terrain and meteorological conditions is not known. In addition, tests of the effect of aircraft size (type), speed, and near terrain masking on detection were needed.

b. Range Estimation. Very little test information exists concerning man's ability to judge when high speed aircraft are within the effective range of air defense weapons. In 1966, HumRRO conducted several studies comparing different methods of training gunners to estimate engagement distances of 400, 800, 1,500, and 2,500 meters, the approximate open and cease fire ranges of various forward area air defense weapons. Although the training did reduce gross judgmental errors and reduced the variability of judgments among observers, all training and testing had been done in desert terrain. As a result, the affect on ground-to-air distance judgment of different aircraft backgrounds, different types of terrain, and aircraft size were not known. It was also not known how well the estimation skills developed during the desert training would transfer to other type of terrain and aircraft.

## 3. TEST OBJECTIVES.

a. As originally conceived, the tests of visual detection and range estimation to be conducted in the Oklahoma/Arkansas portion of Test 3.1/3.5 (NF) were designed to evaluate the effects of specific independent test factors, such as the scheduled variation in aircraft altitudes, speed and type, the accuracy of the early warning (EW) information which would be provided the observers, the time and distance at which the aircraft was unmasked from the near terrain or horizon, and the ambient visibility and illumination conditions.

b. The tests that were designed to evaluate these factors of interest to Test 3.1/3.5 (NF) were based on the following assumptions concerning the results of Test 4.1.

(1) The time and distance at which each aircraft flight became unmasked to each ground target would be available for use in computing the fundamental unmask-to-detection performance measures and for use as a covariable in the evaluation of the effects of the test factors on the performance measures.

(2) Valid visibility measurements would be provided for each trial (defined as the flight of an aircraft over the target area). Variation in the visibility measurements from trial-to-trial would be used as a covariable in the evaluation of other test factors. Visibility variation also would be examined for its effect on the visual observations.

(3) The variation that would exist among the aircrews in their ability to navigate to each ground target would be equated for each combination of test variables, such as the three aircraft speeds or the two programmed flight altitudes. This assumption was critical because of technical requirements of the planned statistical analysis.

4. TREATMENT OF TEST OBJECTIVES.

a. The original objectives established for the Oklahoma/Arkansas portion of Test 3.1/3.5 (NF) were not achieved due to problems associated with the instrumentation used for measuring the aircraft unmask and visibility conditions, loss of ground observer event data, and large variations in the altitudes and flight paths of the aircraft. The extent and magnitude of these problems was not ascertained until after the data collection portion had been completed.

b. During the data reduction portion of the Test 4.1, it was found that there were a considerable number of unaccountable irregularities in the unmask time and distance events which were based on radar sensings between the aircraft and the ground target. As a result, it was concluded that the radar unmask data could not be used in evaluating the results of either Test 4.1 or Test 3.1/3.5 (NF) because the time at which the aircraft became unmasked at the target was a significant factor in the design of the air-to-ground target acquisition tests, terrain surveys were made and topographical map studies were conducted after data collection was completed. These surveys resulted in the preparation of a mask profile for each trial which displayed the aircraft's altitude in relation to the computed masking due to horizon and local masking features. Because the exact range at which an aircraft became unmasked for each trial could not be determined with any reasonable assurance from the profiles, the computed unmask ranges associated with each ground target were used qualitatively in evaluating the field test results presented in this report.

c. The accuracy of the visibility measurements made during each trial was similarly questioned by Test 4.1. It was concluded that these measures would not be used in any precise or quantitative analysis of the field test results reported here.

d. The nonavailability of reliable measurement of the unmask events and visibility conditions made it necessary to limit the test objectives. After extensive inspection of the test event data and the aircraft flight profiles, it was concluded that valid data was available for evaluating the following test objectives.

(1) Determine the relationship between the frequency of visual detection and the slant range of the aircraft summed over all observing conditions.

(2) Determine the relationship between the frequency of visual detection and the apparent size of the aircraft summed over all observing conditions.

(3) Determine the relative frequency with which the aircrew visually acquired the ground target before the aircraft was detected by the observer.

(4) Determine the relative frequency with which the ground observer detected the aircraft before the aircrew visually acquired the ground target.

(5) Describe the relationship between the frequency of visual detection and the distance to the aircraft for each ground target separately.

(6) Determine the accuracy with which ground observers judge engagement distances of 400, 800, 1,500, and 2,500 meters under conditions different from those used during training.

SECTION 2

CONDUCT OF THE TEST

1. FIELD TEST OPERATIONS.

a. The field test was conducted in a rectangular section of Oklahoma/Arkansas approximately 60 NM by 40 NM centered on Mena, Arkansas. The test area consisted of rolling terrain that provided natural surface undulations suitable for aircraft in flight to mask themselves from visual and electromagnetic line-of-sight and also to provide visual masking of certain target locations. It was made up of forests, meadows, rural roads, and cultural features representative of small to medium population communities in the temperate zone worldwide.

b. The flight courses to the targets were arranged to cross ridge lines nearly perpendicular to the final reference point (FRP) to target line to provide definite unmask events for each target. Each aircrew was oriented to the geographical location of the FRP for each target and had the task of visually acquiring each prebriefed target.

c. The aircraft used for the 3.1/3.5 portion of the test included the F-4C, A-6, and F-105D. These aircraft flew over the target area at the speeds and altitudes shown in Table 2-1. A more detailed description of the test area and aircraft courses is presented in Report JTF2-4.1, Volume 2, "Low Altitude Test 4.1, Visual Target Acquisition, Field Test Description," dated October 1967.

2. OBSERVERS. Sixteen male enlisted personnel, eight US Army and eight US Marine Corps, were assigned as observers. The Army personnel were selected by their commanders and came from units stationed at Fort Polk,

Fort Sill, and Fort Hood. The Marines were selected by a team composed of one JTF-2 representative and one Human Resources Research Office (HumRRO) representative. The Marines were from the 3d Light AA Missile Battalion, Cherry Point, North Carolina. All observers had 20/20 vision, corrected if necessary, and ranged in age from 18 to 24 years. The average General Testing (GT) aptitude score was 111 and ranged from 83 to 130.

a. Observer Training. The 16 observers, plus noncomissioned officers (NCO), were trained in the operation of test instrumentation equipment and the estimation of range to aircraft. This training was provided by HumRRO personnel at Fort Bliss, Texas, approximately one week before the field tests began. An F-100 was used as the target aircraft for the range estimation training. The aircraft flew 36 passes each of two days. Equal numbers of passes were flown at 250 and 750 feet altitude, and the passes were equally divided between overhead flights and 200 meters offset. For one-half of the passes, the aircraft's heading was north; for the remainder, the heading was south. The objective of the training was to have each observer accurately estimate when the aircraft was at 400, 800, 1500, and 2500 meters from the observer's position on both the inbound and outbound portions of the pass. A more detailed description of the training method is contained in Appendix B.

3. TEST SITES.

a. The observer groups were located at four of the Test 4.1 ground targets. The targets used were identified as West 1 (W1), West 4 (W4), East 3 (E3), and East 4 (E4), located respectively at Cherry Hill, Arkansas; Plunketsville, Oklahoma; Gravelly and Washita Bridge, Arkansas. Aerial photographs of the targets are contained in Report JTF2-4.1, Volume 2, Field Test Description, dated October 1967.

b. These targets were selected prior to the test by a team comprised of Sandia Laboratory and HumRRO personnel to provide unmask distances to ground targets from 3 to 15 miles. (See Appendix C for the observer locations at each target.)

4. GROUND SITE INSTRUMENTATION PACKAGE (GSIP).

a. General Description.

(1) Each test site was equipped with a GSIP provided in support of JTF-2 Test 4.1. The GSIP telemetered the following information to recorders in orbiting C-130 aircraft: Unmask and remask time of the test aircraft, the visibility and illumination measurements, and the occurrence of 4 real time events and 10 nonreal time questions from each of the 4 observer response boxes (ORB) at each site. A complete description of the instrumentation is contained in JTF2-4.1, Volume 2, Field Test Description.

(2) Since the distance measuring equipment (DME) had a predicted measurement of ± 50 feet, the ground observers were located at specified points within a circular area having a 100-foot diameter, centered at the GSIP box. The actual observer locations depended upon site characteristics. Figure 2-1 is an example showing the arrangement of observer positions for Target E3. Each observer position was marked with a stake; and the observers were geographically oriented to a 180-degree search sector containing the expected flight paths of the aircraft. All observers at a test site were oriented to the same 180-degree search sector.

b. Unmask Time. Unmask and remask time of the aircraft was to be measured by means of L-band continuous wave transmission from the test aircraft to a receiver at the GSIP.

c. Aircraft Position. The location of the aircraft with reference to the ground at any instant was determined by means of DME carried on board orbiting C-130 instrumentation aircraft. The C-130s received DME slant range data from the test aircraft. This data, when combined with

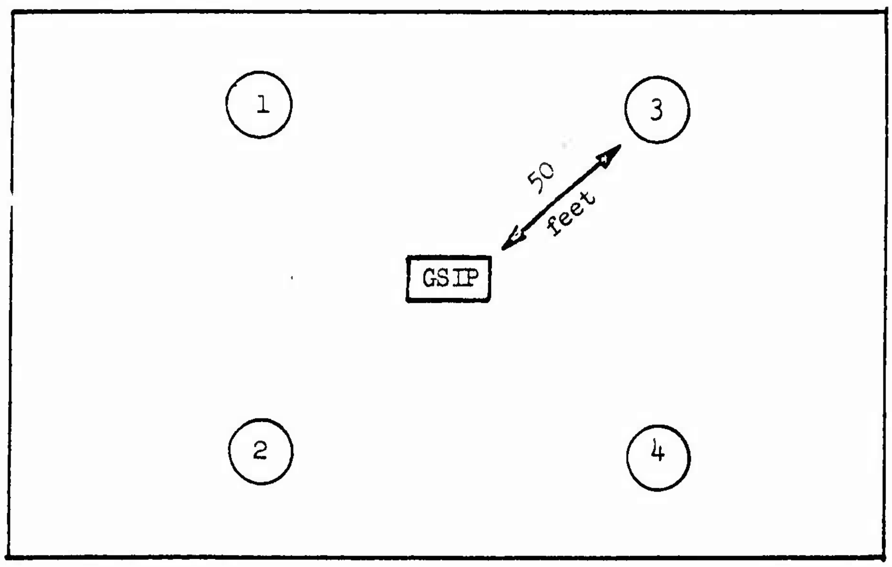


Figure 2-1 Observer Positions: Target E3

the DME information concerning the position of the C-130 aircraft, permitted computation of the ground location and altitude of the test aircraft.

d. Timing. All event timing was recorded in inter-range instrumentation group (IRIG-B) format.

e. Visibility and Illumination. For Test 4.1, each site was equipped with instrumentation to measure the sky/ground ratio, total illumination, and atmospheric transmissivity (scattering). This equipment consisted of an illuminometer for measuring sky illumination and shadow, photometers for measuring the sky/ground illumination ratio in the direction of flight, and a telephotometer for measuring atmospheric scattering.

f. Observer Response Boxes (ORB). Four ORB were connected by cable to the GSIP at each test site. The ORB consisted of two units; a real time event unit worn by the observer and a nonreal time question box placed on the ground at each observer position.

(1) The real time section of the ORB was operated in the following manner:

(a) At the time the observer saw the aircraft, he depressed the "Detect" button located at the top of the ORB.

(b) When the observer believed the aircraft was at the specified incoming range, he depressed the middle, or "Inrange," button.

(c) When the observer believed the aircraft was at the specified outgoing distance, he depressed the "Outrange" button.

(d) A shielded spring-loaded error switch was located on the side of the real time section of the CRB. This switch was used by the observer to record any accidental button pushes.

(2) The nonreal time section of the CRB permitted entering the following coded information:

(a) observer identification,

(b) incoming range specified for each observer each day,

(c) outgoing range specified for each observer each day,

(d) early warning condition for each flyover (or trial) (Yes or No),

(e) aircraft exhaust smoke was noticed at the time of detection (Yes or No),

(f) background of aircraft at time of detection (clear sky, clouds, or terrain), and

(g) aircraft was heard before it was seen (Yes or No).

5. DAILY SEQUENCE OF TEST PROCEDURES.

a. Rotation of Targets. The 16 men were divided at random into 4 observer groups, A, B, C, and D, containing 2 men from each service. The composition of the groups remained constant throughout the duration of the test to facilitate cycling observer groups to test sites in the event of aircraft aborts, inclement weather, or other reasons. The groups were systematically rotated to all 4 test sites during the first 4 test days. During the remaining 15 test days, the groups were selectively assigned to specific sites to provide maximum utilization of the Test 4.1 flights.

b. Test Monitors. There was one HumRRO monitor located at each test site. Monitors were rotated periodically between sites and had the following duties:

(1) they supervised the movement of observers to the test sites,

(2) monitors gave observers the instructions for the day and the ranges that they were to estimate,

(3) monitors checked each ORB to insure proper connection with the GSIP box and to insure the correct observer code had been put into the ORB,

(4) the monitor, stationed near the communication equipment, monitored all messages from Test 4.1 Control and relayed appropriate information to the observers, such as early warning time, and aircraft aborts, and

(5) the monitors recorded the time, course, test site number and aircraft type for each trial during a test day. All deviations or changes in the prescribed test procedure were recorded, as well as known reasons for missing data.

c. Procedures Prior to the First Trial. Immediately upon arriving at the test site, the group monitor called Test Control and reported that his group was at their site. The group monitor gave the test instructions to each observer, which included the incoming and outgoing distances that were to be estimated by each observer. Each observer at each site had 1 of 16 combinations of incoming and outgoing distances each day. The same distances were estimated for all trials during the day for which complete early warning was given by Test 3.1/3.5 (NF) Control. Except for the no early warning trials, the group monitor announced the time the first trial was to begin. Each observer moved to his position and became familiar with the sector he was to search on the first trial.

d. Procedure During the No Early Warning Trials. The observers were instructed that on certain trials they would not be informed of the exact time that the aircraft would appear. They were instructed to search a sector of 180 degrees. Anytime the observer initially detected the aircraft visually, he was instructed to immediately depress the "Detect" button, even if the aircraft had passed his site. As soon as the aircraft had been visually detected, the observer answered the posttrial questions. There was no range estimation to be accomplished on the no early warning trials.

e. Procedure for Complete Early Warning Trials.

(1) When complete early warning was provided, the observer knew within approximately $\pm$ 20 degrees the expected approach of the aircraft and the approximate time of arrival, accurate within 1 to 2 minutes. The observers soon learned that most aircraft approached each test site from approximately the same azimuth. In fact, some observers reported that they knew the direction after they saw one trial over each test site.

(2) Test 4.1 Control transmitted information to the test sites concerning the aircraft's time of arrival at designated check points. This information was used by each monitor to determine the probable time of arrival of the aircraft at the test site. This early warning information was relayed to the observers.

(3) On all trials, when complete early warning was given, the observers also made two estimates of range, one incoming and one outgoing. After the aircraft had been detected, the observers continued to watch the aircraft. When the observer believed the incoming aircraft was at the assigned range from him, he was to depress the "Inrange" button on his response box. He was to continue to watch the aircraft as it passed over his position and as it was outbound. When he believed the outgoing aircraft was at the assigned range, he was to depress the "Outrange" button on his response box. The trial was over when he made the outgoing range estimation. The observers then answered the posttrial questions.

| Aircraft | Assigned | |
|---|---|---|
| | Speed (knots) | Altitudes (feet) |
| F-4C | 550 | 500-900<br>0-400 |
| | 420 | 500-900<br>0-400 |
| | 360 | 0-400 |
| A-6A | 360 | 500-900<br>0-400 |
| F-105D | 420 | 400-900 |

Table 2-1 Aircraft Assigned Speeds and Altitudes

SECTION 3

## DATA PROCESSING AND ANALYSIS

1. GENERAL. The data processing consisted of reducing and editing the Test 3.1/3.5 (NF) Oklahoma/Arkansas event data, time relating this event data with applicable Test 4.1 aircraft position data, and creating a data bank for use in the analysis effort.

2. QUALITY CONTROL OPERATIONS.

a. The event data were recorded on magnetic tape in the C-130 aircraft. These tapes were delivered to Sandia Laboratory, where they were processed through a playback station and formated for the CDC-3400 computer. The event data were processed by a program called QUICKORB, which provided preliminary information which was transmitted to the Mena Test Range concerning the availability of event data from completed trials.

b. The data event tapes were edited manually to remove invalid trials and individual observations.

(1) Allevent data associated with a trial (that is, the flight of an aircraft near a ground target) were deleted if either the aircraft was grossly off-course, or it penetrated the target area outside the assigned 180-degree search sector, or no aircraft position data were available.

(2) An individual observation was deleted if the event occurred out of sequence or at an improper time during a trial: For example, if

a detect event was recorded for an observer after he made an inrange estimate, the detect event was discarded.

3. DATA REDUCTION.

a. The ground observer event data were time-related to Test 4.1 aircraft position data by use of computer programs. At this time, the performance measures were computed, as were the values of the independent variables to be used in subsequent statistical analyses.

b. The independent variables calculated for each event included such factors as the aircraft slant range (SR), the sun angle (SA), and aircraft angular velocity.

c. The performance measures included detection distance, algebraic range estimation errors, and the pilot acquire minus observer detection time interval.

4. ANALYSIS PLAN. This section describes the general approach used for statistical analyses of the data. A more detailed discussion of the analysis approach and methods is presented in Appendix D.

a. Descriptive statistics included histograms and cumulative frequency plots which presented the frequency of occurrence of the specific values of the performance measures and independent variables; and scatter diagrams (SCD), which graphically presented the concurrent frequency distributions of two measures, such as the concurrent (or x, y) distributions of detection range and aircraft angular velocity. Also computed for each variable were the mean, median, standard deviation and maximum and minimum values used.

b. Analysis of variance (ANOVA), analysis of covariance (ANCOVA), and regression analysis (RA) methods were subsequently used to evaluate the statistical reliability of the data and the strength of the dependency relationships among the independent variables and the performance measures. A technical discussion of the scope of these analyses also appears in Appendix D.

5. EFFECT OF DATA REDUCTION ON THE ANALYSIS PLAN.

a. As discussed in Section 1, a number of problems with Test 4.1 instrumentation became evident during the data reduction phase of that test. Data losses, absence of unmask and visibility data, and the aircrews' frequent failure to fly assigned altitudes and speeds made it necessary to alter the original analysis plan.

b. Following the data reduction phase, it was known that the numbers of observations actually obtained for each combination of independent variables were very unbalanced. Table 3-1 presents the detection data matrix that was available following the data reduction phase for each combination of observer, ground target, aircraft, and early warning level. The total lack of observations in many of the cells of Table 3-1 indicates the extent of the unbalance.

c. Although valid analysis procedures were performed on the data, the results were uninterpretable. The inability to interpret the results of the ANOVA and RA was primarily attributed to the trial-to-trial variation in the aircrafts' flight paths, speeds, and altitudes. These sources of unequal variation were confounded with the lack of balance in the number of observations obtained for each cell of the data matrix.

d. If unmask and visibility measures had been available, the trial-to-trial variation in detection ranges as a function of the aircrafts'

| Target | Aircraft | Warning Condition | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E4 | A-6A | W | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| | | N | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | F-105D | W | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | | N | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | F-4C | W | 5 | 6 | 5 | 6 | 3 | 4 | 3 | 3 | 2 | 2 | 2 | 3 | 4 | 3 | 4 | 5 |
| | | N | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 0 |
| E-3 | A-6A | W | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | N | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | F-105D | W | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| | | N | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | F-4C | W | 3 | 4 | 5 | 4 | 5 | 4 | 4 | 3 | 5 | 4 | 5 | 4 | 6 | 5 | 5 | 5 |
| | | N | 5 | 5 | 4 | 5 | 1 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| W4 | A-6A | W | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 3 | 0 | 0 | 0 | 0 |
| | | N | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| | F-105D | W | 2 | 2 | 2 | 2 | 1 | 1 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | | N | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | F-4C | W | 7 | 8 | 8 | 9 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 5 | 2 | 3 | 3 | 3 |
| | | N | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 5 | 5 | 5 | 5 | 3 | 3 | 4 | 2 |
| W1 | A-6A | W | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 3 |
| | | N | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| | F-105D | W | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| | | N | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | F-4C | W | 5 | 5 | 6 | 6 | 8 | 10 | 8 | 10 | 9 | 9 | 9 | 9 | 5 | 5 | 5 | 5 |
| | | N | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 4 | 3 | 4 | 3 | 3 | 3 | 3 | 3 |

N = No Early Warning
W = Early Warning

Table 3-1 Detection Event Data Matrix Showing Number of Observations Obtained flight characteristics could have been adjusted by statistical correlation techniques. In the absence of unmask data, the variations in detection range could not be meaningfully attributed to any of the independent variables. Similar confounding of uncontrolled variables with test variables affected the analyses of the distance estimation errors. The net result was a decision to limit the analyses to the gross descriptive statistics for each of the performance measures.

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## SECTION 4

## RESULTS AND DISCUSSION

1. (U) INTRODUCTION. This section presents the results and discussion of the data pertaining to aircraft detection, the posttrial questionnaire, $\Delta_t$ (time differences between aircrew acquisition and observer detection), and range estimation. The major emphasis in the presentations is on descriptive statistics. Results of the more sophisticated analyses are not presented for the reasons already cited in Section 3.

2. (C) DETECTION.

a. The functional relationship between cumulative percent detection and aircraft slant range was determined for the 678 observations available in the data bank. These data indicate that the aircraft were detected 50 percent of the time before they were approximately 5000 meters from the ground target. Ninety percent of the detections occurred at a range of 2000 meters or greater, and ten percent of the aircraft were detected at 12,500 meters or greater. The relationship between cumulative percent detection and slant range is presented in Figure 4-1 and may be approximated by $C_p = 3.639 - .37098 \text{ Ln } R$, where $C_p$ = cumulative percent detection, and R = slant range in meters.

b. Figure 4-1 presents a comparison of the overall detection performance obtained in the Oklahoma/Arkansas Test and the results of previous detection tests reported by the Human Engineering Laboratories (see reference 1) and HumRRO (see reference 5) which were conducted in a desert environment. The HumRRO test used a search sector of less than 30 degrees, and temporal early warning was provided within 5 minutes of the trial. The Human Engineering Laboratories' (HEL) test used search sectors up to 360 degrees

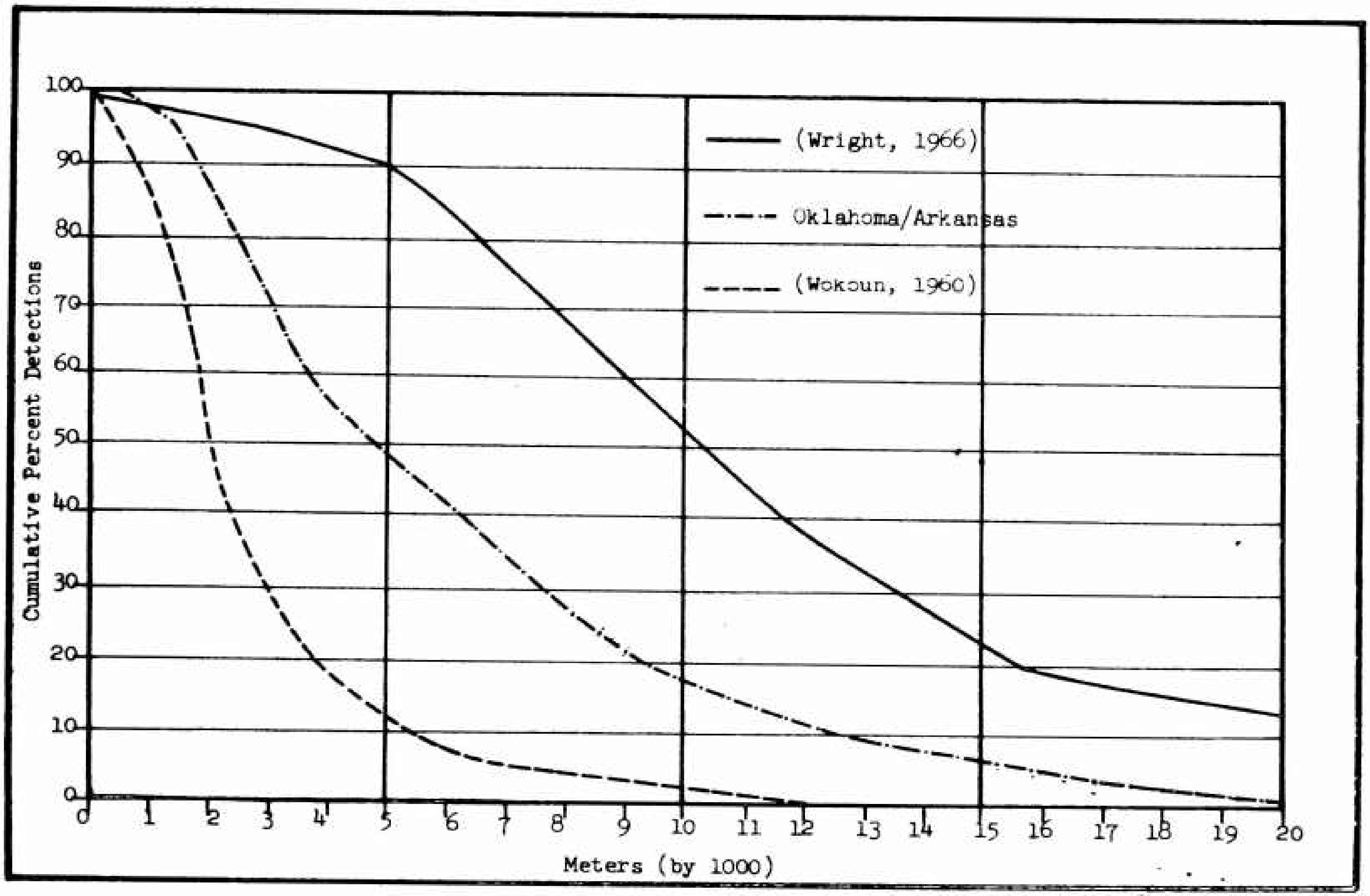


Figure 4-1 Percent Detection Compared with Prior Field Studies. (U)

and no temporal early warning. The Test 3.1/3.5 (NF) Oklahoma/Arkansas detection data is contained within the envelope described by these earlier tests. Further comparisons are tenuous since different aircraft are represented in the three tests. The HumRRO test used F-4, F-100, and T-33 aircraft. The HEL test used F-100, T-33, and F-86 aircraft. The different results obtained in the three tests may be, in part, due to differences in terrain environment, search sector used, early warning conditions and aircraft characteristics. The HumRRO test may represent the ideal field detection situation because of the narrow search sector, imminent early warning, desert visibility and unobstructed terrain used. The HEL test may represent the worst case detection situation where excellent terrain and meteorological conditions are employed because of the large search sectors used and lack of temporal early warning. The Test 3.1/3.5 (NF) detection data represent a more typical field detection situation where warned observers are deployed at tactical ground targets, and the terrain and meteorological environments were representative of tactical conditions.

c. Percent detection as a function of slant range does not reflect aircraft characteristics. A measure of detection performance which reflects variation in aircraft size and heading is the aircraft subtended angle (ASA). ASA is the angle subtended by the diameter of a circle having an area equal to that presented by an aircraft at a specified slant range from the observer.

d. Cumulative percent detections is correlated .965 with ASA. This relationship can be used to predict the probability of detection given an aircraft slant range. The equation describing this relationship is: $C_p = 2.717 + .316 \text{ Ln ASA}$, where $C_p$ = cumulative probability of detection, and ASA = aircraft subtended angle in radians. ASA may be approximated as

$$\text{ASA} = 2 \times \tan^{-1} \frac{\sqrt{\frac{\text{target area}}{\pi}}}{R}$$

e. The area presented by the target used in the ASA equation may be approximated* as Target Area = $\frac{A_S \times R_0 + A_B \times H + A_F \sqrt{R^2 - R_0^2 - H^2}}{R}$, where $A_S$ = aircraft side area, $A_B$ = aircraft bottom area, $A_F$ = aircraft frontal area, $R_0$ = flight path offset from observer, H = aircraft altitude, and R = aircraft slant range of interest.

f. Figure 4-2 presents the cumulative percent detection as a function of aircraft slant range for each of the four ground targets used in the test. A quantitative description of the target sites is not available; however, ground survey data was available which described the computed masking conditions at the target sites. Figure 4-3 presents the computed unmask profiles for each site. These profiles indicate the altitude at which an aircraft had to fly in order to be visually unmasked for each ground target as a function of ground range. These profiles assume that the aircraft flew on course, that slant range and ground range were equivalent, and that no near mask such as trees obscured the observer's vision.

g. Inspection of these profiles indicated that targets W1 and W4 had very similar unmask profiles. As might be expected under this circumstance, the cumulative percent detection plots for targets W1 and W4 are very similar. The cumulative detection functions for targets E3 and E4 appear quite different both from each other and from targets W1 and W4. On target E3, the abrupt change in mask altitude at a ground range of 6500 meters (Figure 4-3) represents a ridge line. Inspection of topological maps indicated that beyond this ridge line, aircraft could fly below the mask altitude and would be visually masked. It may be inferred from the cumulative percent detections (Figure 4-2) at target E3 that the aircraft were, in fact, rarely available for visual detection prior to crossing the ridge line.

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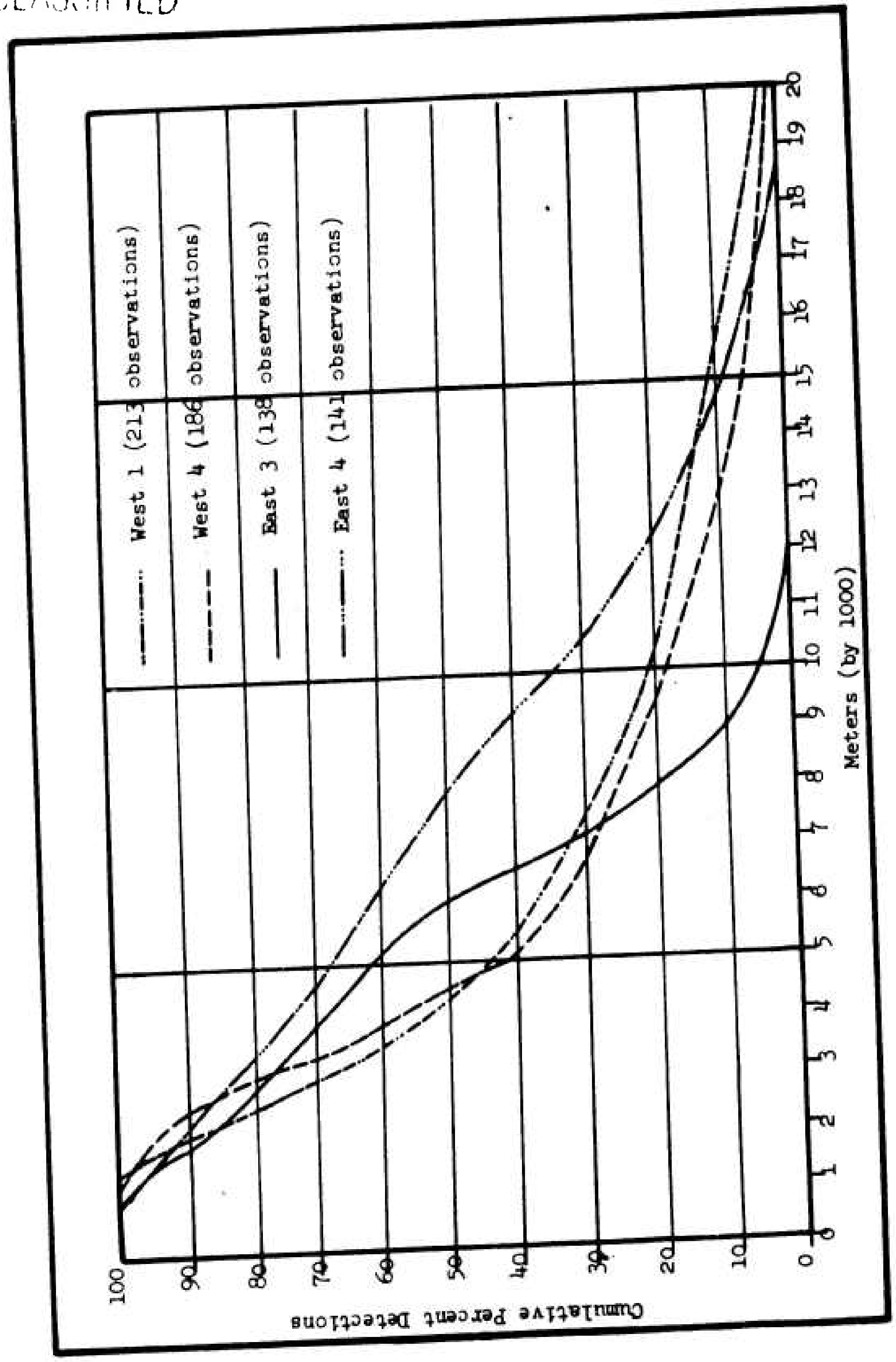


Figure 4-2 Cumulative Percent Detection by Ground Target Site (U)



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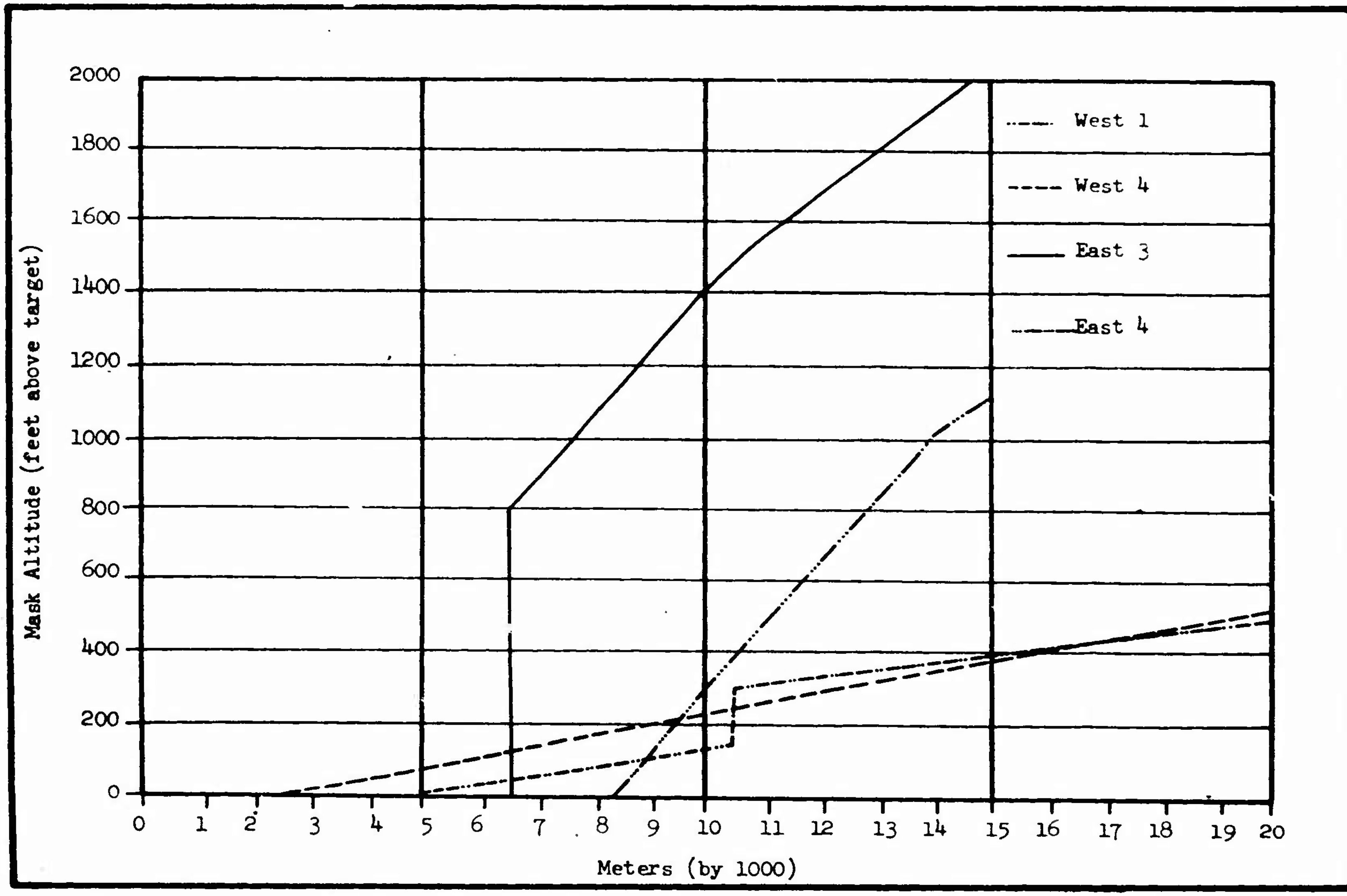


Figure 4-3 Computed Unmask Profiles for Each Ground Target (U)

h. The increase in masking altitude at target E4 apparently was due to a gradual rise in the terrain height. Inspection of topological maps indicated that aircraft flying the briefed course would not fly below the mask altitude at this target. The cumulative percent detections for this ground target reflect the influence of this terrain characteristics in that the largest proportion of detections in the 5,000 to 15,000 meter range occurred at this target.

3. (C) POSTTRIAL QUESTIONS:

a. Scope. After each trial, the ground observers were required to answer a series of questions concerning aircraft and trial conditions. Three questions of potential significance for detection concerned the aircraft's background at the time it was detected, whether or not the exhaust smoke was seen rather than the aircraft itself, and was it heard before it was seen.

b. Questionnaire Results. Table 4-1 presents the frequency with which the observers reported detecting the exhaust smoke and the reported background of each type of aircraft at the time of detection.

c. Aircraft Background. For 58 percent of the observations (439 of 749) the aircraft were reported to be against a cloudy background when detected. In 32 percent (238 of 749) of the cases, the aircraft were reported as viewed against a terrain background. In the remainder of the observations the observers reported that the aircraft were against a clear sky background.

d. Smoke.

(1) The relative frequency with which the observers reported detecting the aircraft because of exhaust smoke was largest (70 percent)

| Aircraft Type | No. of Trials | Smoke Question | Cloud | Clear | Terrain | Total |
|---|---|---|---|---|---|---|
| F-4C | 523 | Smoke | 208 | 127 | 30 | 365 |
| | | No Smoke | 94 | 49 | 15 | 158 |
| A-6A | 160 | Smoke | 49 | 14 | 5 | 68 |
| | | No Smoke | 54 | 17 | 21 | 92 |
| F-105D | 66 | Smoke | 11 | 20 | -- | 31 |
| | | No Smoke | 23 | 11 | 1 | 35 |
| | | Totals | 439 | 238 | 72 | 749 |

Table 4-1 Responses to Aircraft Background and Smoke Questions (U)

for the F-4C and smallest for the A-6A (35 percent). The percentages of F-105 detections reported for smoke and no smoke were approximately equal.

(3) ANOVA. A nonparametric analysis of variance (Friedman Two-Way ANOVA) revealed a statistically reliable ($p < .01$) difference among aircraft. The relative frequency of reporting exhaust smoke detection of the F-4C was reliably greater than for the F-105D and A-6A; however, the latter two aircraft did not differ reliably in this respect.

e. Visual Versus Auditory Detection. When averaged over all trials, aircraft were reported to have been heard before being visually detected for only 17 percent of the trials. There were not sufficient data to evaluate differences among aircraft or the individual targets.

4. (C) TIME BETWEEN PILOT ACQUISITION AND OBSERVER DETECTION.

a. Introduction.

(1) One of the performance measures selected for the Oklahoma/Arkansas portion of Test 3.1/3.9 (MF) was the difference between the time the aircrew visually acquired the ground target and the time the ground observer visually detected the aircraft. This difference, $\Delta_t$, was computed in hundreths of a second for each observer detect event for each target aircraft encounter. The quantity $\Delta_t$ is positive for those events in which the observer detected the aircraft first, and negative for those events in which the aircrew acquired the target first.

(2) There is a presumed advantage in locating the enemy first. If the ground observer detects the aircraft first, the defenses can be made ready, and it may be possible to launch an attack before the aircraft has opportunity to take evasive action. On the other hand, if the aircrew acquires the ground target before the ground observer detects the aircraft,

the aircraft has the advantage in that evasive action can be taken, and preparations can be made for the type of ground defenses expected. For these reasons, information on who detects first, and by how long a time, was considered important.

b. Performance Over All Trials. Figure 4-4 is a histogram showing the distribution of $\Delta_t$ across all trials. The overall range of $\Delta_t$ is quite large, ranging from - 79.45 seconds to + 79.45 seconds. The mean of + 6.51 seconds indicates that, on the average, the observer detected before the aircrew acquired. Approximately 28 percent of the $\Delta_t$ are within the range of $\pm$ 5 seconds.

c. Differences Among Targets.

(1) Table 4-2 presents the mean acquisition and detecting ranges and $\Delta_t$ data for each of the ground targets. The differences obtained between the targets are not difficult to explain in terms of gross characteristics of the targets. As shown in Figure 4-3, unmask conditions for targets W1 and W4 were approximately the same. However, W1 was a radar site consisting of vehicles and equipment painted olive drab located on relatively low ground, while W4 was a SAM site, containing missiles painted white, which was located on the side of a hill. The observers detected the aircraft at the radar site before pilot acquisition far more frequently than they did at the SAM site containing white missiles. Since the aircraft unmask conditions were similar, the mean detection ranges for these two sites differ very little, while the mean acquisition range at the radar site was slightly less than half of that for the SAM site. Although the observers detected first only 50 percent of the time at W4, the mean detection range was some 600 meters larger than the mean acquisition range. This difference was due to the fact that there were a number of detections at very long ranges (over 20,000 meters) at this target, with no aircrew acquisitions occurring at comparable ranges.

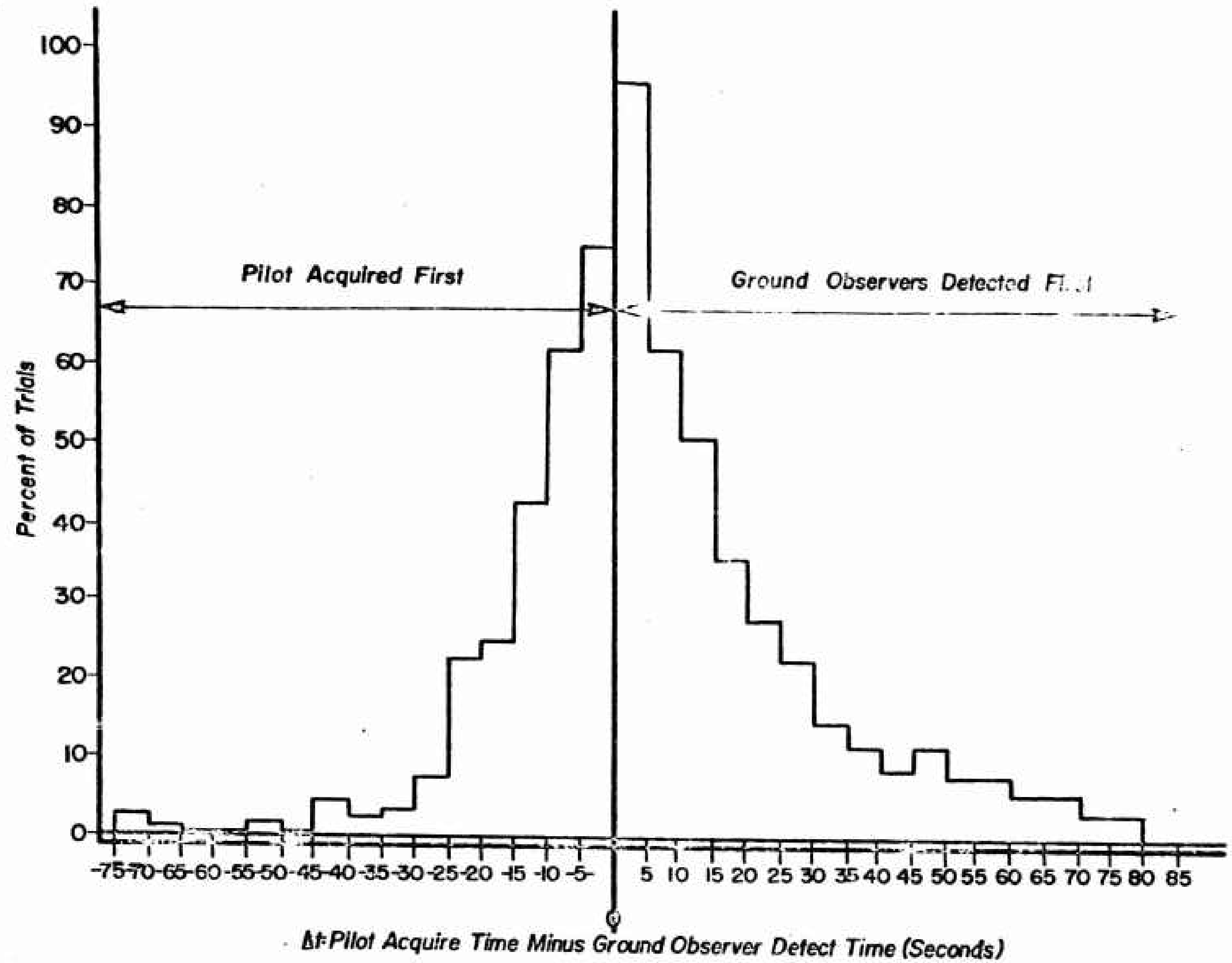


Figure 4-4
Distribution of Δt (U)

| Target | Number of Observations | Pilot Mean Acquisition Range (meters) | Observer Mean Detection Range (meters) | Percentage of Positive $\Delta_t$ | Mean $\Delta_t$ (seconds) |
|---|---|---|---|---|---|
| W1 | 163 | 2440 | 6091 | 79 | 16.96 |
| W4 | 177 | 5159 | 5751 | 50 | 2.85 |
| E3 | 127 | 5541 | 5494 | 55 | -0.37 |
| E4 | 140 | 6356 | 7694 | 56 | 5.20 |
| All Targets | 607 | 4782 | 6231 | 60 | 6.51 |

Table 4-2 Pilot Acquisition and Observer Detection Statistics by Targets (U)

(2) At target E3 the acquisition and detection ranges were approximately the same. This target was an airstrip so located that unmask was normally relatively short, occurring as the aircraft flew over a ridge line approximately 6,500 meters from the target. At this unmask range, aircraft should be plainly visible. Also, at this range, a target as large as an airstrip should have been plainly visible from the air. Therefore, it is not surprising that pilot acquisition and observer detection occurred at approximately the same time and same range. While the observers tended to detect before acquisition somewhat over half the time, neither the difference between the acquisition and detection ranges nor the mean $\Delta_t$ for the target indicate any advantage for either aircrew or observer.

(3) Target E4 was a bridge, and unmask range was quite large, although remask was easily possible. Both aircrew acquisition and observer detection ranges were larger for this target than any other. The average $\Delta_t$ data indicated some advantage for the ground observer.

d. Trial Effects.

(1) For any given trial, either none, one, two, three or all four observers stationed at a target could detect before the aircrew acquired. Table 4-3 presents the percentages each of these events occurred during the 134 trials where responses were available for all four observers. For 42 percent of the trials, all 4 observers detected prior to aircrew acquisition, and for 23 percent of the trials the aircrew acquired the target before any of the observers detected the aircraft. The figures in the row labeled Expected Percentage were obtained from the Binomial Theorem by assuming that the probability any given observer would detect before aircrew acquisition on any trial was 0.60 (that is, the same as the proportion of positive $\Delta_t$ that occurred). The analysis indicated that either none of the observers or all four of the observers detected first far more frequently than would be expected. (This indicates that the observations were not independent, as assumed.) Although this result may be due to differences in the manner in

| | Observer Detection Before Pilot Acquisition | | | | |
|---|---|---|---|---|---|
| | 4 | 3 | 2 | 1 | 0 |
| Percentage of Trials the Event Occurred | 42 | 14 | 11 | 10 | 23 |
| Expected Percentage | 13 | 35 | 35 | 15 | 3 |

Table 4-3 Percent of Observers Who Detected the Aircraft Before Pilot Acquisition for Trials Where All Four Observer Responses Were Available (U)

which ircraft were flown on different trials, flight profile data were not available to examine this post facto hypothesis.

(2) A further observation can be made from Table 4-3. It was noted from Table 4-2 that the overall likelihood of a single observer detecting before aircraft acquisition was 60 percent. However, the data in Table 4-3 indicate that at least one of a crew of four observers making independent judgments would detect prior to aircrew acquisition 77 percent of the time. This result suggests that utilization of multiple ground observers would provide a definite engagement advantage to ground based air defense weapons.

e. Discussion. It is assumed that a distinct tactical advantage is gained by a ground defense if ground observers detect an attacking aircraft before the crew of the aircraft acquire the ground target. The data available indicate that the ground observer does have some overall advantage. Individually, ground observers detected the aircraft prior to aircrew acquisition 60 percent of the time. However, if the observers were considered to be working as teams of four men, at least one member of the team would have detected the aircraft before aircrew acquisition 77 percent of the time. There are indications that the visibility of the target from the air and unmask range both affect the likelihood of the observer detecting first. Also, there are indications that the behavior of the aircraft in flight has a significant effect on the likelihood that either detection or acquisition will occur first.

5. (C) POSTTEST INTERVIEWS.

Individual interviews were conducted with each of the observers during the last three days of testing. The 12 questions and the observers' responses are presented in Appendix B. For the majority of the questions no clea. nsensus was reflected in the observers' responses. The observers dia agree on the following points:

(1) smoke output caused the F-4C to be the easiest aircraft to detect,

(2) each observer tended to return to his "favorite" lookout point at each of the targets,

(3) early warning information was heard via the radio located at the target area during the no early warning test trials. This information was useful for target W1, but of little assistance on the other three targets, and

(4) the observers also reported that they had a pretty accurate idea of where the target would appear by the end of the first test week. This contention is supported by the size of the search areas reported for the four targets. On the average, the search sectors were reported to vary between approximately 50 and 90 degrees even though the observers had been instructed to search a 180-degree sector.

6.(C) RANGE ESTIMATION ACCURACY.

a. The range estimation results are presented graphically in Figures 4-5 through 4-12 and are summarized in Table 4-4. These figures and table describe range estimation performance under the following conditions:

(1) test conditions (before training, after training, first week field test, and last week field test),

(2) direction of aircraft flight (incoming or outgoing), and

(3) engagement range to be estimated (400, 800, 1,500, and 2,500 meters).

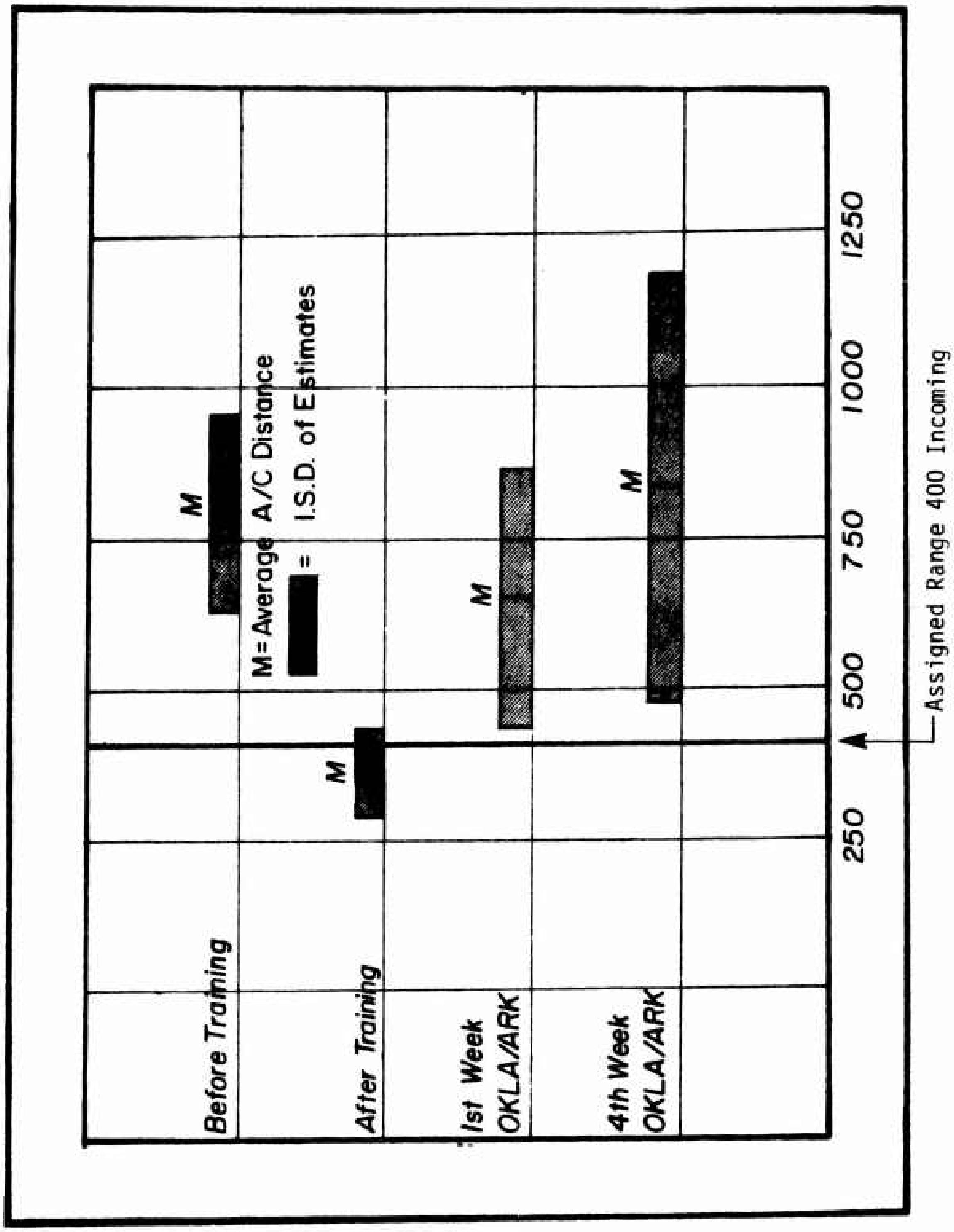
M = Average A/C Distance
= I.S.D. of Estimates
Before Training
After Training
1st Week OKLA/ARK
4th Week OKLA/ARK
M
M
M
M
250
500
750
1000
1250
Assigned Range 400 Incoming

Figure 4-5 (U)

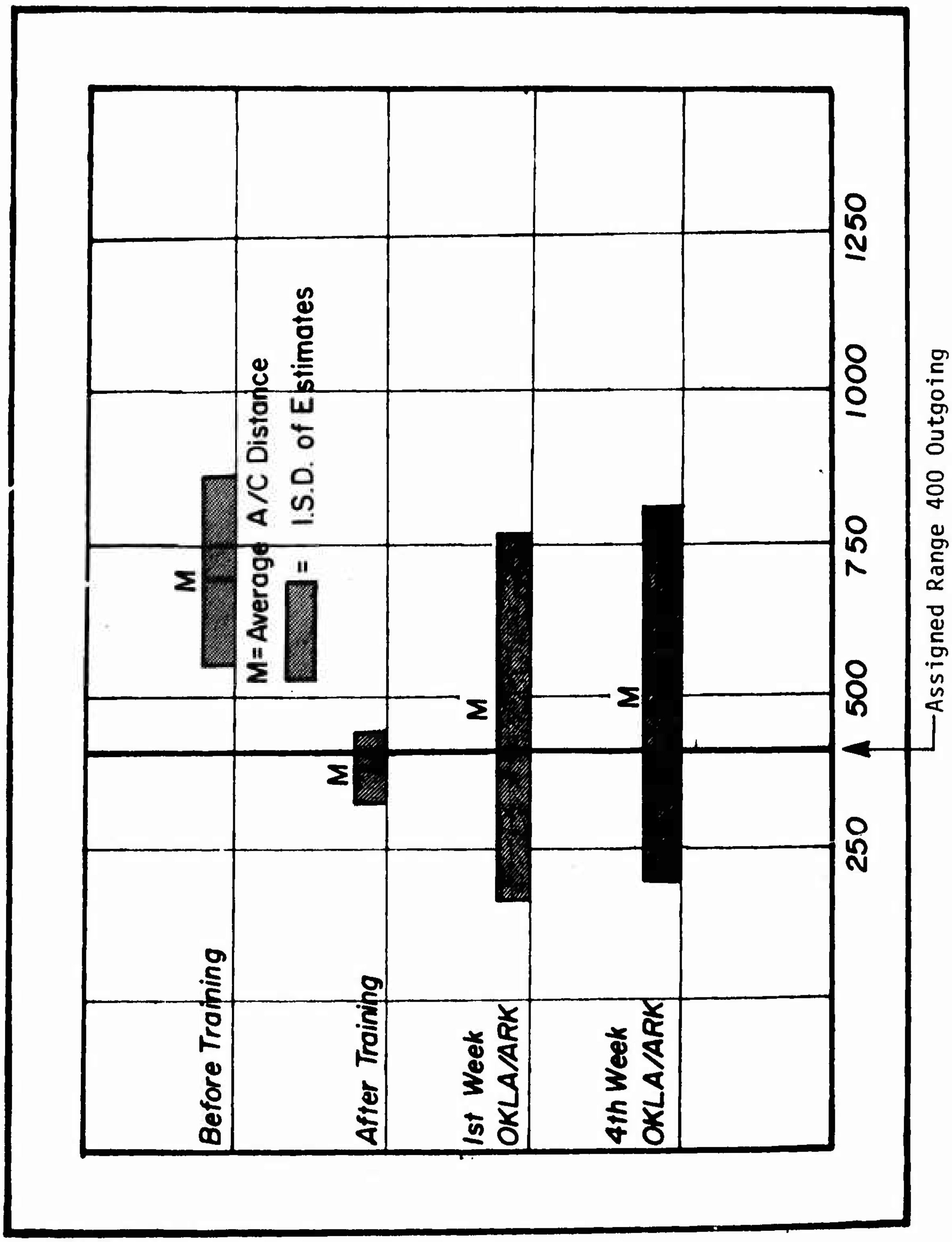
Before Training
After Training
1st Week
OKLA/ARK
4th Week
OKLA/ARK
M
M= Average A/C Distance
= I.S.D. of Estimates
250
500
750
1000
1250
Assigned Range 400 Outgoing

Figure 4-5 (U)

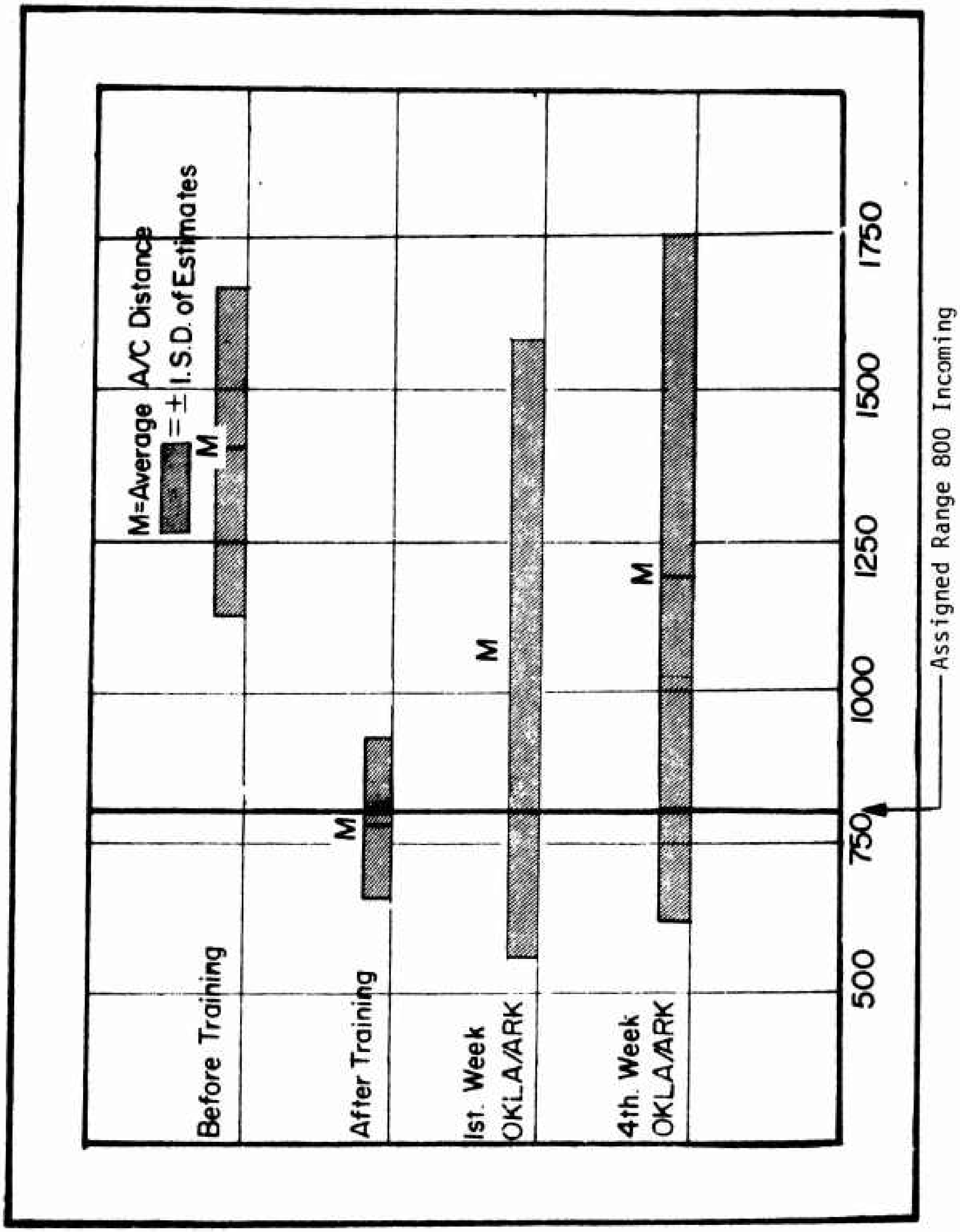
M=Average A/C Distance
= ± I.S.D. of Estimates
Before Training
After Training
Ist. Week OKLA/ARK
4th. Week OKLA/ARK
M
500
750
1000
1250
1500
1750
Assigned Range 800 Incoming

Figure 4-[illegible] (U)

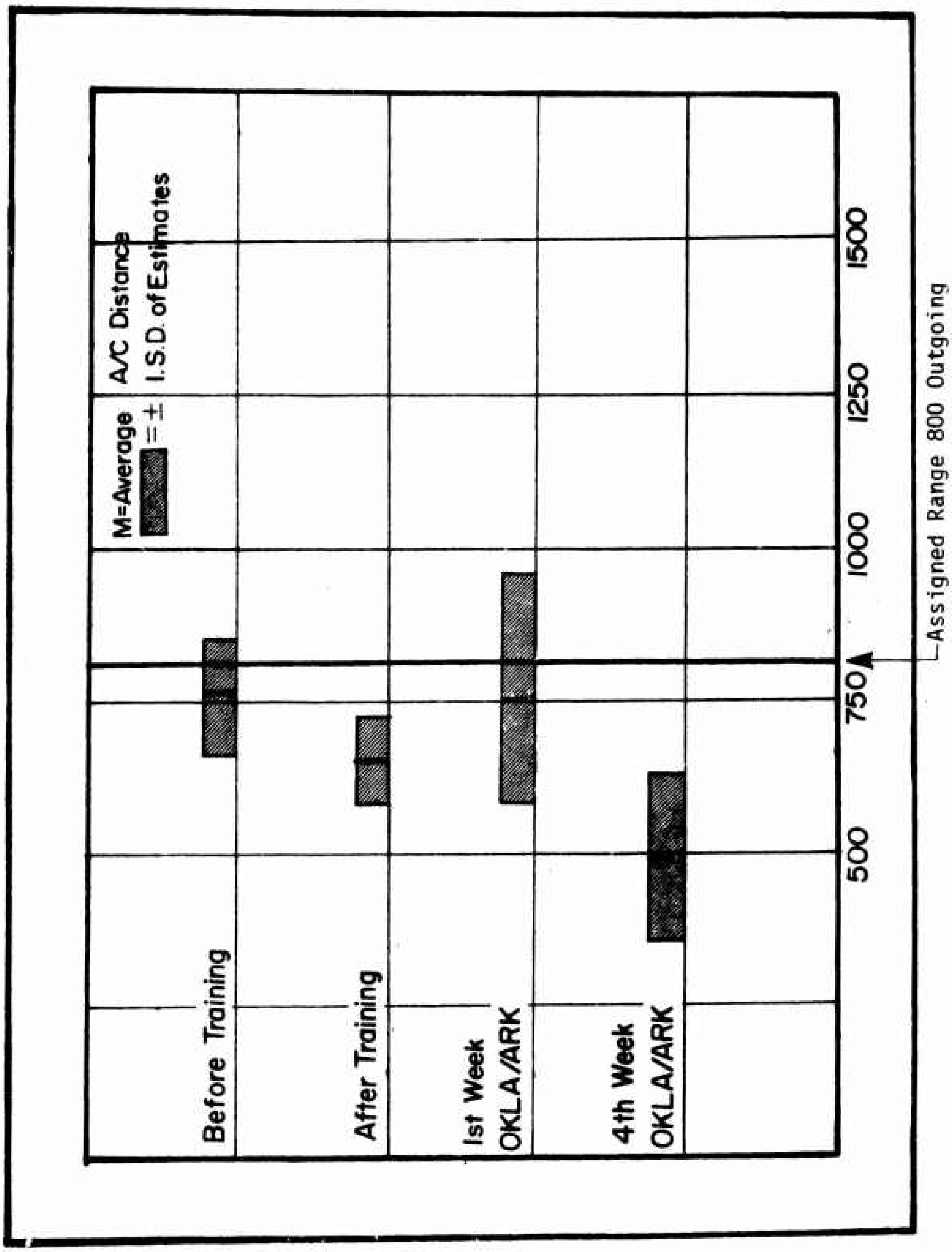
M=Average
= ± I.S.D. of Estimates
A/C Distance
Before Training
After Training
1st Week OKLA/ARK
4th Week OKLA/ARK
500
750
1000
1250
1500
Assigned Range 800 Outgoing

Figure 4-7 (U)

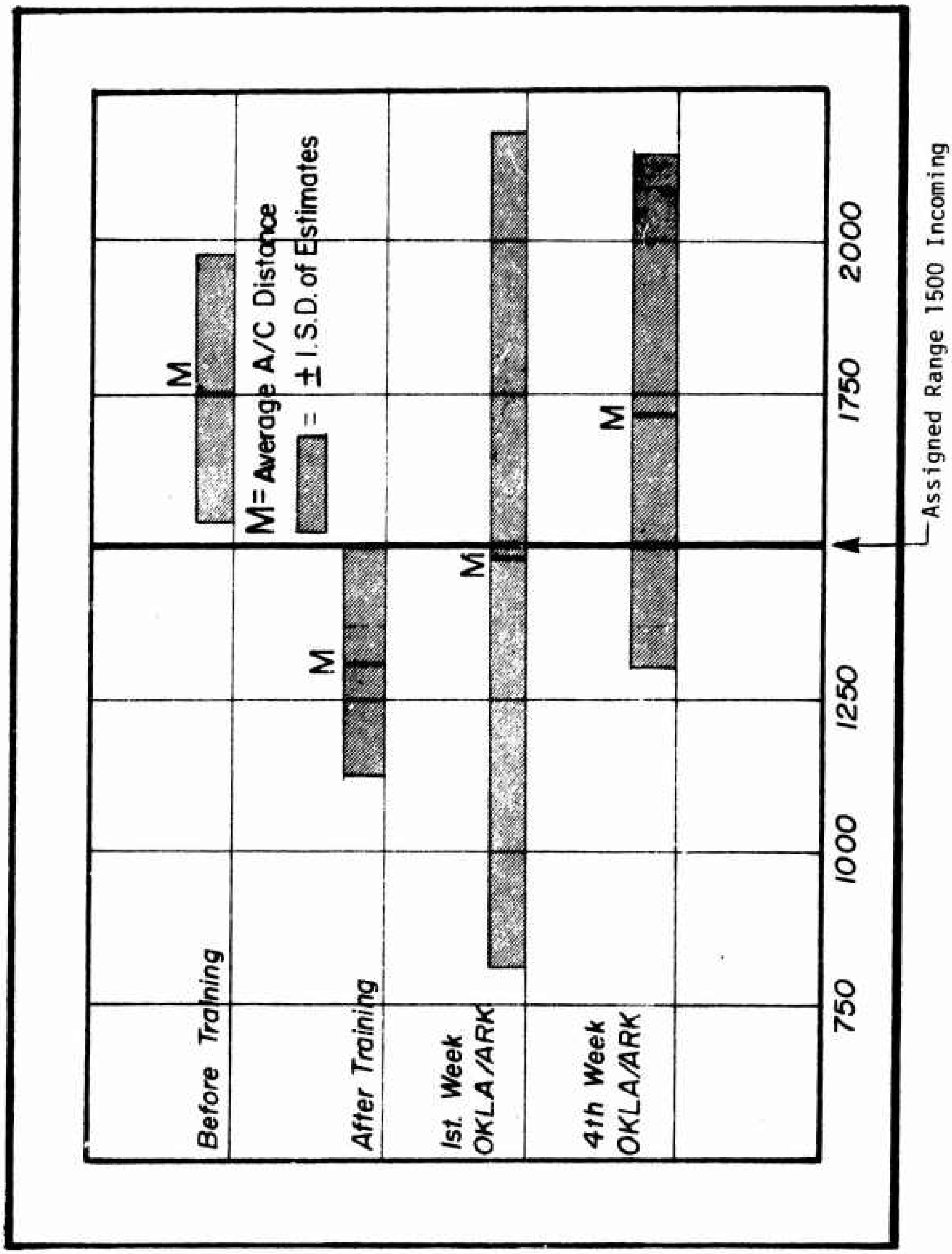
Before Training
After Training
1st. Week
OKLA/ARK
4th Week
OKLA/ARK
M
M= Average A/C Distance
= ± 1 S.D. of Estimates
750
1000
1250
1750
2000
Assigned Range 1500 Incoming

Figure 4-7 (U)

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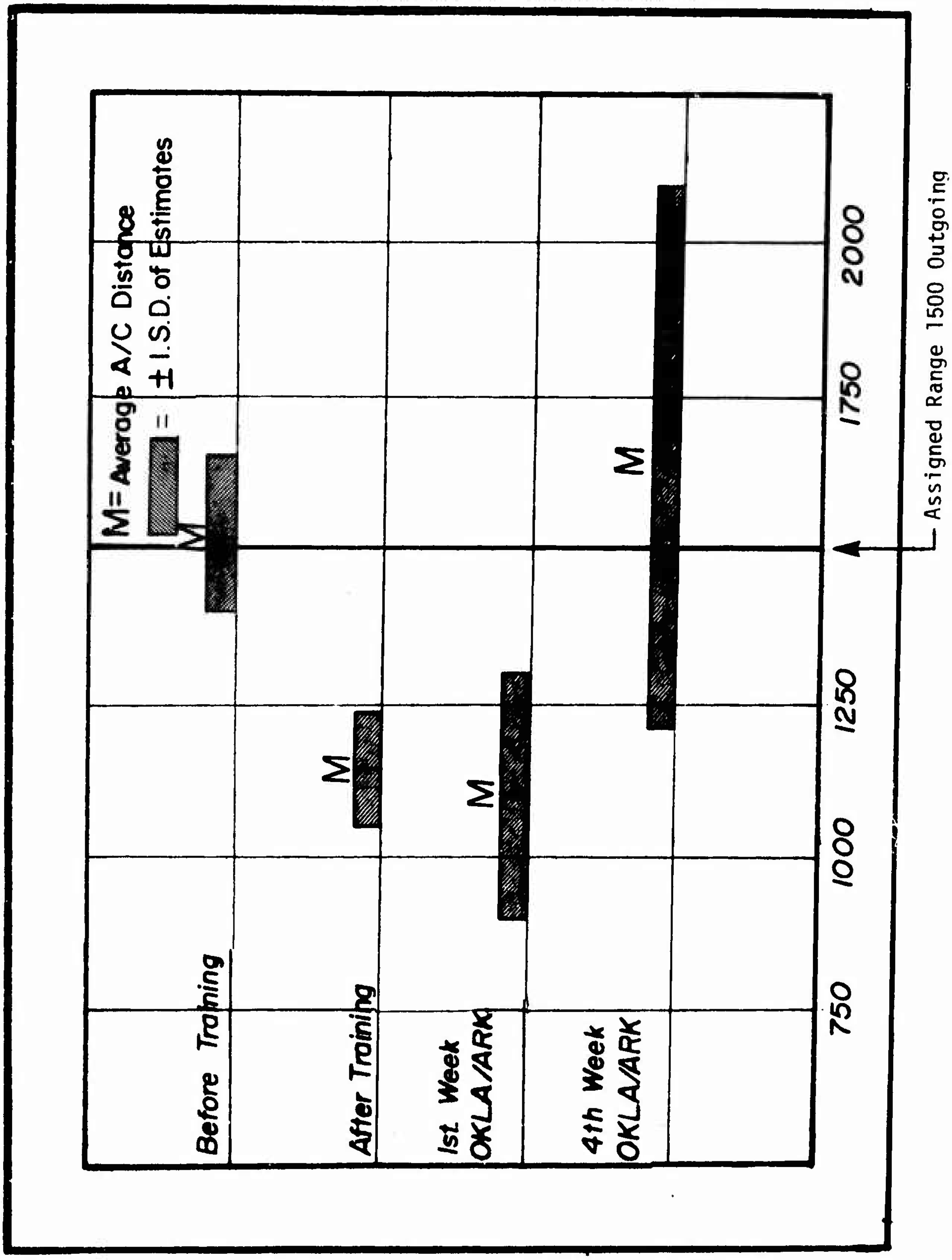


Figure 4-7 (U)



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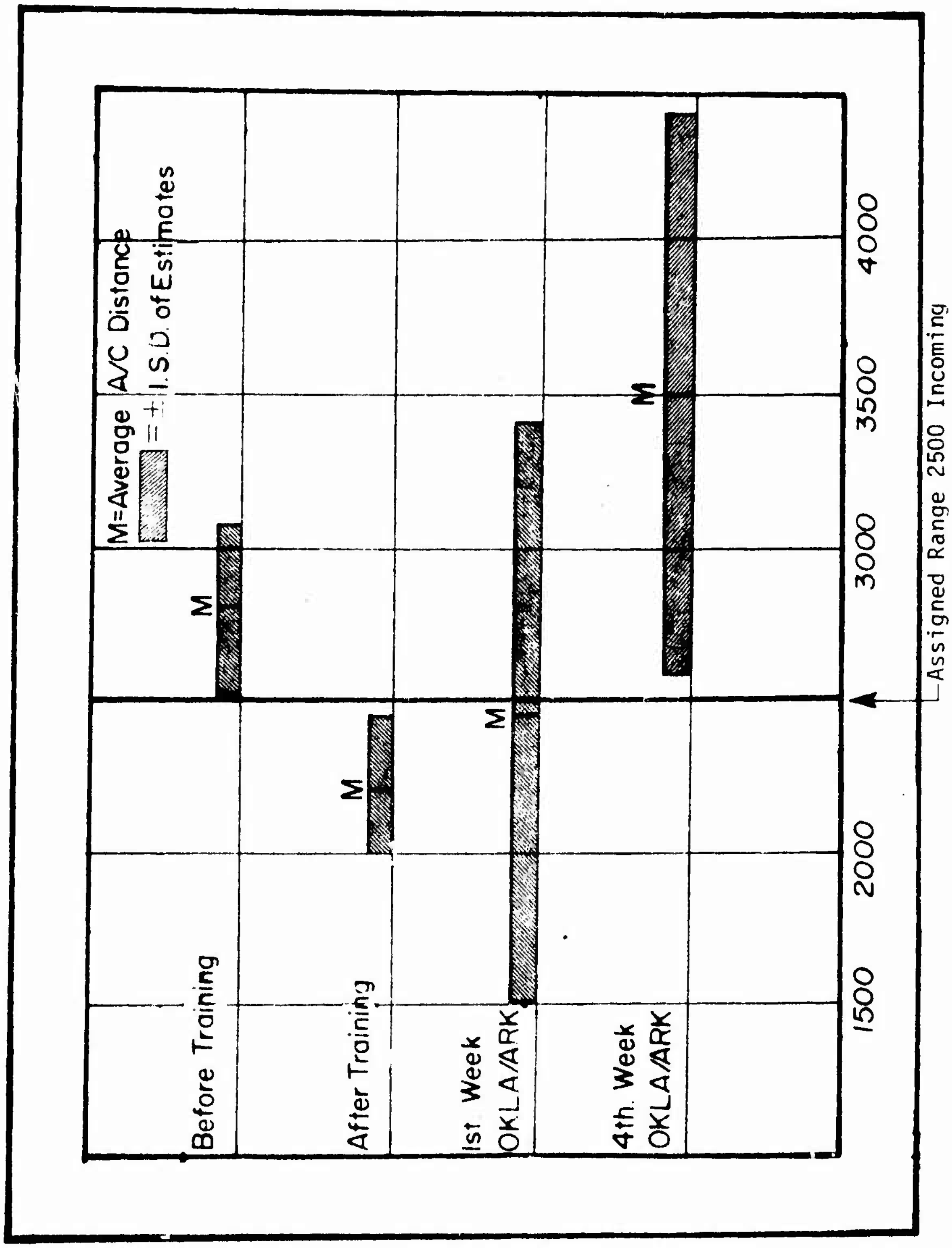
M=Average A/C Distance
= ± 1 S.D. of Estimates
Before Training
After Training
1st Week OKLA/ARK
4th. Week OKLA/ARK
M
M
M
M
1500
2000
3000
3500
4000
Assigned Range 2500 Incoming

Figure 4-8 (U)

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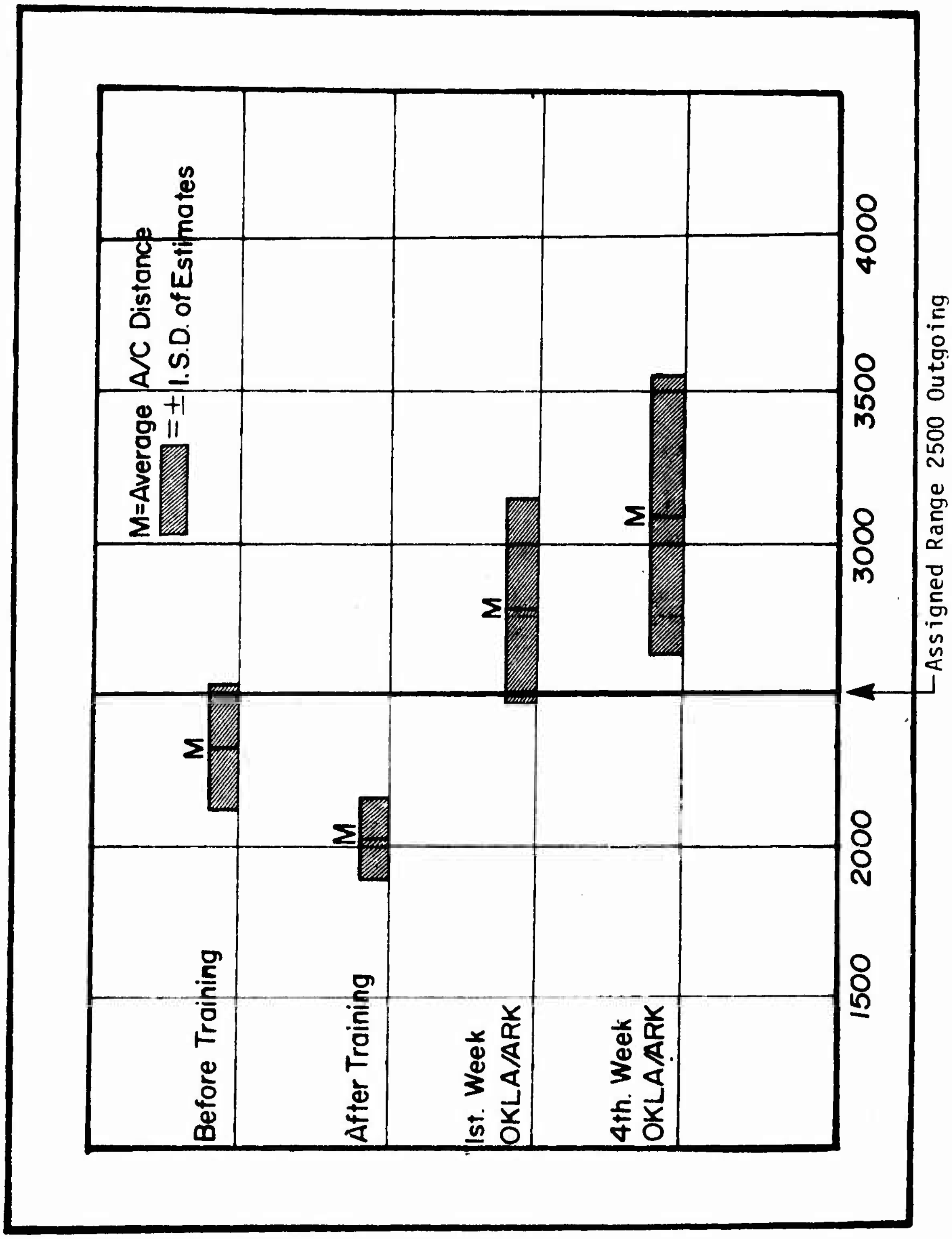


Figure 4-8 (U)



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| Course | Assigned Range | Mean and Standard Deviation | Before Training | After Training | First Week of Test | Last Week of Test |
|---|---|---|---|---|---|---|
| Incoming | 400 | $\bar{X}$ | 797 | 357 | 548 | 830 |
| | | $\sigma$ | 162 | 73 | 213 | 352 |
| | 800 | $\bar{X}$ | 1394 | 789 | 1093 | 1335 |
| | | $\sigma$ | 259 | 120 | 485 | 420 |
| | 1500 | $\bar{X}$ | 1752 | 1307 | 1482 | 1692 |
| | | $\sigma$ | 238 | 188 | 672 | 408 |
| | 2500 | $\bar{X}$ | 2790 | 2209 | 2428 | 3500 |
| | | $\sigma$ | 282 | 212 | 941 | 909 |
| Outgoing | 400 | $\bar{X}$ | 711 | 376 | 459 | 498 |
| | | $\sigma$ | 154 | 55 | 294 | 306 |
| | 800 | $\bar{X}$ | 764 | 642 | 748 | 472 |
| | | $\sigma$ | 84 | 77 | 171 | 138 |
| | 1500 | $\bar{X}$ | 1514 | 1134 | 1085 | 1644 |
| | | $\sigma$ | 123 | 94 | 197 | 440 |
| | 2500 | $\bar{X}$ | 2317 | 2017 | 2797 | 3088 |
| | | $\sigma$ | 203 | 128 | 328 | 446 |

Table 4-4 Aircraft Distance for Four Assigned Incoming and Outgoing Ranges (U)

b. An inspection of the before and after training data indicates that, in general, training served to decrease estimation error. Negative training effects, which were partly caused by an instrumentation bias in the training procedure, were obtained for some of the longer ranges on the outgoing portion of the flight path. The training was most effective in reducing trial-to-trial variability of estimation errors, as shown by a reduction in the size of the standard deviation for each assigned range. In general, the training levels achieved by these observers were comparable to the levels of performance obtained during previous range estimation training investigations (see reference 6).

c. One objective of the range estimation analysis was to compare proficiency during training, which was given under one set of conditions, with the test performance of the trained observers obtained under a completely different set of conditions. The training was accomplished in a desert environment under excellent visibility conditions with one aircraft which flew a constant speed at two programmed altitudes and offsets. The testing, however, took place in a semi-mountainous region with very high humidity, which tended to reduce visibility. The test environment also included three different aircraft which flew numerous speeds, altitudes, and offsets over four different test sites.

d. It was expected that the influence of changing environmental and stimulus conditions from training to testing could best be determined by comparing the end-of-training scores with the scores for the first week of the test.

e. Figures 4-5 through 4-12 indicate that estimation errors increased from the training condition to the test condition for the 1500-meter and 2500-meter incoming estimates and the 800-meter and 2500-meter outgoing estimates. In general, the average estimation errors slightly increased from the training to the test environment, but the variability of the estimation errors drastically increased between the after training (T) and the field test first week ($F_1$) testing conditions. Voss and Wickens (see reference 7) found that when observers were trained to estimate a range of 1,700 yards under one set of conditions, the accuracy and variability of estimation remained approximately the same over a 6-day period. Since there was a 5-day period between end-of-training and testing for the Oklahoma/Arkansas test, the complete change of environmental and stimulus conditions appears to be at least partly responsible for the large increase in variability of estimation.

f. At the end of the fifth week in the test environment, the overall variability of estimation remained approximately as it was after the first week, but the accuracy of estimation was decreased. This finding is inconsistent with results obtained by Horowitz and Kappauf (see reference 8). They found that range estimation performance after training was stable for a period of 60 days without additional training.

g. The most consistent result of the range estimation evaluation was the occurrence of large variability in the estimation errors during the Oklahoma/Arkansas testing. As shown in Table 4-4, the standard deviations of the errors were very large. These results suggest that retention of this skill deteriorates rapidly over time, particularly when no feedback concerning error magnitude is available to the observers, and the environment is much different from that used in training.

h. HumRRO has reported a series of studies concerning range estimation accuracy (see reference 6), which included a comparison of the accuracy of judging a 350-meter distance with and without the use of an occluding or stadimetric aid.

i. In one of the HumRRO studies, men were trained to estimate 350 meters distance to an aircraft. One group of men were trained using techniques similar to those subsequently used for the 3.1/3.5 observers.

A second group of men were trained to use their index finger, which occludes a liaison aircraft at approximately 350 meters, as a stadimetric aid. Use of the occluding device was found to reduce average bias and variability in comparison with the unaided training. It was incidentally learned that the front sight guards, or tangs, of military rifles also could serve as the job aid for determining when to open and cease fire against aircraft.

i. In 1968, HumRRO began a study to identify existing components or appendages on US air defense weapons which would function as stadimetric aids. The results of the 3.1/3.5 distance estimation tests support the need for some type of simple job aid which gunners could use to estimate the open and cease fire events.

# APPENDIX A
# BIBLIOGRAPHY

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## APPENDIX B

## RANGE ESTIMATION TRAINING

1. INTRODUCTION.

a. Previous field studies conducted at Fort Bliss, Texas, concerning range estimation training methods indicated that instruction using immediate knowledge of results is the most effective and efficient method. The use of this method had resulted in rapid improvement in a short period of time with smaller errors than when other methods were used. For these reasons, the method of immediate knowledge of results was selected for training the 16 observers.

b. The training was conducted over a three-day period. At the end of each day's training session, a test was given to determine each individual's status as training progressed. A test was also given before the first training session to provide a performance baseline in order to evaluate the effects of the training.

2. DESCRIPTION OF TRAINING ENVIRONMENT.

a. The training was conducted during late morning and early afternoon hours at Hueco Range No. 2, Fort Bliss, Texas. The relatively flat desert terrain provided for meteorological range of approximately 75 miles. To the near west and distant north there was a mountainous background, and northeast, east, and south there was sky background.

b. In order to reduce the possible influence of terrain features as cues for range estimation, three training sites, several thousand meters apart, were used. Training was conducted at a different site each day.

c. Two parallel flight paths were set up for the F-100 target aircraft to follow. A "red" course passed 200 meters to the west of each site, and a "yellow" course passed directly through each site. The aircraft flew at one speed, 400 knots true air speed, but used two altitudes in order to vary the aircraft aspect. These altitudes were 250 feet and 750 feet. Alternately the aircraft flew from the north and south.

3. TRAINING PROCEDURE.

a. The observers were initially instructed as to the nature of the training. They were then positioned so that each could see the entire flight path in both directions. The instructor prepared the observers with a warning (READY) a few seconds before each signal to estimate was given. As the aircraft flew over the course, the observers made two estimates of the slant range to the aircraft when a signal (ESTIMATE NOW) was given by the instructor. These estimates, one while the aircraft approached and one after the aircraft passed over the site, were recorded by each observer on special record forms. Immediately after the second estimates were made, the instructor announced the correct ranges at the time the signals were given. At that time, by referring to his record form, each observer could immediately determine his error of estimation.

b. The observers had been told specifically that they were going to be trained to accurately estimate four different ranges; 400, 800, 1,500, and 2,500 meters; but that during training, the signal to estimate would be when the aircraft was anywhere from 300 meters to 2,900 meters from them.

c. During each day's training session the aircraft flew 36 passes, 18 in each direction. On each trial (aircraft pass) two estimates were made, one incoming and one outgoing. Over the three days of training, each observer made a total of 216 estimates.

d. The signals to estimate given by the instructor were based upon a timing system which relied for accuracy upon the ability of the aircraft to maintain a programmed speed and course within some limits. In order to check the accuracy of this system of determining true aircraft range, as the aircraft passed over the training site during test trials, a "crossover" mark was put onto the event recorder used to record observer test responses. By comparing the timing system with these crossover marks, it was discovered that errors existed in the system. These errors resulted in training the observers to use a different "yardstick" than was programmed. That is, when the observers were told during training that the aircraft was 400 meters away, incoming, it was actually closer to 525 meters away. Table B1-1 shows the actual ranges of the aircraft when the observers were told it was at the programmed range.

4. TEST PROCEDURE.

a. A total of four 12-trial tests were scheduled, one before training commenced on the first test day and one at the end of each of the three days of training.

b. Just before the aircraft began a pass, the observers were told the two specific ranges they were to estimate on that pass, one incoming and one outgoing. They were told to indicate when they believed that the aircraft was at the specified ranges. Each observer was provided with a pushbutton connected to a channel of an event recorder. When the observer through the aircraft was at the specified ranges, he pressed his pushbutton. A mark was made on the event recorder when the aircraft was at the programmed specific ranges for the purpose of checking each observer's test responses.

| Course | Assigned Range | Actual Range |
|---|---|---|
| Incoming | 400 | 525 |
| | 800 | 925 |
| | 1500 | 1445 |
| | 2500 | 2410 |
| Outgoing | 400 | 360 |
| | 800 | 585 |
| | 1500 | 1185 |
| | 2500 | 2040 |

Table B1-1 Actual Target Ranges During Training Compared to Programmed Ranges

c. The aircraft scheduled to fly the test trials on the final day had mechanical problems and did not fly. As a result, the final test trials had to be cancelled. The result of the training has been evaluated based upon performance on the test trials at the end of the second day of training.

5. RESULTS OF PRETRAINING TEST.

a. The 16 observers that were trained varied in age from 18 to 24 years. All had 20/20 vision, uncorrected or corrected. GT scores ranged from 83 to 130, with a mean of 111 and standard deviation of 11.

b. At the beginning of the first day of training, the observers were told that they were to be given some training in range estimation to aerial targets, but that first they would be tested to see how well they could estimate various ranges before training. The results of the pre-training test are indicated in Table B1-2.

c. The incoming ranges of 400 meters and 800 meters and outgoing ranges of 400 meters were greatly overestimated. This shows that the observers believed that these ranges were much greater distances than they actually were. The remaining means of estimates were accurate, but variation was relatively large in all cases.

| Course | Estimated Range | Actual Range | Standard Deviation |
|---|---|---|---|
| Incoming | 400 | 797 | 162 |
| | 800 | 1394 | 259 |
| | 1500 | 1752 | 238 |
| | 2500 | 2790 | 282 |
| Outgoing | 400 | 711 | 154 |
| | 800 | 764 | 84 |
| | 1500 | 1514 | 123 |
| | 2500 | 2317 | 203 |

Table B1-2 Means of Range Estimates (in meters) Prior to Training

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APPENDIX C

ARKANSAS POSTTEST INTERVIEWS

1.(U) OBJECTIVE.

a. A set of questions was asked of the 16 military personnel who served as observers for the human factors studies conducted in Oklahoma/ Arkansas as part of JTF-2 Test 3.1/3.5 (NF). The questions were presented during individual interviews conducted during the last three days of the testing. All interviews were conducted by one human factors scientist.

b. The interviews were prefaced with the following introductory statement:

"Now that we are nearing the end of our tests here in Arkansas, we have a number of questions to ask you concerning your test activities during the past few weeks. It is hoped that your answers to these questions will help us clear up the minor confusions and uncertainties that always appear after field testing is done."

2.(C) INTERVIEW QUESTIONS. The below 12 questions were asked of each observer participating in the test. For each question the responses are indicated in summary form.

a.(U) Qustion No. 1. "We understand that many of the observers have missed detecting some of the aircraft for one reason or another. About what percentage of the aircraft do you think you missed? Or, in other words, out of every ten flights, how many did you not detect until the aircraft was at crossover or behind you?"



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(1) Summary of Answers.

| Category | Frequency |
|---|---|
| Less than once | 6 |
| Once | 6 |
| Once or twice | 3 |
| Two or three | 1 |

(2) Individual Answers.

| Observer ID No. | Answer |
|---|---|
| 63 | Less than 1 |
| 43 | 1 |
| 61 | 1 |
| 13 | 2 or 3 |
| 51 | 1 |
| 62 | 1 or 2 |
| 23 | 2 or 3 |
| 12 | Less than 1 |
| 41 | Less than 1 |
| 21 | Less than 1 |
| 22 | Less than 1 |
| 53 | 1 or 2 |
| 31 | 1 or 2 |
| 11 | 1 |
| 42 | 1 |
| 52 | 1 |

b. (C) Question No. 2 "Have you missed a greater percentage of one kind of aircraft than another?"

(1) Answers.

(a) Nine observers indicated that the F-4C was easiest to detect because it emitted a lot of exhaust smoke. Observers detected smoke before seeing the aircraft's form.

(b) Six of the observers stated that the F-105D was hardest to detect since it gave off very little or no smoke. One observer thought the F-105D also tended to fly higher and slower.

(c) Two observers thought the A-6A was hardest because it gave very little smoke.

(d) Four observers thought there were no differences between the ease of detecting the three types of aircraft.

(e) Two observers believed that the camouflaged F-4Cs were difficult to detect when the aircraft were viewed against a terrain background. The rest of the observers either had no opinion or said there was no difference.

c.(U)Question No. 3. "Why do you think you missed seeing the aircraft?"

(1) Answers.

(a) Six observers said the aircraft were off course (missed target) to the side or penetrated from the from the wrong direction.

(b) Eight observers stated the aircraft were obscured by trees because they were off course.

(c) Three observers stated they were day-dreaming or in a trance-like state.

(2) Several miscellaneous reasons were offered including the following:

(a) Looked like a bird.

(b) Missed seeing it when it first came over the hill and lost it in the trees.

(c) Glare and spots in eyes.

(d) Looking in the wrong direction.

d. (C) Questions No. 4 & 5. "What search angle do you usually use at this target site? Show me what landmarks you use. What search angles do you use at the other target sites?"

(1) Summary of Answers.

| Target | Search Angle |
|---|---|
| W1 | 54 degrees |
| W4 | 80 degrees |
| E3 | 92 degrees |
| E4 | 70 degrees |

(2) Individual Answers.

| Observer | Search Angle At | | | | M |
|---|---|---|---|---|---|
| | W1 | W4 | E3 | E4 | |
| 22 | 30 | 75 | 45 | 40 | 48 |
| 11 | 65 | 80 | 80 | 60 | 71 |
| 42 | -- | -- | 90 | -- | -- |
| 52 | 40 | 20 | 20 | 40 | 30 |
| 21 | 90 | 65 | 120 | 50 | 81 |
| 41 | -- | -- | 90 | -- | -- |
| 12 | 20 | 90 | 30 | 120 | 65 |

| Observer | Search Angle (in degrees) At W1 | W4 | E3 | E4 | M |
|---|---|---|---|---|---|
| 23 | 60 | 90 | 180 | 75 | 101 |
| 62 | 60 | 90 | 135 | 120 | 101 |
| 51 | 45 | 45 | 45 | 45 | 45 |
| 13 | 20 | 180 | 180 | 45 | 106 |
| 61 | 70 | 45 | 180 | 100 | 99 |
| 43 | 60 | 150 | 60 | 60 | 82 |
| 63 | 45 | 45 | 45 | 45 | 45 |
| 53 | 90 | 90 | 120 | 120 | 105 |
| 31 | 60 | 60 | 60 | 60 | 60 |
| N | 14 | 14 | 16 | 14 | |
| M | 54 | 80 | 92.5 | 70 | |
| $\sigma^2$ | 454.21 | 1658.80 | 1781.63 | 914.28 | |

e. (U) Question No. 6. "Do you have a favorite location at each target site, and do you always go to the same location?"

(1) Answers. All observers except two answered affirmatively to this question. There were two "nonconformists" in one group that rotated positions (Numbers 12 and 13 claimed to have been at all ORB locations at all four target sites, but this assertion was not supported by the other two men in that group).

f. (U) Question No. 7. "What is your location at each target site?"

(The relative observer positions at each site are shown in Figures C-1-1 through C1-4. The position numbers are indicated in brackets.)

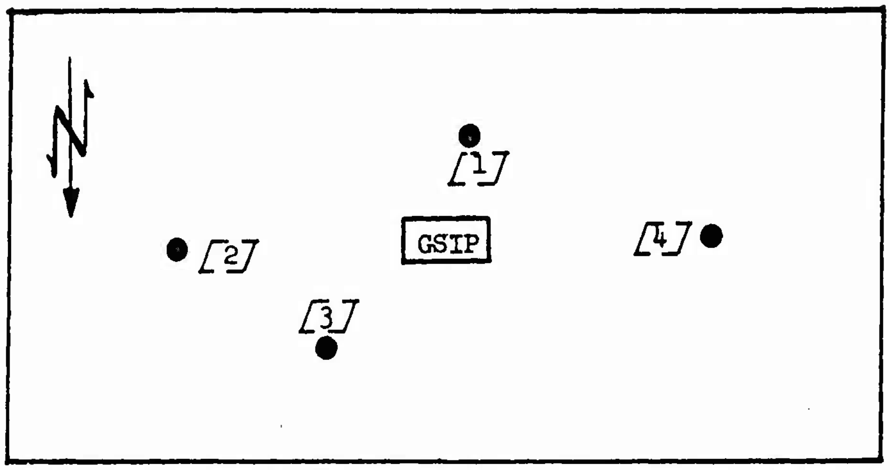


Figure C1-1 Target W1 (Cherry Hill)

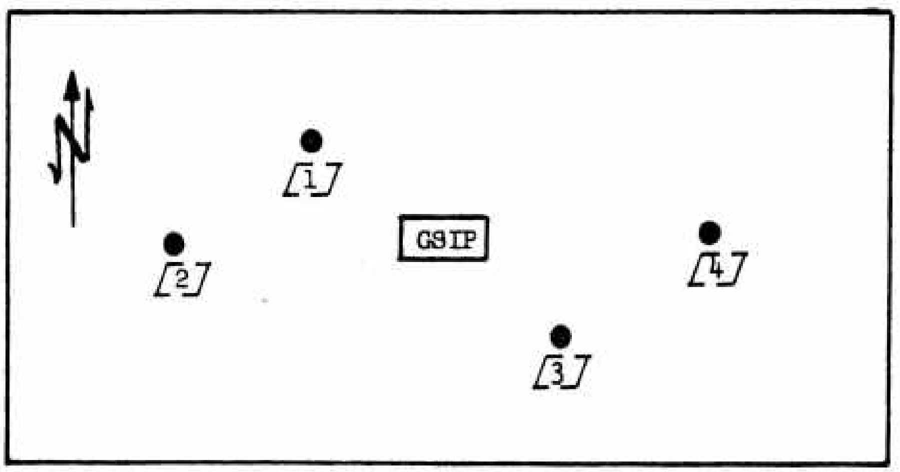


Figure C1-2 Target W4 (Plunketville)

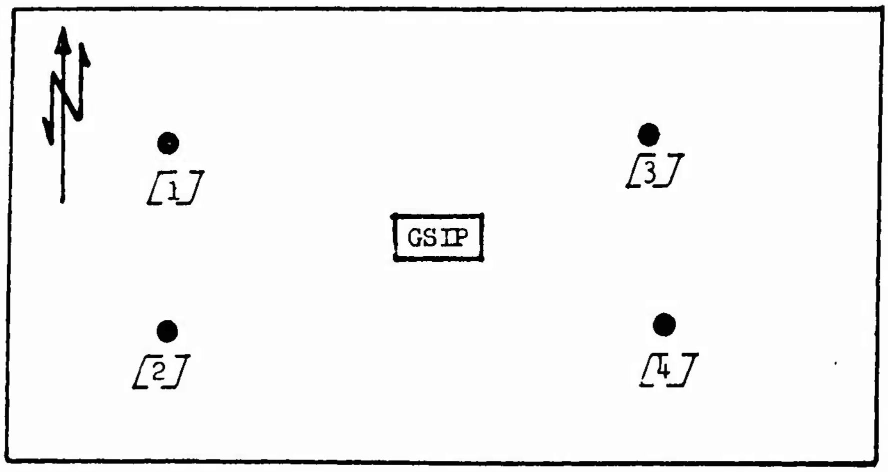


Figure C1-3 Target E3 (Gravelly)

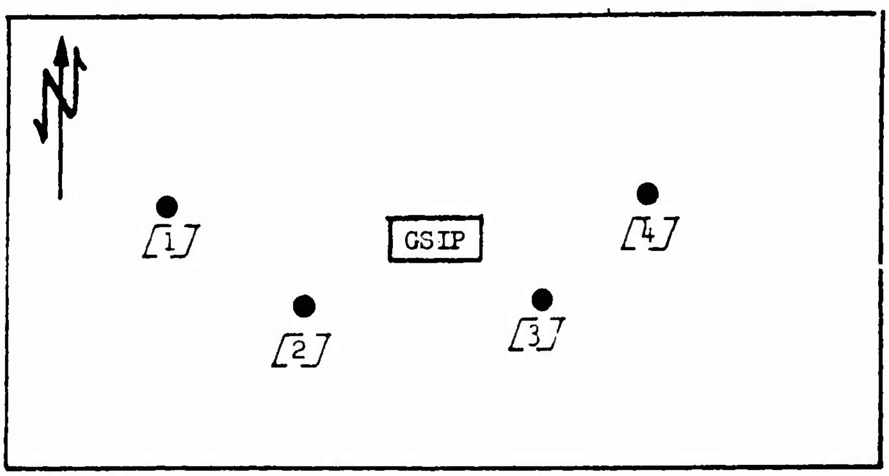


Figure C1-4 Target E4 (Washita Bridge)

(1) Answers. The location of each observer at each target site is shown below.

| Observer Number | Location at Target Site W1 | W4 | E3 | E4 |
|---|---|---|---|---|
| 11 | 4 | 4 | 1-4 | 1,3,4 |
| 12 | 1-4 | 1-4 | 1-4 | 1-4 |
| 13 | 1-4 | 1-4 | 1-4 | 1-4 |
| 22 | 4 | 1 | 1 | 3 |
| 21 | 2 | 2 | 3 | 4 |
| 23 | 1 | 4 | 2 | 2 |
| 31 | 2 | 3 | 4 | 1 |
| 41 | 2 | 2 | 3 | 2 |
| 42 | 3 | 4 | 1 | 4 |
| 43 | 4 | 4 | 4 | 4 |
| 51 | 1 | 1 | 1 | 3 |
| 52 | 4 | 2 | 1 | 4 |
| 53 | 3 | 1 | 4 | 1 |
| 61 | 4 | 3 | 2 | 3 |
| 62 | 2 | 4 | 1 | 2 |
| 63 | 2 | 2 | 2 | 3 |

g. (U) Question No. 8. "Do the four test monitors do their job in the same way? For example, do all the monitors give you the same amount of early warning?"

(1) Answers.

(a) Seven observers stated all four monitors did their job in the same way.

(b) Three men said Monitor A put the men on search earlier for the no early warning trials.

(c) Three other men said Monitor B put the men on search earlier for the no early warning trials.

(d) Three additional men said both Monitors A & B put the men on search earlier.

h. (U)Question No. 9. "Have you picked up early warning information from the radio, particularly on the no early warning trials?"

(1) Answers.

(a) All of the men answered affirmatively to this question.

(b) The men felt the radio report of Zulu Time for the observers at W1 was particularly helpful.

(c) When the observers were at W4, E3, and E4, hearing Echo or Zulu Time did not aid them very much because the "time over target" varied considerably, and there were many times the aircraft missed these targets.

i. (U)Question No. 10. "How many days passed before you had a pretty accurate idea where the aircraft would appear at each target?"

(1) Answers.

(a) Ten observers said by the end of the first test week.

(b) Three observers weren't sure until after the second day they were stationed at each target.

(c) Two men said they were sure after the first three flights at each target during the first week.

(d) One man said he knew by the second test day because the GSIP antennas were centered on the flight path.

j.(U)Question No. 11. "If you were the NCOIC of a caliber .50 MG, how would you organize your crew for the search and detection functions required for defense of a 180-degree perimeter?"

(1) Answers. The 14 different answers are listed below.

(a) Two men rotating on duty every 15 minutes.

(b) Four men on duty for one-half hour watch.

(c) Three men on watch for one hour if it is cool weather. If it's hot, three men for one-half hour.

(d) Two men for one hour.

(e) Two men for two hours (three observers mentioned this method).

(f) Two men for three hours.

(g) Three men for one hour.

(h) Two men for as long as necessary, each with a 90-degree sector.

(i) Two men for four hours, but have them trade positions every 10 minutes.

(j) Three men for one to one and one-half hours.

(k) Four men for one to one and one-half hours.

(l) Four men for two hours.

(m) Six men for two hours.

(n) Three men for one hour, each with a 60-degree sector.

k. (U)Question No. 12. "This next question concerns range estimation, and consists of two parts. For some of the target sites, the low-flying aircraft have a tree or terrain background; for other targets the aircraft are seen against a sky background. Does this difference in backgrounds affect your ability to estimate range? What techniques do you use for estimating range?"

(1) Answers.

(a) The answers to part one of this question (sky or terrain easier) were almost equally divided among three alternatives:

| | | |
|---|---|---|
| 1 | Sky background is easier: | 4 |
| 2 | Tree background is easier: | 5 |
| 3 | No difference: | 5 |
| 4 | No answer: | 2 |

(b) The answers to part two (techniques used in estimating range) of the question were as follows:

| Technique | Frequency | Observer ID |
|---|---|---|
| Apparent size if aircraft is high and aircraft details if it is low. | 3 | 11,13,43 |
| Aircraft size only. | 1 | 12 |
| Distance to terrain if aircraft is low and size if it is high. | 4 | 53,63,22,21 |
| Distance to terrain. | 1 | 41 |
| Aircraft details. | 3 | 62,42,61 |
| No information obtained | 4 | 52,23,31,51 |

APPENDIX D

# DATA PROCESSING AND ANALYSIS

by

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1. GENERAL. The data processing consisted of reducing and editing the Test 3.1/3.5 (NF) Oklahoma/Arkansas data, time relating this event data with applicable Test 4.1 aircraft position data, and creating a data bank for use in the analysis effort.

2. QUALITY CONTROL OPERATIONS.

a. The event data were recorded on magnetic tape in the orbiting C-130 aircraft. These tapes were processed through a playback station and formated for the CDC-3400 computer. The event data were processed by a program called QUICKORB, which provided preliminary information which was transmitted to the Mena Test Range concerning the availability of event data from completed trials.

b. The data event tapes were subsequently edited manually to remove invalid trials. An observation was considered invalid for any of the following reasons:

(1) the aircraft had not passed within 2000 meters of the ground target,

(2) the aircraft was grossly off course; that is, it penetrated the target area outside the assigned 180-degree search sector, and

(3) aircraft position data were not available.

c. Each response was evaluated to assure that the individual responses used in the analysis were plausible. These data checks were incorporated into the data reduction programming effort. Much of the rationale for these data checks was based upon manual review of the data. The field data contained many situations where responses were not in sequence or occurred at unacceptable times (outrange estimates prior to crossover, etc.). The quality control standards adopted were based upon the characteristics of the target or geometrical considerations. Below is a list of the data checks used for deleting individual invalid observations:

(1) detect occurred after crossover,

(2) the pilot acquired after crossover,

(3) an inrange estimate occurred after crossover,

(4) an outrange estimated occurred prior to crossover,

(5) a time difference between pilot acquire and observer detect greater than 200 seconds indicated an invalid detect event because at the test speeds flown, the aircraft was not available for 200 seconds,

(6) the detect event must occur before the inrange event, and

(7) the inrange event must occur before the outrange event.

3. DATA REDUCTION.

a. The data were subsequently time related to preliminary Test 4.1 data by use of a program called CRBDATA. The time-related data were sorted on magnetic tape for use in the final processing.

b. The final processing consisted of time relating the observer response data to the final Test 4.1 aircraft position data, which included computing the performance measures and creating the data bank for analysis.

c. The ORBDATA program time related Test 4.1 data to the observer data, computed the values of the performance measures and the independent variables, and created the data bank. The data used from Test 4.1 were the aircraft position and the pilot acquire events.

(1) The terrain data for targets W1, W4, E3, and E4 were also obtained from Test 4.1. The horizon features for each target were selected and recorded on magnetic tape. These horizon features consisted of the angle of elevation above and below the target's plane; that is, the plane tangent to the earth at the local target. The horizon elevation angles were given as a function of the azimuth angle, $\pm$ 90 degrees, relative to the line connecting the target and the FRP.

d. The following quantitative variables were calculated for each occurrence of an observer response:

(1) local slant range of aircraft (SR),

(2) horizon subtended angle (HSA),

(3) sun angle (SA),

(4) aircraft subtended angle (ASA),

(5) aircraft speed (S),

(6) apparent contrast of the aircraft (C),

(7) total angular velocity ($\omega$),

(8) slant range rate ($\dot{R}$),

(9) azimuth rate ($\dot{\theta}$),

(10) elevation rate ($\dot{\phi}$), and

(11) aircraft altitude (altitude above target plane) (A).

e. The following performance measures were calculated:

(1) detection range (R),

(2) inrange algebraic error (EI),

(3) percentage error inrange (PI),

(4) outrange algebraic error (EO),

(5) percentage error outrange (PO), and

(6) pilot acquisition minus observer detection time interval ($\Delta$t).

f. These data were time related and recorded on magnetic tape along with the observer response time, answers to questions, and training and aptitude scores. Each response was in a separate data record. ID information such as aircraft type (A/C), target number (ST), early warning condition (EW), observer number (OB), and all visibility data were included in each data record.

4. ANALYSIS.

a. Statistical Methods. This section describes the statistical techniques and computer programs used in the analysis.

(1) Descriptive statistics used included histograms, cumulative frequency plots and scatter diagrams (SCD). Included with the histograms were the mean, standard deviation, median, maximum and minimum values for the data used. Cumulative frequency plots were derived from the histograms. SCD were merely x - y plots for specified pairs of continuous variables.

(2) Analysis of variance (ANOVA), analysis of covariance (ANCOVA), and regression analysis were the techniques employed through the analysis phase. These analyses were accomplished by the use of two computer programs described below.

b. Weighted Regression Analysis Program (WRAP). WRAP is a computer program that performs the calculations required of multiple linear regression (see reference 3). Observations can be weighted and data can be transformed in the program. The program selects a significant subset of independent variables by a fixed F value or fixed probability level. Also included is a flexible system for testing hypotheses in balanced or unbalanced designs. The method of analysis is the usual least squares method for obtaining estimates of the regression parameters. The output from WRAP normally consisted of the following:

(1) all correlation coefficients (between $X_i$, $X_j$, and $X_i$, $y$),

(2) $(X'X)^{-1}$ (the variance-covariance, or the "C" matrix for the regression parameters),

(3) ANOVA for total regression model,

(4) multiple regression coefficient ($b_i$'s), R, $R^2$, residual variance and standard deviation,

(5) each regression coefficient, its standard error, t value F ratio, and sum of squares,

(6) residual information consisting of observed y, predicted y, observed-predicted, (observed-predicted)/residual standard deviation, weight value (= one unless weights are assigned), standard deviation of observed-predicted value, and

(7) ANOVA, where factor sums of squares are adjusted for other factors included in the ANOVA.

c. Multivariate Analysis of Variance (MANOVA). MANOVA is a computer program that performs univariate and multivariate analysis of variance, covariance and regression (see reference 4). It handles balanced and unbalanced designs, including missing cells. The outputs usually obtained in this analysis are as follows:

(1) the complete ANOVA table containing factors sums of squares adjusted for other factors in the analysis,

(2) contrasts for factor levels and interactions in the model. With respect to main effects, the contrast is the deviation of the treatment mean from the grand mean. In the case of two-way interactions, the contrast is the value of $y_{ij.}-y_{i..}-y_{.j.}+y_{...}$, which represents the deviation of the cell mean from the grand mean corrected for associated main effects,

(3) correlations of contrasts with standard deviations of contrasts, divided by standard deviations of variables on the diagonal, is printed out in matrix form. These values are used to compute the variances of contrasts or linear combinations of contrasts,

(4) Within cell coefficients and the "C" matrix $(X'X)^{-1}$ (with sums of squares regression in ANOVA table) when covariables are present.

d. Both the MANOVA and WRAP programs have properties useful to the analyst. In the early analysis phase, WRAP was used exclusively due to the availability of correlations between the variables, residuals and individual sums of squares for all variables. In the final analysis, MANOVA and WRAP were utilized on the same model as each program contained information only available from the other through much hand manipulation of the data.

5. IMPACT OF DATA REDUCTION ON THE ANALYSIS PLAN.

a. The test design has been discussed in Section 1, paragraph 3, and quality control operations in Section 3, paragraph 2. Problems were encountered in the aircraft position data obtained by Test 4.1 instrumentation and responses obtained for Test 3.1/3.5 (NF). Data losses, absence of unmask data, and failure to fly assigned altitude and speed made it necessary to alter the original analysis plan. Each of these problems is discussed below.

(1) The rationale for deleting data was given in the quality control section. Additional losses resulted from the absence of Test 4.1 position data and pilot behavior; e.g., on targets W4 and E4, the pilots frequently switched off test instrumentation causing substantial losses in outrange estimation data.

(2) The unreliability of unmask range and time resulted in its deletion as a quantitative variable. This caused major revisions in the detection analysis. The analysis was redirected to investigating the target and altitude effects in the hope that these variables would be closely related to unmask range.

(3) The pilots' failure to fly assigned speeds and altitudes resulted in a confounding of these variables with other test factors. As a result of this confounding, the study planned for comparing the effect of three speeds (360 knots, 420 knots and 550 knots) for the F-4C at altitudes of 0 to 500 feet was no longer possible. An attempt was then made to evaluate detection performance for the F-4C using speed and altitude as quantitative variables.

6. RATIONALE FOR THE ANALYSIS PLAN. This paragraph defines the basic analysis flow that was originally planned. Subsequent paragraphs will elaborate on how the analysis progressed in actuality.

a. Initially, the various plots were to be reviewed and possible areas of investigation were to be noted. SCD would be the major source of information concerning quantitative variable-response relationships, while histograms, means and standard deviation would give indications of the effects of qualitative variables.

b. Based upon the observed relationships noted in the SCD and histograms, a beginning model would be created and processed using WRAP. Subsequent analyses would be directed towards refining the significant relationship. ANCOVA models would be used in this phase. WRAP was the program to be used as the correlations and individual variables information in the output would make it possible to see improvement quite easily. Reduction of the residual error would be the primary criterion.

c. As the final series of models were selected, the models would be processed using both WRAP and MANOVA.

d. Models would be formed to identify significant sources of variation in the data with predictive capabilities as a secondary consideration (although WRAP always yields a predictive regression equation). This would result in considerable utilization of qualitative variables unique to this test, such as aircraft type, target, or early warning, that would not be desirable in predictive models. The quantitative variables were to be used as concomitant information.

7. MODIFIED DETECTION ANALYSIS.

a. Three sets of covariables were used in the analysis of detection for describing aircraft performance. These were:

(1) altitude, speed, minimum range, ASA, HSA, SA,

(2) $\dot{\Theta}$, $\dot{\phi}$, $\dot{R}$, ASA, HSA, SA, and

(3) $\omega$, $\dot{R}$, ASA, HSA, SA.

b. The qualitative variables included in the analysis at various times were aircraft type (A/C), target (ST), early warning (EW), and observer (OB). The descriptive statistics on detection range utilized these variables. Descriptive statistics obtained were as follows:

(1) histograms and cumulative frequency plots on detection range for each classification of aircraft type, site, observer, early warning, A/C by ST, A/C by OB, ST by OB, and all data,

(2) SCD across all trials for detection range versus $\dot{\Theta}$, $\dot{\phi}$, $\dot{R}$, ASA, HSA, SA, S, A, $\omega$, $C_A$, Vis, and $R_o$, and

(3) histograms on S and A (computed at detection) for each aircraft type, site, observer, early warning, and across all trials.

c. Based on information presented by the SCD and histograms, a beginning function was evolved for each covariable. These were linear, quadratic, exponential functions that had simple interpretations. Some beginning terms were: $1/ASA$, $EXP\{-(HSA)^2/100\}$, $SA$, $1/\dot{\phi}$, $\dot{R}$, $SA$, $A$, $S$, $R_0$, $EXP\{-(\dot{\Theta} - .002) \times 10^3\}$, and $EXP\{-(\omega - .002) \times 10^3\}$. The constants in the HSA, $\dot{\Theta}$ and $\omega$ expressions were estimates. Throughout the analysis, the functional or structural relationship was most important, whereas the constants would likely be unique with this test.

d. The WRAP program was used to perform regression analysis using covariables from each system and the qualitative variables. Correlations, residuals, and information on each regression coefficient were examined. Three covariables were deemed worthy of further consideration because of their relationships with detection range. These were 1/ASA (correlation = .9719), altitude (correlation = .6164), and speed (correlation = .2415). The functions involving $\dot{\Theta}$ and $\omega$ were strongly correlated with detection range, but were nearly perfectly correlated with 1/ASA, whereas 1/ASA, A, and S were poorly correlated with each other.

e. Many quantitative variables were not useable due to the complexity of the functional relationships between them and the dependent variable. It was important that any terms used as covariables must be of interpretable value. These decisions to remove certain variables from consideration were based mostly on WRAP results, since the scatter plots could not be used to evaluate the influence of the covariable in the presence of qualitative variables.

f. The next step was to conduct a series of straight ANOVA to assess the effects of the qualitative variables in the absence of any covariables. This was done via WRAP since individual factor levels could be investigated in addition to the usual ANOVA evaluation. Prior to the ANOVA there was no indication that problems were present in the data. Considerable care had to be exercised in incorporating the covariables into the ANCOVA models. In order to determine if there was confounding between the qualitative and quantitative variables (other than by using a long, exacting computational cycle), it was necessary to examine the effects of qualitative variables with and without covariables present.

The ANOVA gave the first indications of problems in the data. Prior to any analysis it was known that the design was very unbalanced. Table 3-1 presents the data matrix showing the number of observations which were obtained for each combination of observer, target, aircraft, and early warning level. The lack of observations in many of the cells of Table 3-1 indicates the degree of unbalance. By running models using main effects only and later including interaction terms that were estimable, one can observe how the inbalance and confounding affected the results. This information was available when the ANCOVA were conducted.

g. The variable aircraft subtended angle (ASA) was deemed unsuitable for future use as a covariable as it was essentially another measure of range. However, ASA is normally not available in detection studies and some utilization was desirable. Thus, the following information was provided on ASA and detection range:

(1) SCD of detection range versus ASA for all trials, each aircraft type, each site, each warning condition, and each observer,

(2) SCD of cumulative percent detection versus ASA and 1/ASA for all trials, each aircraft type, each site, each warning condition, and each observer,

(3) for each classification in (2), the following regression equations were provided;

(a) $CP = 1 - A \cdot EXP\{B(Detection)\}$,

(b) $CP = A + B \ Ln \ R$,

(c) $CP = A + B \ Ln \ ASA$,

(d) $CP = 1 - A \cdot EXP\{B(ASA)\}$,

(e) $\text{Detection Range} = 1 - A \cdot EXP\{B(ASA)\}$, and

(f) $\text{Detection Range} = A/(ASA)^{B}$.

h. Speed (S) and altitude (A) were included individually and together in ANCOVA models. Types of models used were as follows:

(1) $y_{ijkl} = \mu + A/C_i + ST_j + EW_k + (A/C \times ST)_{ij} + (ST \times EW)_{jk} + \beta_1 A_{ijkl} + \beta_2 A^2_{ijkl} + e_{ijkl}$,

(2) $y_{ijkl} = \mu + A/C_i + ST_j + EW_k + (A/C \times ST)_{ij} + (ST \times EW)_{jk} + \beta_1 S_{ijkl} + \beta_2 S^2_{ijkl} + e_{ijkl}$, and

(3) $y_{ijkl} = \mu + A/C_i + ST_j + EW_k + (A/C \times ST)_{ij} + (ST \times EW)_{jk} + \beta_1 A_{ijkl} + \beta_2 A^2_{ijkl} + \beta_3 S_{ijkl} + \beta_4 S^2_{ijkl} + \beta_5 (A \cdot S)_{ijkl} + e_{ijkl}$.

Most combinations were tried with the qualitative variables (aircraft, ST, EW) being the only terms common to the series of models. Both WRAP and MANOVA were used to analyze the models. By reviewing the contrasts in MANOVA and individual regression coefficient information in WRAP, it was possible to identify many sources of confounding.

i. Variability in aircraft altitudes measures at the various event times caused many of the problems. A correlation of .62 was obtained between aircraft altitude above target plane and detection range for all trials. Correlations ranging from .83 to .90 were obtained for the F-4C aircraft alone when computed separately for each of the four ground targets. However, the magnitude of these correlations is misleading. For all targets, the ground level tended to slope upwards from the target along the expected flight path. Since the aircraft tended to fly at approxim... the same altitude above the local ground level, their altitude above the target plane gradually decreased as they approached the target. Therefore, aircraft detected at greater ranges would be expected to be at higher altitudes than those detected at closer ranges. Furthermore, the targets were effected differently as the angle of the slope varied from target to target. For this reason, it was impossible to evaluate the effect of altitude on detection range.

j. The above is one example of the types of confounding present. Altitude was confounded with ST, aircraft and EW. The tremendous unbalance contributed to the problem and definitely prohibited any attempts to solve the problem. The use of speed encountered problems similar in nature to those of altitude.

k. As a result of the findings above, the emphasis returned to ANOVA models. To remove some problems and get a design with filled cells, a specific sort using F-4C aircraft and 11 of 16 observers was analyzed. This model was : $y_{ijkl} = \mu + ST_i + EW_j + OB_k + (ST \times EW)_{ij} + (ST \times OB)_{ik} + (EW \times OB)_{jk} = e_{ijkl}$. Target by observer interaction was the most significant factor, and this prompted some further investigations of this model using A and S as covariables. However, this approach did not remove the confounding described earlier. An additional model incorporating ST by EW by OB was analyzed. The significant factors were ST, ST by OB, and ST by EW by OB which essentially says that observers behaved differently at different sites under different early warning conditions. The mean values responsible for the interactions did not follow any consistent pattern.

l. The final step was to investigate the observer within group and between group behavior. This was as a result of the ST by EW by OB interaction. This led to the final decision that the variables employed did not explain the situation. The responses were apparently dependent o...

the somewhat unique aircraft trajectory of each trial and the target terrain. No suitable variables were available to sufficiently describe the data.

m. In summary, the extensive analyses performed on the detection data yielded little in the way of positive results. The reasons above are sufficient to preclude any meaningful findings. Statistical analyses yielded many relationships that seemed to demonstrate the basic problems in the data. Any analysis more sophisticated than descriptive statistics was not effective due to the unbalance and confounding present.

8. STUDIES OF PILOT ACQUISITION MINUS OBSERVER DETECTION TIME INTERVAL ($\Delta_t$).

a. This performance measure was not analyzed extensively. The preliminary analyses yielded findings similar to those on detection range. The plots on $\Delta_t$ utilized in the analyses were as follows:

(1) histograms and cumulative frequency plots on $\Delta_t$ for each classification of aircraft type, site, observer, early warning, A/C by ST, AC by OB, ST by OB, and all data, and

(2) SCD across all trials for $\Delta_t$ versus $\dot{\theta}$, $\dot{\phi}$, $\dot{R}$, SR, ASA, HSA, SA, S, A, $\omega$ and $C_A$ computed at detection and pilot acquire. Additional SCD on $\Delta_t$ were on S, A, $\dot{\theta}$, $\dot{\phi}$, $\dot{R}$, ASA, SA, $C_A$, $\omega$ and SR at detection versus the same variable computed at pilot acquire.

b. In addition to computation of descriptive statistics, several WRAP were conducted. Inspection of these analyses did not reveal any meaningful relationships between $\Delta_t$ and the quantitative and qualitative variables. Because of the concomitant difficulties with evaluation of the detection data, further analysis of $\Delta_t$ was not made.

c. Useful information on the range of differences between pilot and observer performance is contained in $\Delta_t$. No inferences on why $\Delta_t$ varied are possible with the data presently available because of the somewhat unique trial trajectories which affected both the acquire and detection events.

9. RANGE ESTIMATION STUDIES.

a. The problems associated with range estimation (RE) were slightly different than those associated with the detection studies. Angular rates, altitude, speed, minimum crossing range ($R_o$), detection range and ASA were the only variables computed that would seemingly effect distance estimation.

b. The procedure used for analyzing inbound and outbound estimates followed the procedure used on detection data. Many of the unusual relations discovered in the direction data carried over to the RE. The set of qualitative variables differed as EW was not used and assigned ranges were included (used as a qualitative variable or a quantitative variable). The descriptive statistics utilized in the analysis were as follows:

(1) histograms and cumulative frequency plots on EI and EO for each classification of aircraft type, site, observer, assigned range, A/C by ST, A/C by OB, ST by OB, A/C by assigned range, OB by assigned range, ST by assigned range, F-4C A/C by ST by assigned range, and all data,

(2) SCD on EI and EO versus $\dot{\theta}$, $\dot{\phi}$, $\dot{R}$, ASA, HSA, SA, S, A, and computed at inrange and outrange estimates, respectively. Additional SCD on EI and EO versus $R_o$, assigned range and RE training score for inrange and outrange estimates, respectively, were plotted.

c. For the analysis of EI, the quantitative variables retained for extensive investigations were; inrange training score, 1/ASA, $1/\omega^{\frac{1}{2}}$, $\dot{\theta}$, 1/ASA x $1/\omega^{\frac{1}{2}}$, outrange training score, and assigned inrange (AIR). For the analysis of EO, the quantitative variables were; minimum crossing range, 1/ASA, $1/\omega^{\frac{1}{2}}$, 1/ASA x $1/\omega^{\frac{1}{2}}$, outrange training score, and assigned outrange (AOR). The interpretation of products; i.e., 1/ASA by $1/\omega^{\frac{1}{2}}$, were discussed and valid interpretations were considered possible.

d. The evaluation of ANOVA yielded additional information concerning the confounding. Less data was available resulting in greater unbalance.

e. The following type of model was used in analysis of the range estimation data: $y_{ijkl} = \mu + A/C = ST_j + A^{O}_{I}R_k + (A/C \times ST)_{ij} + (A/C \times A^{I}_{O}R)_{ik} + (ST \times A^{I}_{O}R)_{jk} + \beta_1(1/ASA)_{ijkl} + \beta_2(1/\omega^{\frac{1}{2}})_{ijkl} + e_{ijkl}$. Covariables were tried in several combinations, and a series of models resulted. They were processed using both WRAP and MANOVA.

f. In the analysis of EI, the qualitative variables affected by covariables were aircraft, AIR, and ST by AIR. ST, aircraft by ST and aircraft by AIR were always significant. By looking at contrasts and regression coefficient data, it was noted that 1/ASA and $1/\omega^{\frac{1}{2}}$ caused the greatest reversals. Further investigation showed these variables strongly correlated ( $\sim .50$) with AIR. This resulted in evaluation using AIR or 1/ASA and $1/\omega^{\frac{1}{2}}$ separately. These results indicated that AIR did not behave consistently. The ANOVA showed that aircraft by AIR, ST by AIR, ST by aircraft, and ST were significant. The results were not meaningful; i.e., the information available about the sites gave the analysts no insight into why ST by AIR should be significant.

g. The following types of models were used in the analysis of the range estimation data employing covariables:

(1) $y_{ijk} = \mu + A/C_i + ST_j + (A/C \times ST)_{ij} + \beta_1(1/ASA)_{ijk} + e_{ijk}$,

(2) $y_{ijk} = \mu + A/C + ST_j + (A/C \times ST)_{ij} + \beta_1(1/ASA)_{ijk} + \beta_2(1/\omega^{1/2})_{ijk} + e_{ijk}$, and

(3) $y_{ijk} = \mu + A/C_i + ST_j + (A/C \times ST)_{ij} + \beta_1(1/ASA)_{ijk} + \beta_2(1/\omega^{1/2})_{ijk} + \beta_3(1/ASA \times 1/\omega^{1/2})_{ijk} + e_{ijk}$.

h. A similar set of models using $\dot{\theta}$ in place of $1/\omega^{1/2}$ was analyzed. The results showed reversals due to the covariable present. ST was the only qualitative variable consistently significant; whereas, aircraft was never significant. Interaction of aircraft by ST was very sensitive to the covariable(s) present.

Unclassified

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS

4. TITLE (and Subtitle)

GROUND OBSERVER ABILITY TO DETECT AND ESTIMATE THE RANGE OF JET AIRCRAFT FLYING OVER HILLY TERRAIN

5. TYPE OF REPORT & PERIOD COVERED

Consulting Report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(S)

R.D. Baldwin, E.W. Frederickson, A.L. Kubala, M.R. McCluskey, and A.D. Wright

8. CONTRACT OR GRANT NUMBER(S)

DA 44-188-ARO-2

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Human Resources Research Organization (HumRRO)
300 North Washington Street
Alexandria, Virginia 22314

10. PROGRAM ELEMENT PROJECT TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

Office of the Chief of Research and Development
Department of the Army
Washington, D.C. 20310

12. REPORT DATE

August 1968

13. NUMBER OF PAGES

96

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)

Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Cleared for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Research performed by HumRRO Division No. 5, El Paso, Texas (now HumRRO Western Division, El Paso Office) under Work Unit TESTAID.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

air defense systems
aircraft detection
observer performance
range estimation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

During a series of tests to provide operational and technical data for evaluating the capabilities of surface-based air defense systems against attacks by low-altitude high-performance aircraft, the capabilities of ground observers to detect and estimate the range to aircraft flying attack missions against prebriefed ground targets were examined. Observer performance was obtained for three aircraft flying three programmed speeds

(Continued on p 1473 B)

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Continued
(cont fr p1473A)

and two programmed altitudes. Sixteen observers searched a 180 deg sector for each trial, with early warning of an aircraft approach being provided for some trials. Three real time events--time at detection, time when the aircraft was at the estimated inbound range, and time when the aircraft was at the estimated outbound range--were recorded for each observer for each trial.

1473B