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The Performance of Ground Observers in Detecting, Recognizing, and Estimating Range to Low-Altitude Aircraft

by

A. Dean Wright

HumRRO Division No. 5 (Air Defense)

AD ________

December 1966

Prepared for:

Office, Chief of Research and Development Department of the Army

Contract DA 44-188-ARO-2

HumRRO

The George Washington University
HUMAN RESOURCES RESEARCH OFFICE
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CRDHF

SUBJECT: The Performance of Ground Observers in Detecting, Recognizing, and Estimating Range to Low-Altitude Aircraft

TO:

COMMANDER
DEFENSE DOCUMENTATION CENTER
CAMERON STATION
5010 DUKE STREET
ALEXANDRIA, VIRGINIA 22314

1. This report describes a field study to determine man's capability of visually detecting and recognizing low-altitude aircraft at different ranges under near optimum conditions of visibility.

2. Researchers studied the effects on visual detection and aircraft recognition of using or not using binoculars, varying the distance of observers from the flight path, and varying the type of aircraft. Range estimation performance was also studied.

3. Low-altitude aircraft can be detected and recognized at considerable distances under optimum field conditions; range estimation errors were large. Experience during the research suggested that filmed simulation of the recognition task might have considerable potential as a training tool.

4. The findings of this report should be of interest to those involved in establishing doctrine and training and materiel requirements associated with forward area weapons.

FOR THE CHIEF OF RESEARCH AND DEVELOPMENT:

ROBERT B. BENNETT
Colonel, GS
Acting Chief, Human Factors and
Operations Research Division

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

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Technical Report 66-19
Exploratory Study 44

The Human Resources Research Office is a nongovernmental agency of The George Washington University, operating under contract with the Department of the Army (DA 44-188-ARO-2). HumRRO's mission is to conduct research in the fields of training, motivation, and leadership.

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FOREWORD

This report presents the results of aircraft detection and recognition tests conducted 5-8 April 1965 at Dona Ana Range Camp, Fort Bliss, Texas. The research was performed in connection with a Human Resources Research Office Exploratory Study, Training Methods for Forward Area Air Defense Weapons (ES-44). The research was initiated in response to a Technical Advisory Service (TAS) request from the U.S. Army Air Defense Center; subsequently, the U.S. Army Combat Developments Command, Air Defense Agency stated a requirement for a broader program of research, in which the HumRRO research was included as ES-44.

Interim results of these tests were reported in July 1965 to Army agencies directly concerned with doctrine, training, and materiel requirements associated with forward area weapons. Subsequent tests under ES-44 will be described in a Technical Report entitled "Aircraft Detection, Range Estimation, and Auditory Tracking Tests in a Desert Environment," in preparation.

The tests described in the present report were conducted by HumRRO Division No. 5 (Air Defense) under Dr. Robert D. Baldwin, Director of Research. Mr. Edward W. Frederickson and Dr. Baldwin were active members of the team planning and conducting the research. Virtually all research members of Division No. 5 were involved in the test, as monitors or advisors.

The U.S. Army Air Defense Center provided troops, range facilities, and Army aircraft, and also initiated contacts for interservice participation. MAJ Daniel L. Ford, Project Officer, U.S. Army Air Defense Center, provided extensive assistance in every phase of the test effort.

Instrumentation and preliminary data reduction were provided by the U.S. Army Air Defense Board. Tactical air support and forward air controllers were furnished by the Twelfth Air Force. Major Mitchell, Twelfth Air Force Project Officer, and Major Edinburgh, 366th Tactical Wing Project Officer, provided valuable assistance in the planning and execution of the test.

LTC Leo M. Blanchett, Jr., who was chief of the U.S. Army Air Defense Human Research Unit at the time of the tests, served as military test officer and coordinated military and civilian activities. Personnel of the U.S. Army Air Defense Human Research Unit and the U.S. Army Air Defense Center acted as test monitors.

Assistance in the initial planning of the test was provided by members of the U.S. Army Air Defense Center; U.S. Army Air Defense School; U.S. Army Combat Developments Command, Air Defense Agency; U.S. Army Air Defense Board; and White Sands Missile Range.

HumRRO research efforts are conducted under Army Contract DA 44-188-ARO-2 and Army Project 2J024701A712 01, Training, Motivation, Leadership Research.

Meredith P. Crawford
Director
Human Resources Research Office

Military Problem

The Department of Defense has recently shown increasing interest in man's ability to visually detect, recognize, and estimate the range to low-flying aircraft. This interest is due in part to the development of small, highly mobile, non-radar equipped gun and missile systems designed for local low-altitude air defense.

Research Problem

The primary objective of the test described in this report was to determine man's unaided ability to visually detect and recognize low-altitude aircraft under optimum field conditions. Secondary objectives were (a) to determine the effect upon visual detection and recognition of several factors—the use of binoculars, the amount the observer is offset from the flight path, and the type of aircraft, and (b) to obtain data concerning man's ability to estimate aircraft range.

Method

The study was conducted in April 1965 in a relatively flat, desert environment approximately 20 miles north of El Paso, Texas. This test area provided excellent meteorological conditions and little or no terrain masking of aircraft on long, low-altitude approaches.

Eight aircraft types were specified for the test. The jet class of aircraft included an F-4C, an F-100, and a T-33. The propeller class included a U-1A, a U-6A, and an O-1A. The helicopters included an OH-13 and an OH-23. The jet aircraft flew at approximately 400 knots, the propeller aircraft at 100 knots, and the helicopters at 75 knots. The fixed-wing aircraft flew at altitudes of approximately 100-300 feet above the terrain. The helicopters typically flew below 100 feet altitude.

Ten different flight paths were flown by the aircraft. They were chosen to give a wide representation of target-observer-sun angles and were evenly distributed across and within the aircraft classes.

Twenty-seven noncommissioned enlisted men served as observers in the test. They were selected by the U.S. Army Air Defense Center to be representative of typical crewmen assigned to visually sighted weapon systems. Visual acuity as measured on a standard test was 20/25 or better for all observers. They received informal training in visual search techniques, use of binoculars, aircraft recognition, and range estimation during the week prior to the field test. The observers also practiced detection and recognition in the field for one and one-half days prior to data collection.

The observers were randomly assigned to one of the nine combinations of the two test variables: (a) Observer offset, including no offset, 650-meter offset, or 1,400-meter offset, and (b) use of 6x30 binoculars, including no binoculars, binoculars for recognition, or binoculars for detection and recognition.

Each observer was co-located with a test monitor. The monitor provided early warning, accurate within $\pm$ 15°, of the expected heading of the aircraft. Temporal early warning was a semicontrolled variable which preceded the appearance of the aircraft by five seconds to five minutes depending upon aircraft speed and time of arrival upon flight path. The test monitor also recorded the observer's responses. Observers were located at least 60 yards apart to assure independence of responses.

The observers were required to respond in the following sequence: (a) detection, (b) range estimate at detection, (c) tentative recognition, (d) range estimate at tentative recognition, (e) positive recognition, and (f) range estimate at positive recognition.

Results

(1) *Jet Aircraft*

(a) The visual detection and recognition ranges obtained proved to be greater than those obtained in previous studies.

(b) Visual detection of jet aircraft occurred at or before approximately 10,000 meters 50% of the time.

(c) The .5 probability of recognition of jet aircraft occurred at approximately 6,500 meters for tentative recognition and approximately 3,250 meters for positive recognition.

(d) The tentative recognition responses were 86.2% correct, and the positive recognitions were 97.6% correct.

(2) *Propeller Aircraft*

(a) The .5 probability of detection occurred at or before approximately 8,800 meters for the propeller aircraft.

(b) The .5 probability of recognition occurred at approximately 5,900 meters and 3,300 meters for the tentative and positive recognition responses, respectively.

(c) The tentative recognition responses were 64.4% correct, and the positive recognition responses were 89.5% correct.

(3) Binoculars increased the range at which jet and propeller aircraft were recognized.

(4) Binoculars increased the detection range of jet targets when the observers were offset from the flight path. The use of binoculars, however, decreased the detection range on the head-on jet targets.

(5) A relatively crude 35mm slide proficiency test administered at the end of classroom training was found to correlate significantly with field recognition performance.

(6) The range estimation abilities of the observers ranged from a mean overestimation of approximately 50% to a mean underestimation of approximately 50%.

Conclusions

These data indicate man can detect and recognize low-altitude aircraft at a considerable range under near-optimum field conditions.

In general, binoculars and offset both tend to increase the range at which aircraft are recognized. This effect holds over a wide variety of conditions.

The value of binoculars for detection of low-altitude aircraft appears to be dependent upon a number of environmental and aircraft characteristics including: (a) observer offset from flight path, (b) accuracy of early warning, (c) aircraft speed, and (d) smoke characteristics of the aircraft. Under the conditions employed in this test, binoculars tended to reduce detection range on the most threatening targets, that is, high-speed, head-on jet aircraft.

Filmed simulation of the recognition task appears to be a promising training technique as well as a valid technique for research purposes. However, replication or extension of the findings in this study would be needed to establish the value of the technique for training.

The range estimation test results indicate that the training given in estimating the distance to ground objects was ineffective for ground-to-air estimation. Range estimation over the relatively long ranges involved appears to be a complex task which has not been systematically explored to date.

CONTENTS

Tables | Page

The Performance of Ground Observers in Detecting, Recognizing, and Estimating Range to Low-Altitude Aircraft

RESEARCH PROBLEM

Background

The resurgence of interest in man's ability to visually detect, recognize, and estimate range to aircraft is due to recent efforts to provide local air defense capability against low-altitude aircraft. The weapons that will provide low-altitude air defense may include rifles, machine guns, World War II-type antiaircraft guns (up to 40mm), as well as the shoulder-launched Redeye, and the readily transportable Chaparral missile systems. All of these weapons currently require visual target detection, recognition, and some form of range estimation.

Visual detection and recognition ranges obtained under optimum field conditions are required to determine the system limitations imposed by the man component in these highly man-dependent air defense systems. These data are also needed to determine training requirements for the weapons to be used and to provide inputs for computer simulations of the forward area air defense problem.

Several studies have been done that indicate man's capability as a visual detector of aircraft (Frederickson, Follettie, and Baldwin 1; Adelsberg et al., 2; U.S. Army Combat Development Experimentation Center, 3; General Dynamics, 4; Wokoun, 5; Zimmer and McGinnis 6). These studies evidence considerable variability in detection ranges and furnish little data concerning identification range. The data obtained by Wokoun (5) at the U.S. Army Ordnance Human Engineering Laboratories (HEL) provided a good indication of detection ranges likely to be obtained under "observation post" settings, but lacked the variety of aircraft types necessary to determine meaningful detection or identification ranges for aircraft other than interceptor-type jets.

Objectives

A study to gather additional detection and identification information was undertaken by the Human Resources Research Office.[1] The principal objective was to determine man's unaided ability to visually detect and recognize low-altitude aircraft under optimum field conditions.

Secondary objectives were to (a) determine the effect upon visual detection and recognition of use of binoculars, the observer's location relative to the aircraft flight path, and the class of aircraft; and (b) obtain data concerning man's ability to estimate the range to low-altitude aircraft.

METHOD

Test Conditions

The following test conditions were required to ensure that the data would represent a reasonable upper limit of man's ability to visually detect and recognize low-altitude aircraft:

(1) A terrain environment that provided long, unmasked, low-altitude approaches and excellent meteorological conditions.

[1] In a subsequent phase of the study to the one reported here, research was extended to auditory detection and tracking skills and to the range at which an aircraft's structural components are recognized. Tests were performed in a desert environment. This report is in preparation (1).

(2) Early warning in time and position that is as accurate as can be obtained in the field. It is common knowledge that search for periods exceeding 30 minutes will drastically reduce the probability of detecting a target. It is also well known that the probability of visual detection decreases as search area increases.

(3) Training and field experience for observers in aircraft detection and recognition prior to testing.

Test Site and Meteorological Conditions

The test was conducted during 5-8 April 1965 at Dona Ana Range Camp, Fort Bliss, Texas. The test area is flat desert terrain, the same as was used in the detection tests conducted by White Sands Missile Range (6). It allowed low-altitude aircraft approaches up to 20 miles in length that were unobstructed by terrain masking. Visibility was greater than 90 miles for all test days except one morning, when visibility was not less than approximately 50 miles.

Early Warning

Each observer was paired with a test monitor. To maintain independent responses, each observer-monitor pair was separated by at least 60 yards from any other pair within a test group.

The monitors were linked by phone with test control. At the start of an aircraft pass, the monitor informed his observer that an aircraft was inbound and provided him with the clock bearing to the aircraft. The observer was oriented to the clock bearings in terms of prominent landmarks located at 12, 3, and 9 o'clock.

The monitor provided early warning for expected time of arrival (temporal early warning) and direction of flight (positional early warning). Positional early warning was accurate within ± 15°. Temporal early warning was provided between five seconds and five minutes before the aircraft could become visible to the observer, depending upon speed and time of arrival on flight path.

Observers

Twenty-seven enlisted men served as observers in the test. They were selected by the U.S. Army Air Defense Center to be representative of typical crewmen assigned to visually sighted weapon systems. Their visual acuity was 20/25 or better as measured on a standard test. They were randomly assigned to one of the nine test conditions.

Observer Training

The observers were given one week of training in visual target detection, recognition, and range estimation. A total of eight hours of aircraft recognition training, primarily concerning the aircraft to be used in the test, was provided each observer. Classroom training and testing made use of 35mm slides of model jet aircraft, and included the standard WEFT (7) and Sargent (8) training techniques.

The observers correctly identified 73.8% of the jet aircraft shown in a 40-item, 35mm slide test given at the end of this recognition training. No end-of-training slide test was available for the propeller and helicopter aircraft.

As a part of target detection, all observers were given training in search techniques. The search technique employed was a horizontal scan with frequent orientation to distant terrain. The main purpose of this training was to enable the observers to avoid the development of "empty field myopia," nearsightedness that occurs when the optical stimuli resulting in accommodation are absent. Those observers who were designated to use binoculars were trained in their use for search and in techniques of holding the binoculars steady.

All observers were given experience in range estimation at distances of from 350 to 2,000 meters during a training session prior to field testing. This consisted mainly of practice in estimating range to ground objects and in using the size of familiar objects to estimate range. The major purpose of the training was to provide the observer with a "reasonably calibrated yardstick" to use in making his estimates.

In the field, the observers viewed 27 jet, 15 propeller, and 10 helicopter passes before testing began. Each aircraft type was announced prior to its first pass and feedback on aircraft types was provided on at least two additional passes per aircraft before testing began. The observers, therefore, had received classroom and field training in aircraft recognition prior to testing. No training or feedback concerning estimation of ground-to-air range was provided in the field.

Aircraft

Three classes of aircraft were flown:

(1) Jet targets, consisting of an F-4C, F-100, and T-33. (An F-104 was scheduled and flew four passes during training, but was not available for the test passes.) Their speed was about 400 knots and they flew at about 100-300 feet in altitude.

(2) Propeller targets, consisting of an O-1A, U-6A, and U-1A. Their speed was about 100 knots and their altitude about 100-300 feet.

(3) The OH-23 helicopter. (The OH-13 was also scheduled, but it aborted early in the test phase due to mechanical difficulties.) The helicopter's speed was about 75 knots and its typical altitude was under 100 feet.

For flight safety purposes, only one class of aircraft was flown during each hour. Each of the jet aircraft made four passes during an hour assigned to jets; propeller aircraft made three passes in an hour, and the OH-23 helicopter either two or four passes, depending upon the availability of the OH-13.

Binoculars

Three conditions of visual aids were employed: (a) unaided vision for both detection and recognition, (b) use of 6x30 binoculars for both target detection and recognition, and (c) unaided vision for detection and 6x30 binoculars for target recognition.

Aircraft Flight Path and Observer Offset

Ten different flight paths were flown during the test, three per hour. All of them converged at the center of the test area and data were collected only on the inbound portion. The flight paths were chosen to give a wide sample of target-observer-sun angles that were evenly distributed across and within the aircraft class variable.

Three distributions of offset from the aircraft flight path were used in the study by locating groups of observers at three places: Group A at the center of the test area, Group B about 1,000 meters southeast of the test center, and Group C about 2,000 meters north of the test center.

The specific offset for any test group depended upon the flight path for a given trial. The specific offset for Group A ranged from zero to approximately 200 meters. Group B's offset ranged from about 100 to 1,000 meters, with a mean offset of 650 meters. The actual offset for Group C ranged from about 600 to 2,000 meters, with a mean offset of 1,400 meters.

Figure 1 depicts the offsets of the observer groups and the flight paths.

Offset Sites and Flight Paths

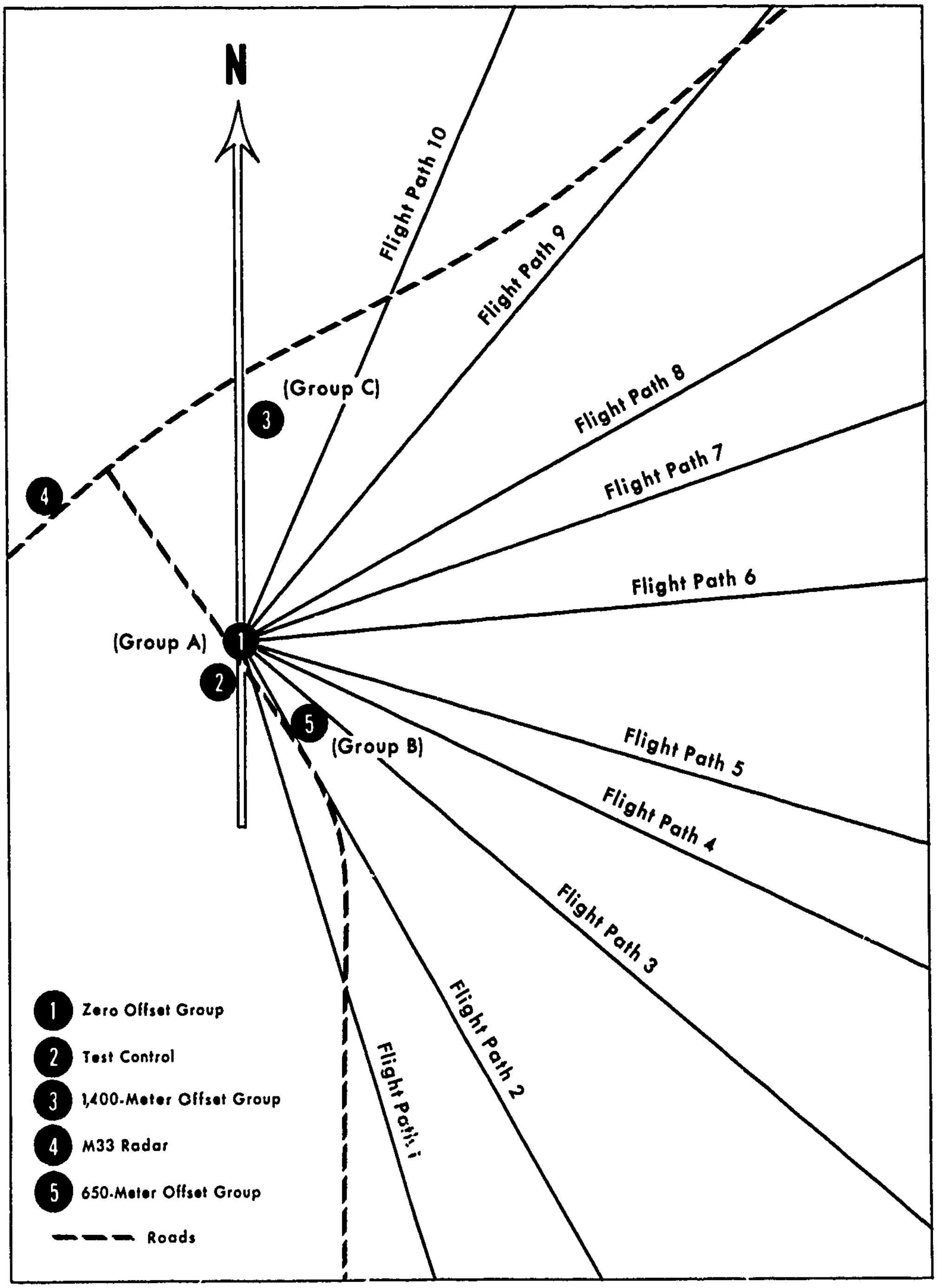

Figure 1

Performance Measures

Each observer was required to give six different responses on each trial. The responses occurred in the following sequence:

(1) Detection, which simply indicated that the observer had located the aircraft.

(2) An estimate of the aircraft slant range—the actual range from the observer—at detection.

(3) Tentative recognition, a response that was subjectively better than a chance guess, but still uncertain (i.e., "I think it's an F-100.").

(4) An estimate of the aircraft slant range at the tentative recognition response.

(5) Positive recognition, a response that the observer was subjectively "certain" was correct (i.e., "I'm sure it's an F-100.").

(6) An estimate of the aircraft slant range at the positive recognition response.

The test monitors immediately recorded the observers' aircraft type recognition and range estimate responses by depressing a switch that caused a mark to be made on an event recorder tape. The event recorders were synchronized to a common time base with radar range data, recorded on magnetic tape, from two M33 radars. These data were used to compute the actual slant range from each observer to the aircraft at the instant of each response.

Conduct of Test

At the start of each aircraft pass, the monitors told the observers that an aircraft was inbound at a given clock position. As soon as the observer detected the aircraft, he informed his monitor and made his first estimate of the range to the aircraft. The monitor then pressed the button that activated the event recorder pen. (The time mark made would later be correlated with the time base of the radar data to obtain actual slant range.) As soon as the observer was willing to identify the aircraft tentatively, he said, "Tentative," and gave the aircraft type designation and his second range estimate. The monitor again recorded the observer's tentative recognition response and range estimate. As soon as the observer was certain of the aircraft type he said, "Positive," stated the aircraft type designation, and made his final range estimate. Again, the monitor pressed the button to record the positive recognition response and range estimate.

Experimental Design and Analysis

The effects of observer offset, binoculars, aircraft class, and response type (detection, tentative and positive recognition) were analyzed using a Lindquist Type VI model (9) extended for a second between-subjects factor. Each cell in the design consisted of data from three observers; each observer's performance, for all trials in each condition, was averaged to provide a single value entered in the cell for that observer. The helicopter data were not included in this analysis because of the relatively small number of observations per observer.

The data of prime interest concerned the probability of detection and recognition as a function of aircraft slant range for various types of aircraft and conditions of observation. These data are simply cumulative probability plots of the data as a function of aircraft range for the conditions of interest.

Statistical tests of these distributions employ the Kolmogorov-Smirnov two-sample test (10, pp. 127-136).[1]

RESULTS AND DISCUSSION

Analysis of Observer Performance

A summary table of an analysis of variance of the observers' performance is presented in Table 1. Mean aircraft slant range for each of the 54 combinations of experimental conditions is presented in Table 2.

All main effects except observer offset were statistically significant. It should be mentioned, however, that observer offset interacted with the remaining variables—binoculars, response, and aircraft class—and was a highly significant factor in certain cases.

The statistically significant effects for use of binoculars were primarily due to the extended recognition range accompanying use of binoculars and should not be construed to mean that binoculars are of general value in target detection. Jet targets were generally detected and recognized at greater ranges than propeller

Table 1

Analysis of Variance of Observer Performance

Source	SS	*df*	MS	*F*	*p*
Between *Ss*	188,650,139	26	–		
Binoculars (A)	68,908,773	2	34,454,387	9.07	<.01
Offset (B)	3,502,728	2	1,751,364	<1.00	NS
AB	47,885,545	4	11,971,386	3.15	<.05
Error (b)	68,353,093	18	3,797,394		
Within *Ss*	1,414,910,784	135	–		
Response (C)	1,229,883,584	2	614,941,792	686.51	<.001
Aircraft type (D)	27,018,601	1	27,018,601	49.68	<.001
AC	26,349,391	4	6,587,348	7.35	<.001
AD	6,389,436	2	3,194,718	5.87	<.05
BC	21,514,537	4	5,378,634	6.00	<.01
BD	3,120,569	2	1,560,285	2.87	NS
CD	13,071,225	2	6,535,613	40.03	<.001
ABC	14,424,842	8	1,803,105	2.01	NS
ABD	10,971,971	4	2,742,993	5.04	<.01
ACD	481,181	4	104,545	<1.00	NS
BCD	3,878, 015	4	969,504	5.94	<.01
ABCD	9,957,724	8	1,244,716	7.62	<.001
Error (w)	47,912,708	90	532,363		
$Error_1$ (c)	32,246,994	36	895,750		
$Error_2$ (d)	9,788,508	18	543,806		
$Error_3$ (cd)	5,877,206	36	163,256		
Total	1,603,560,923	161	–		

[1]Although this statistic assumes independent samples, Edwards (11, p. 282) indicates that for tests assuming related samples to have a statistical advantage over tests assuming random samples, a positive correlation must exist between the pairs of observations that is sufficiently high to offset the number of degrees of freedom lost when observations are paired. The use of the Kolmogorov-Smirnov two-sample test may, therefore, provide a somewhat conservative test of the independence of the distributions involving related samples; that is, aircraft type, aircraft class, and response type. This disadvantage is acceptable; it simply reduces the probability of accepting a difference attributable to chance.

Table 2

Mean Aircraft Slant Range Under Experimental Conditions

(Meters)

Experimental Condition[a]	Aircraft Class	Detection	Tentative Recognition	Positive Recognition
Unaided Vision				
0 Offset	Jet	13,159	4,587	2,180
	Propeller	9,768	3,906	2,007
650-Meter Offset	Jet	11,172	6,199	2,700
	Propeller	8,974	4,962	1,994
1,400-Meter Offset	Jet	8,442	5,347	2,834
	Propeller	9,039	4,714	2,488
Unaided Detection - Aided Recognition				
0 Offset	Jet	12,360	7,335	4,501
	Propeller	9,864	6,696	3,892
650-Meter Offset	Jet	9,421	5,766	3,074
	Propeller	8,592	6,370	3,835
1,400-Meter Offset	Jet	9,722	7,342	4,919
	Propeller	9,553	7,952	5,245
Aided Detection and Recognition				
0 Offset	Jet	9,973	6,227	3,470
	Propeller	9,661	5,370	2,926
650-Meter Offset	Jet	13,081	7,929	5,020
	Propeller	9,695	7,086	4,393
1,400-Meter Offset	Jet	12,539	7,988	4,960
	Propeller	10,255	6,757	4,198

[a]The 650-meter and 1,400-meter offsets are means; the actual offsets range from 100 to 1,000 meters and from 600 to 2,000 meters respectively.

targets. A more sensitive analysis of this variable is found within the plots of detection and recognition range as a function of aircraft type that are presented in a later section.[1]

The differences between the distributions of the three responses—detection, tentative recognition, and positive recognition—are statistically significant. This finding is of interest since it means that tentative recognition may be used as a basis for preparing a system for engagement, and could appreciably reduce reaction time for weapons with long warm-up periods.

The significant third order interaction (the ABCD effect of Table 1) indicates that observer performance is differentially influenced by the various combinations of the four variables examined. This interaction may be described in terms of the changes in detection and recognition ranges that occur under differing combinations of the binocular, offset, and aircraft type variables. Based upon Kolmogorov-Smirnov (10) tests of the appropriate cumulative probability distributions, the following statements describe the principal trends contained within the third order interaction:

(1) Detection range. Neither the binoculars nor the offset affected the detection range of propeller targets (0 offset = 650-meter offset = 1,400-meter offset; and, no binoculars = binoculars at all offsets). For jet targets, detection range increased as offset increased when binoculars were used (1,400-meter offset >0 offset, $p<.05$). When binoculars were not used to detect jet targets, detection range decreased as offset increased (0 offset >1,400-meter offset, $p<.05$).

[1]See Figures 6 and 7.

(2) Recognition range

(a) Tentative and positive recognition ranges increased as offset increased for both jet and propeller targets (1,400-meter offset >0 offset, $p < .05$, both target types).

(b) Tentative and positive recognition ranges increased when binoculars were used for both jet and propeller targets (binoculars >no binoculars, $p < .05$, both target types).

In general, binoculars appeared to increase the range at which low-altitude aircraft were recognized. This effect held over a wide variety of conditions. The value of binoculars for detecting low-altitude aircraft appears to be dependent upon a number of environmental and aircraft characteristics. Unfortunately, under the conditions employed in this test, binoculars appear to reduce detection range on the most potentially threatening targets; that is, the zero offset or head-on, high-speed jet targets.

Comparison of Recent Studies in Detection and Recognition Range

The detection ranges obtained in this study were similar to those obtained by Frederickson, Follettie, and Baldwin (1), who had similar meteorological and early warning conditions. In contrast, Wokoun (5), in the Human Engineering Laboratories (HEL) study, obtained much shorter detection and recognition ranges. In Wokoun's test, meteorological and terrain conditions were similar to those reported here, but temporal early warning was not provided and the angle of search was varied. It is not unreasonable to assume that, in the HEL study, the vigilance effect produced by not providing early warning so degraded performance that the effect of search sector—equivalent in the HumRRO study to early warning concerning position—appeared inconsequential. The shorter detection and recognition ranges obtained by Wokoun represent probable detection and recognition ranges under less than optimum early warning conditions.

The White Sands Missile Range (WSMR) study (6) was conducted at an earlier time at the site used by the center group of the present study. Instead of locating observers at different offsets, the WSMR study changed the flight path. The detection ranges obtained in that study fall between those obtained in the HEL study and those of the study reported here.

Although the WSMR study used a 30° search sector for one condition and a 180° search sector in the remaining two alert conditions, it is unlikely that the 30° search sector was obtained under the test conditions employed. When an aircraft's flight path is tangential to an observer's position, the search area he employs will be determined by the location of the aircraft at detection during previous trials. The accuracy of early warning in time will also increase or decrease the effective search area since, if temporal early warning precedes the appearance of the aircraft by a relatively fixed and short interval, successive aircraft will normally be detected at about the same position. If early warning in time precedes detection by a relatively large interval (perhaps two minutes or more, depending upon the aircraft speed), or in a random fashion, the observer must increase his search sector to be certain he has not inadvertently "missed" the aircraft. In the WSMR test, the observers probably searched an area approximating 180°, rather than the 30° search sector specified, when rather large flight path offsets were used. It is believed that this factor significantly influenced the detection ranges obtained.

It should be noted that this larger search sector also influenced the accuracy of positional early warning for the 650-meter and 1,400-meter offset groups used in the study reported here. The ± 15° search sector employed in this study was undoubtedly an overestimation of the actual search areas employed by the center test group. Admittedly, the effective search area for the 650-meter and 1,400-meter offset groups probably exceeded ± 15° in some cases. However, considering the accuracy of early warning in time and the clock landmarks used for the positional early warning, these cases were the exception rather than the rule.

It is believed that the differences in detection range for comparable aircraft used in the test reported here and in the HEL and WSMR tests are due to differences in search area and temporal early warning, which varied among the studies. Unfortunately, precise knowledge of the accuracy of early warning in time and position is very difficult to measure or control in the field situation; yet it undoubtedly materially influences aircraft detection and, hence, recognition range.

Visual Detection Effects Attributable to Aircraft Exhaust Smoke and Accuracy of Early Warning

Lamar (12) has indicated that the use of binoculars for target detection may decrease detection performance, depending upon the search area involved and the target speed. With binoculars, the field of view is restricted and a longer period of time is required to search a given area; hence, detection ranges are likely to be lower.

Dugas (13) has, in a mathematical analysis of aircraft detection, predicted that target offsets up to 2,000 yards would not appreciably influence detection range.

Superficially, the data reported here do not appear to support either prediction. The detection data were complicated by one or more factors confounded within the present study, and offset per se is not clearly reflected. The accuracy of early warning, and observer offset from the flight path partially determined the effective search sector. Accuracy of early warning decreased as offset increased, because of increased search area. Under these conditions it could be predicted that detection range would decrease as offset increased. The jet aircraft, being within a given search sector for a shorter period of time, would be expected to show a greater loss in detection range as a function of offset than would the slower propeller targets.

These effects occurred for the jet aircraft when binoculars were not employed in the detection task; however, the jet targets were detected at greater ranges as offset increased when binoculars were employed. This reversal of the predicted effects of offset appears to be related to the smoke trails produced by the jets.

Jet aircraft tend to produce smoky exhaust trails at low altitude. The quantity or density of the smoke produced appears to vary between different types of aircraft. In addition, the smoke density for each type of aircraft appeared to depend upon the power setting of the engine and the altitude flown under the conditions employed. In this test, the F-4C produced a very noticeable smoke trail, the F-100 emitted a moderate trail, and the T-33 did not appear to produce any smoke trail. The fact that detection ranges of the jet aircraft varied concomitantly with the smoke density suggests that the differences in exhaust smoke density may be an important determinant of aircraft detection.

The presented area of the smoke trail increased as offset increased. With the binoculars, the exhaust trail presented to the offset groups may have been visible sooner, creating, in effect, a larger target and a smaller effective search area.

Lamar's predictions about the use of binoculars decreasing detection performance can be reconciled with these results if it is assumed that the effective search area varied in the two studies as a function of offset and jet aircraft exhaust smoke.

Dugas' prediction about the effect of observer offsets up to 2,000 yards not appreciably influencing detection range seems appropriate for the propeller targets. Offset does, however, appear to be an important factor in the detection of jet aircraft if they emit smoke and if binoculars are used. But this effect is presumably due to changes in effective search area attributable to the visibility of the exhaust trail, rather than to the simple effect of offset.

Detection and Recognition Range Plots

The empirical probabilities of detection and recognition as a function of aircraft range are shown in Figure 2 averaged over all aircraft and conditions of observation.

The empirical probabilities of detection and recognition as a function of range are shown in Figure 3 for the three classes of aircraft. These plots are averaged over the visual aids and observer offset conditions.

The empirical probabilities of detection and recognition as a function of aircraft range are shown in Figure 4 for the three conditions of visual aids. These plots are averaged over the aircraft class and observer offset conditions.

The empirical probabilities of detection and recognition as a function of range are shown in Figure 5 for the three observer offset conditions. These plots are averaged over the aircraft classes and visual aids conditions.

The empirical probabilities of detection and recognition as a function of range are shown in Figures 6 and 7 for each of the seven aircraft types.

Statements concerning the independence of these plots are contained within the appropriate figures. The Kolmogorov-Smirnov test was used in the statistical analyses.

Empirical Probabilities of Detection and Recognition (Average of All Aircraft and All Conditions)

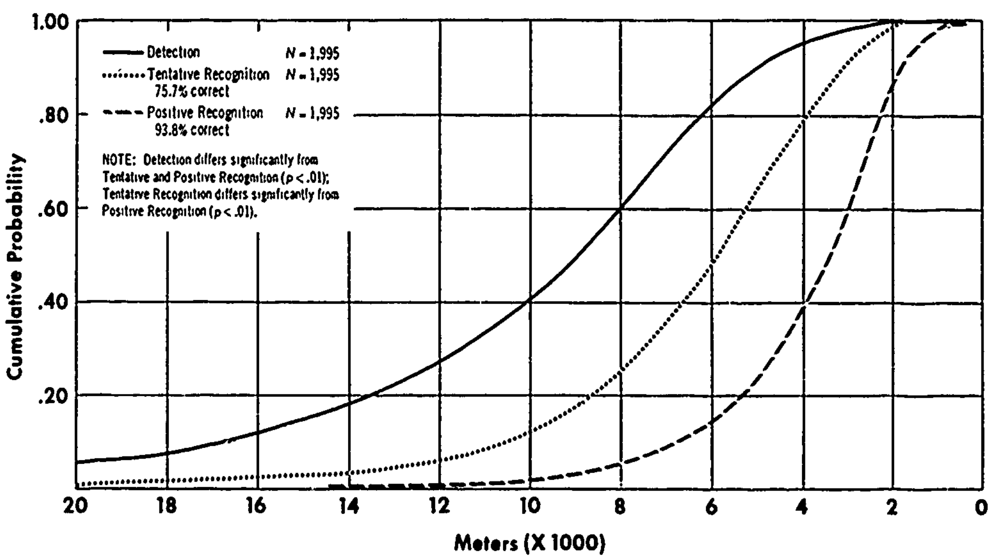

Figure 2

Effect of Aircraft Range and Class on Empirical Probabilities of Detection and Recognition

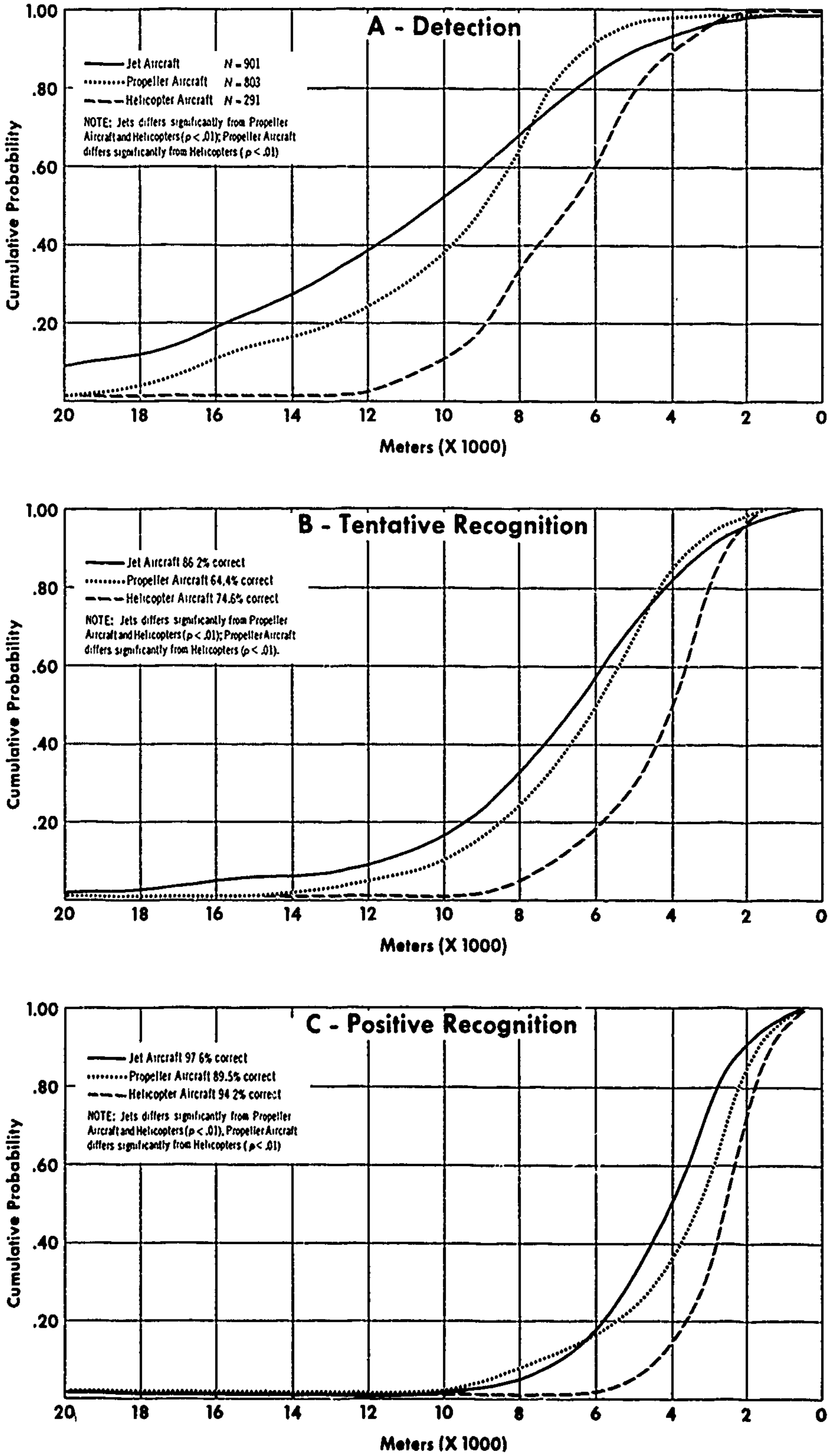

Figure 3

Effect of Aircraft Range and Use of Binoculars on Empirical Probabilities of Detection and Recognition

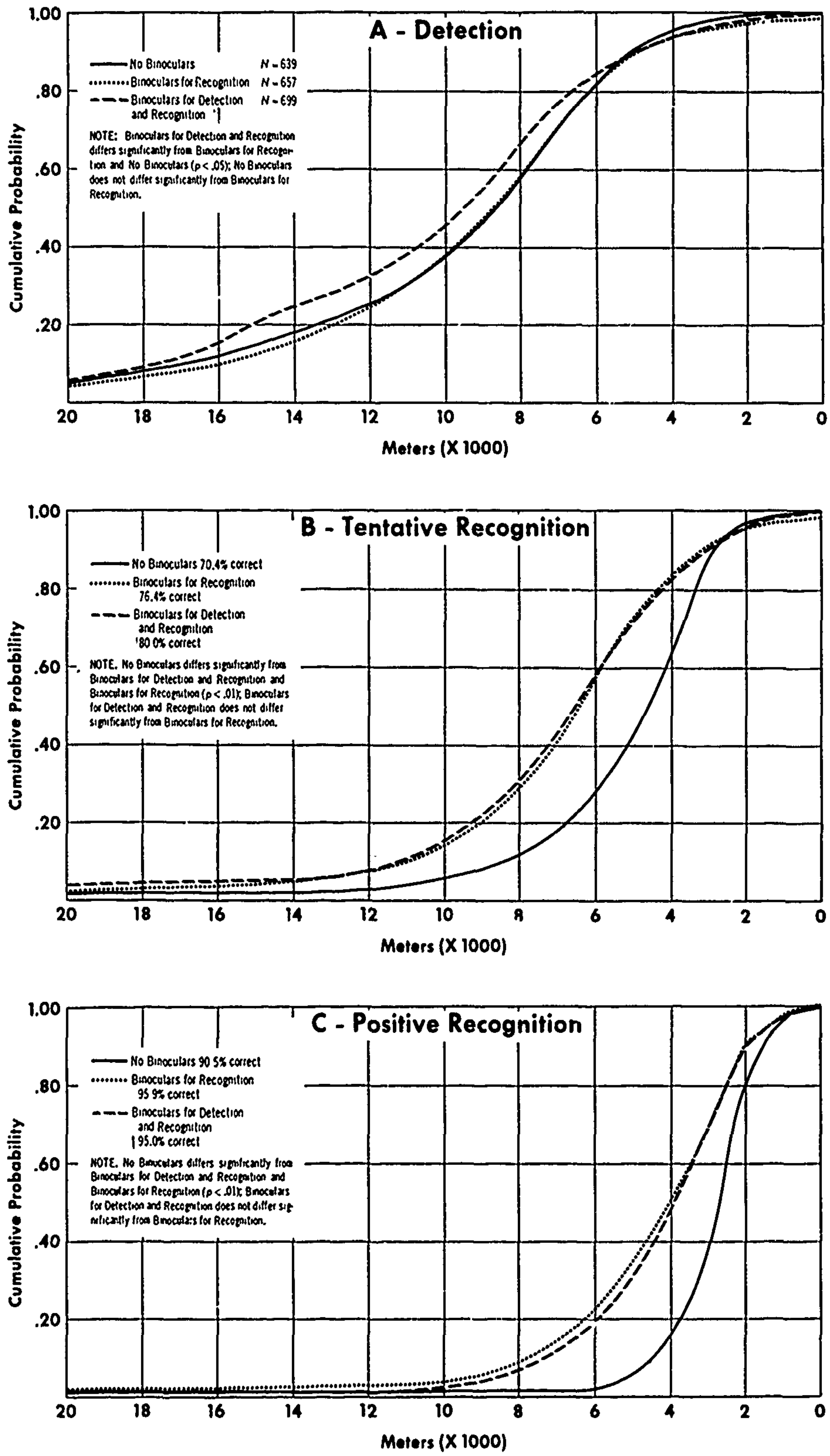

Figure 4

Effect of Aircraft Range and Observer Offset on Empirical Probabilities of Detection and Recognition

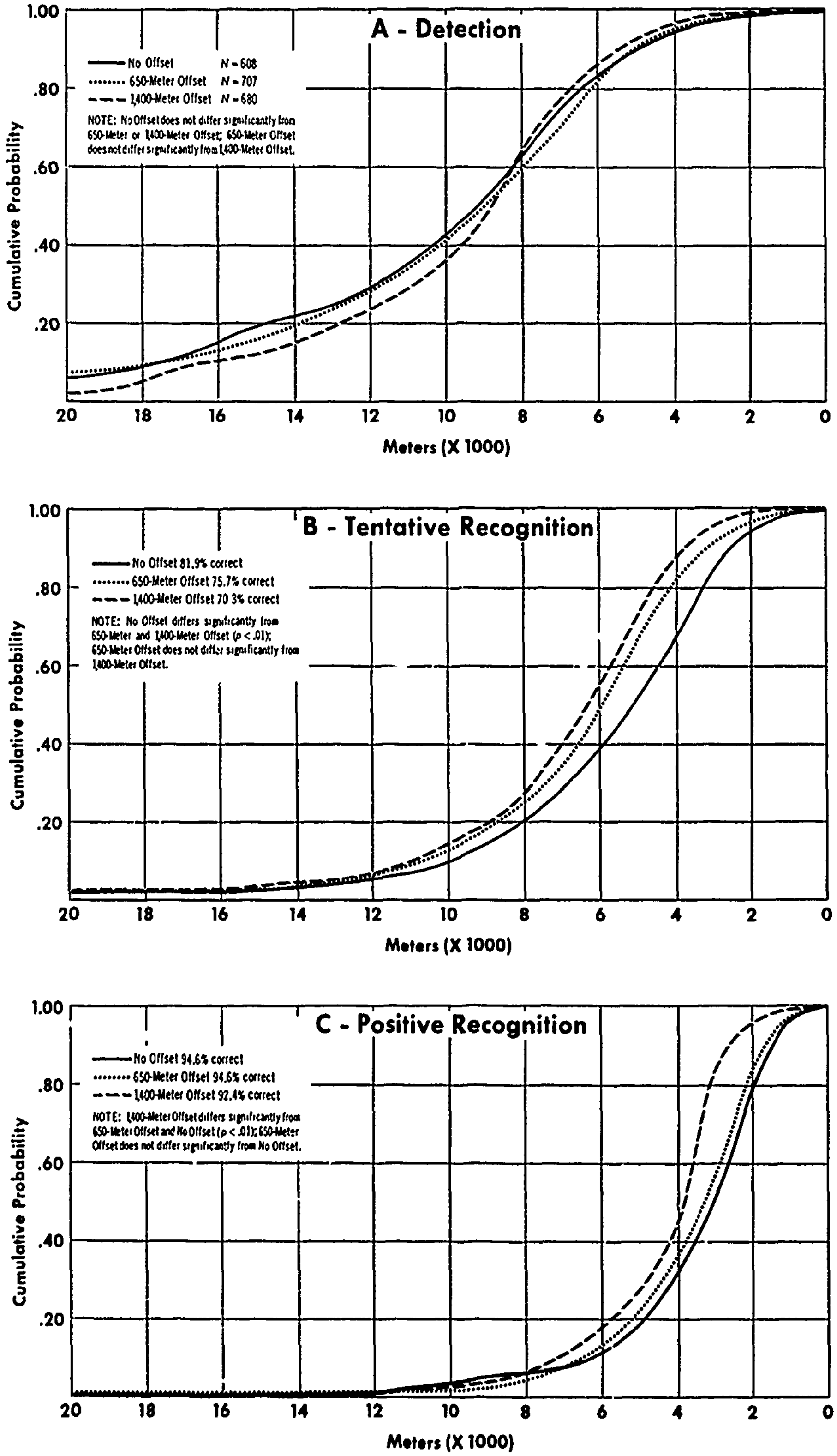

Figure 5

Effect of Aircraft Range and Jet Aircraft Type on Empirical Probabilities of Detection and Recognition

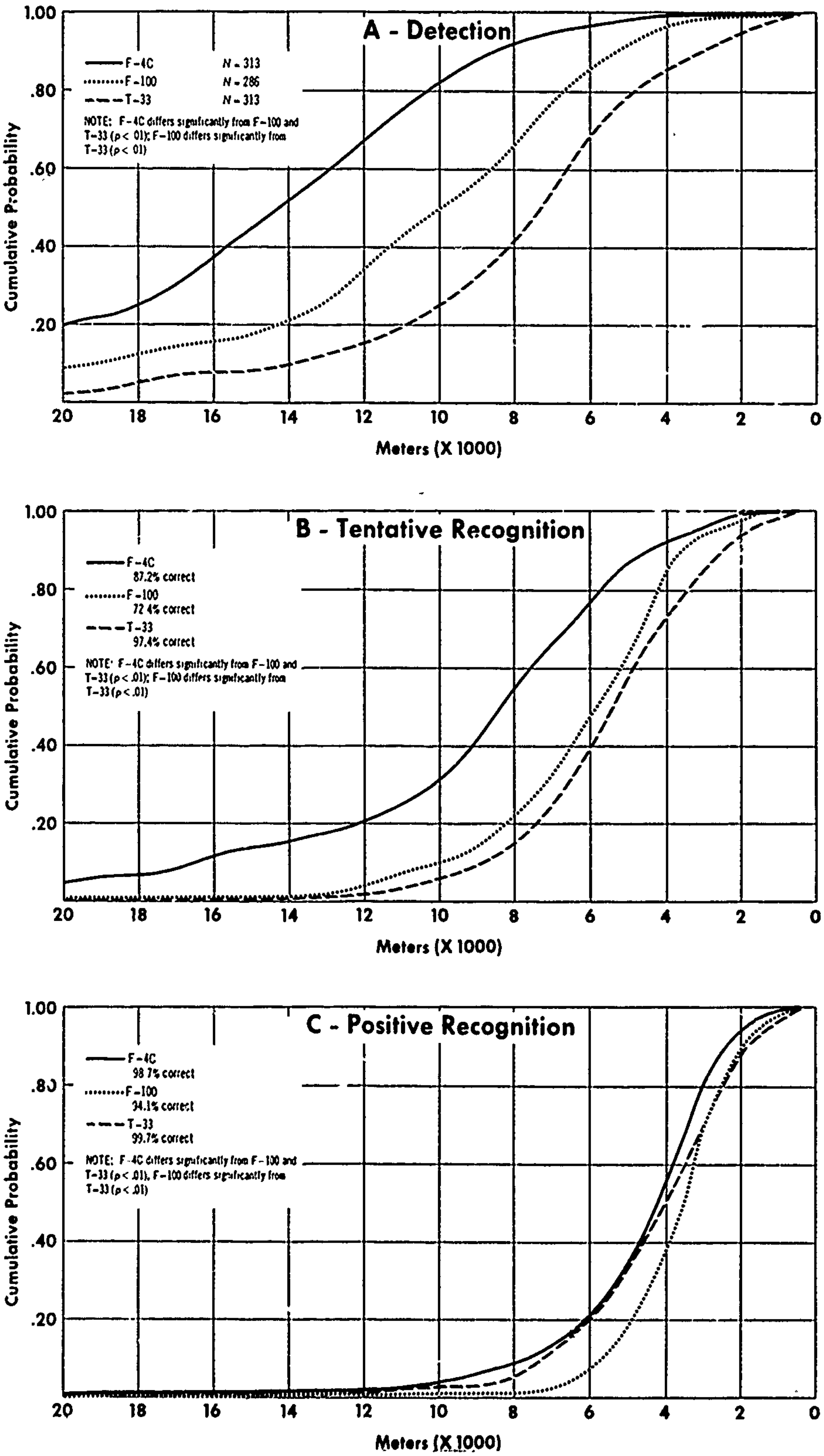

Figure 6

Effect of Aircraft Range and Propeller and Helicopter Aircraft Type on Empirical Probabilities of Detection and Recognition

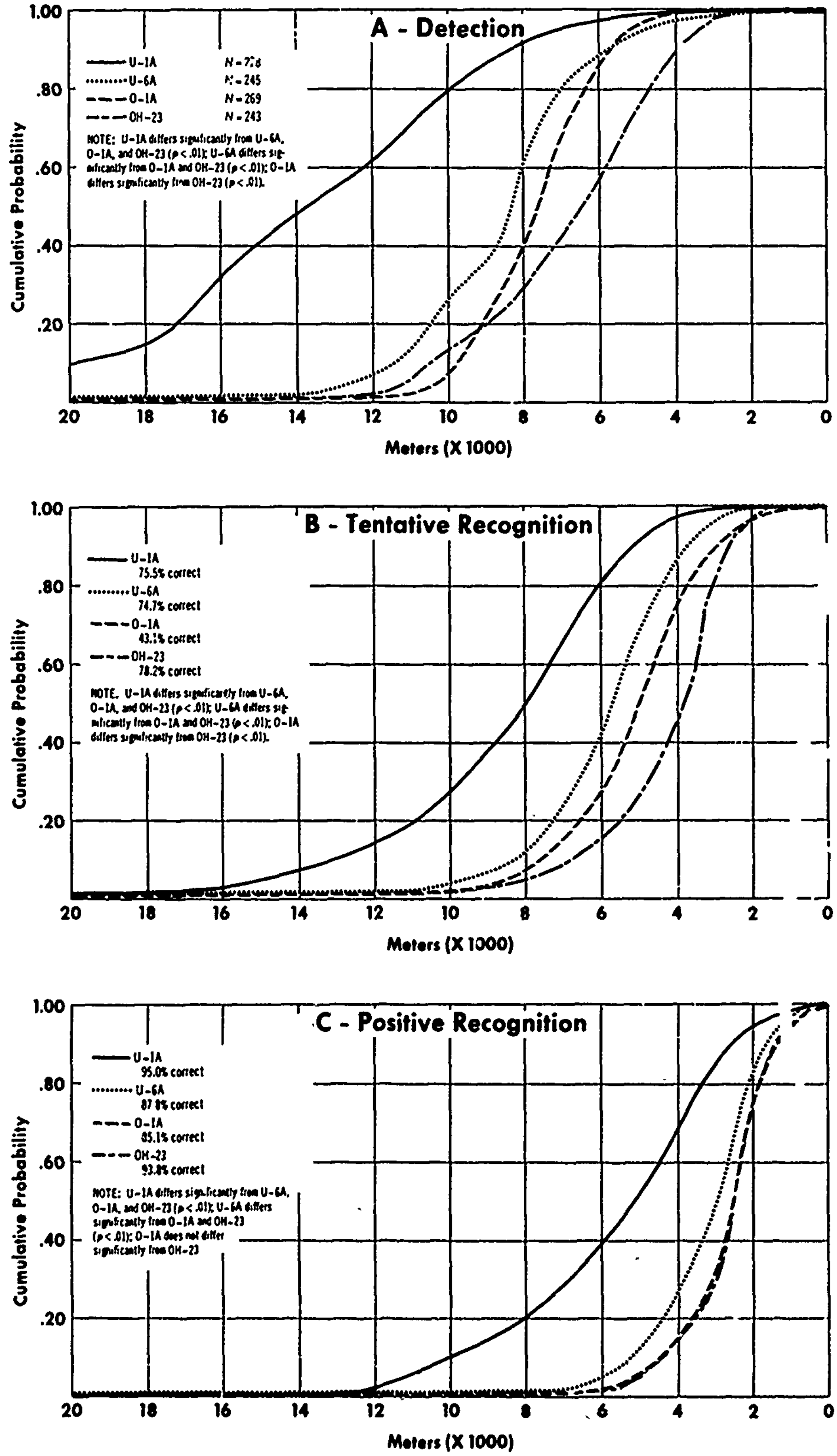

Figure 7

Probability of Correct Recognition

The percentage of correct recognition responses has been included in the plots of recognition as a function of range.

Of the 1,995 tentative recognition responses, 75.7% were correct. Of the 1,995 positive recognition responses, 93.8% were correct. Assuming the observers were simply guessing, they would have been correct 33.3% of the time for the jet and propeller aircraft. The chance percent for the helicopter would have been somewhere between 50 and 100% since the OH-13 did not fly during the later portion of the test. In any case, the results obviously indicate that the observers were not guessing.

It may be argued that if more aircraft had been used in the test, the percentage of correct recognition responses would have been lower. If, however, all observers were trained to recognize all aircraft perfectly, it would not matter how many aircraft were employed; the observers would perform perfectly regardless of the number of aircraft. The data obtained do not fall at either extreme. The observers knew all of the test aircraft well, but not to perfection.

To obtain a very high percentage of correct recognition responses for a larger number of aircraft than was used in this test would undoubtedly require more training time. If it can be assumed that observers can be trained to recognize a larger number of aircraft, then the percentage of correct recognitions and the recognition ranges reported here should closely approximate performance attainable with a larger number of aircraft.

The fact that the jet aircraft produced noticeably different smoke trails (i.e., F-4C heavy, F-100 moderate, T-33 light or none) also influenced the correctness of the recognition responses. This characteristic was quite evident and undoubtedly increased the recognition range and probability of a correct response. Because of the small number of jet aircraft and their smoke characteristics, the recognition ranges obtained in this study are probably overestimates. The jet recognition data may, therefore, approximate a situation where the observer is provided early warning in time and position, as well as being given a tentative recognition of the aircraft.

On the other hand, the propeller aircraft were very similar, perhaps more similar in general configuration and detail than any friend-enemy pair likely to be found. It is unlikely that an observer would be required to make a more difficult discrimination, even with a much larger sample of aircraft, than was required within the propeller class. For this reason, the recognition ranges and probability of a correct recognition response are probably underestimates for the propeller aircraft.

Observer Factors Related to Target Recognition

Prior to training, observers were given a standard test of far visual acuity. This test was scored for the total number of correct responses rather than the usual visual acuity ratio.

Observers were also tested at the end of classroom training to determine their ability to recognize the jet aircraft.

Correlation coefficients were computed between the visual acuity measure, classroom test scores, recognition range, and percentage of correct recognition responses. These correlations were computed separately for jet and propeller aircraft and tentative and positive recognition. These correlations were also computed separately for each binocular condition, since recognition ranges differed for the binocular conditions, and visual acuity and test scores tended to be differentially correlated ($\underline{r} = .11$ to $\underline{r} = .87$) within the three binocular conditions.

Second order partial correlations were then computed for the following:

(1) Classroom test vs. recognition range, with visual acuity and percentage of correct recognition held constant.

(2) Classroom test vs. percentage of correct recognition, with visual acuity and recognition range held constant.

(3) Visual acuity vs. recognition range, with classroom test and percentage of correct recognition held constant.

(4) Visual acuity vs. percentage of correct recognition, with classroom test and recognition range held constant.

The correlations computed on these data are found in Table 3.

Table 3

Second Order Partial Correlations for Four Variables[a]

Variables	Aircraft Class	Recognition Response	Second Order Partial r[b] (df= 11)	Average Second Order Partial r (df= 21)
Test vs. Range (Visual Acuity and Percent Correct Held Constant)	Propeller	Tentative Positive	.70** .50	.61**
	Jet	Tentative Positive	.51 .76**	.65**
Test vs. Percent Correct (Visual Acuity and Range Held Constant)	Propeller	Tentative Positive	.81** .72**	.77**
	Jet	Tentative Positive	.78** –.66*	.13
Visual Acuity vs. Range (Test and Percent Correct Held Constant)	Propeller	Tentative Positive	.09 .08	.09
	Jet	Tentative Positive	.34 .61*	.49*
Visual Acuity vs. Percent Correct (Test and Range Held Constant)	Propeller	Tentative Positive	–.47 –.21	–.35
	Jet	Tentative Positive	.46 –.49	–.02

[a]*indicates $p < .05$; ** indicates $p < .01$.
[b]Average of three Binocular groups.

The second order partial correlations were suprisingly high between the classroom recognition test and both (a) range at which targets were recognized and (b) percentage of correct recognitions. The significant negative correlation between percent correct and positive recognition range of jet targets is undoubtedly spuriously high. This probably occurred because of the extremely restricted distribution of percentage of correct positive jet recognitions. These data indicate that relatively unsophisticated classroom tests of aircraft recognition may be used to predict field performance. It is also interesting that while the classroom test covered only the jet targets, it predicts field performance equally well for the propeller and jet targets. These correlations indicate that filmed simulation might have considerable potential for training purposes.

The second order partial correlations between visual acuity and both recognition range and percentage of correct recognition indicate that visual acuity did not materially influence recognition. An exception to this is the correlation between visual acuity and positive recognition range for the jet aircraft. The correlation between visual acuity and positive recognition range of jet targets appears to reflect the importance of the smoke cues produced by the jets. It appears that persons with high visual acuity were better able to detect the smoke cues produced by the jet targets.

The average correlation between visual acuity and detection range, computed separately for the binocular conditions, was .19 for the jet targets and .11 for the propeller targets. While these correlations are low and not statistically different from zero, it should be remembered that the distribution of visual acuity was restricted to approximately 20/25 or better. It should not be assumed that visual acuity below 20/20 or 20/25 will not reduce detection ranges.

In summary, the correlation between a classroom test of aircraft recognition and field performance was surprisingly high considering the number of uncontrolled variables operating. Filmed simulation of the recognition task appears promising as a training technique though confirmation or extension of these data would be desirable.

Range Estimation

Tables 4 and 5 present the mean actual and estimated ranges for aircraft class, binocular, offset, and response variables. Tables 6 and 7 present the mean percentage range estimation error $\left(\frac{\text{Mean Estimated Range} - \text{Mean Actual Range}}{\text{Mean Actual Range}}\right)$ for these conditions.

It is apparent from Table 7 that the center group tended to overestimate target range, the 650-meter offset group tended to underestimate slightly (not significantly for the recognition responses), and the 1,400-meter offset group consistently underestimated target range. The accuracy of the range estimates appears to be dependent upon the observer site. This effect is most pronounced for the detection response, and the use of binoculars appears to reduce, though not eliminate, the effects.

Table 4

Mean Actual and Estimated Ranges[a]
As a Function of Aircraft Class and Response

Aircraft Class	Mean Range	Detection	Tentative Recognition	Positive Recognition
Jet	Actual	11,024	6,684	3,888
	Estimated	9,407**	5,660**	3,436**
Propeller	Actual	9,470	6,101	3,506
	Estimated	9,403	5,455**	2,520**
Helicopter	Actual	6,429	4,019	2,232
	Estimated	9,609**	5,274**	2,814**

[a]** indicates that Mean Actual Range differs from Mean Estimated Range ($p < .01$).

Table 5

Mean Actual and Estimated Ranges[a]
As a Function of Binoculars, Offset, and Response

Condition	Mean Range	Offset Group: Center	Offset Group: 650-Meter	Offset Group: 1,400-Meter	Mean
Detection					
No Binoculars	Actual	10,524	9,665	8,295	9,445
	Estimated	16,509**	7,158**	3,902**	8,706**
Binoculars for Recognition	Actual	10,518	8,581	9,198	9,406
	Estimated	11,571**	11,397**	5,815**	9,481
Binoculars for Detection and Recognition	Actual	9,243	10,815	10,728	10,289
	Estimated	11,360**	9,501**	9,406**	10,057
Mean	Actual	10,056	9,730	9,433	
	Estimated	12,965**	9,286*	6,432**	
Tentative Recognition					
No Binoculars	Actual	4,351	5,371	4,923	4,931
	Estimated	3,778*	4,089**	2,269**	3,386**
Binoculars for Recognition	Actual	6,675	5,867	7,321	6,634
	Estimated	8,129**	7,725**	4,603**	6,749
Binoculars for Detection and Recognition	Actual	5,423	7,136	7,013	6,554
	Estimated	6,523*	6,606**	5,821**	6,319
Mean	Actual	5,528	6,139	6,454	
	Estimated	6,250**	6,091	4,277**	
Positive Recognition					
No Binoculars	Actual	2,169	2,254	2,609	2,350
	Estimated	1,349**	1,625**	1,278**	1,430**
Binoculars for Recognition	Actual	4,134	3,277	4,914	4,124
	Estimated	5,093**	3,893**	2,289**	3,703**
Binoculars for Detection and Recognition	Actual	2,982	4,386	4,394	3,945
	Estimated	3,662	4,042	3,397**	3,708
Mean	Actual	3,130	3,313	4,005	
	Estimated	3,458	3,169	2,346**	

[a] *indicates that Mean Actual Range differs from Mean Estimated Range ($p < .05$);
**indicates that Mean Actual Range differs from Mean Estimated Range ($p < .01$).

Table 6

Mean Percentage Range Estimation Error[a]
As a Function of Aircraft Class and Response

Aircraft Class	Detection	Tentative Recognition	Positive Recognition
Jet	−14.7	−15.3	−11.6
Propeller	−00.7	−10.6	−28.1
Helicopter	49.5	31.2	26.1

[a] $\frac{\text{Mean Estimated Range-Mean Actual Range}}{\text{Mean Actual Range}} \times 100$

Table 7

Mean Percentage Range Estimation Error[a]
As a Function of Binoculars, Offset, and Response

Condition	Offset Group: Center	Offset Group: 650-Meter	Offset Group: 1,400-Meter	Mean
Detection				
No Binoculars	56.9	−25.9	−53.0	−07.8
Binoculars for Recognition	10.0	32.8	−36.8	00.8
Binoculars for Detection and Recognition	22.9	−12.1	−12.3	−02.3
Mean	28.9	−00.5	−31.8	
Tentative Recognition				
No Binoculars	−13.2	−23.9	−53.9	−31.3
Binoculars for Recognition	21.8	31.7	−37.1	−01.7
Binoculars for Detection and Recognition	20.3	−07.4	−17.0	−03.6
Mean	13.1	−00.8	−33.7	
Positive Recognition				
No Binoculars	−37.8	−27.9	−51.0	−39.1
Binoculars for Recognition	23.2	18.8	−53.4	−10.2
Binoculars for Detection and Recognition	22.8	−07.8	−22.7	−06.0
Mean	10.5	−04.3	−41.4	

[a] $\frac{\text{Mean Estimated Range-Mean Actual Range}}{\text{Mean Actual Range}} \times 100$

No one would contend that these observers were well trained in range estimation. Observers within the three offset groups were given identical training with or without binoculars as was appropriate, but this training did not involve aircraft.

These range estimation data as a function of offset do not agree with the data reported by Frederickson, Follettie, and Baldwin (1). In that test, range estimates varied from underestimates to essentially correct estimates as offset increased. Since the effects obtained in the two studies are in direct contradiction, it is doubtful that range estimates vary from overestimates to underestimates as offset increases.

It seems unlikely that the differences in range estimates were due to inadvertent biasing at the test sites. Discussion with monitors at the three offset groups gave no indication that such biasing might have occurred. The observers were not in verbal contact with one another while at the test sites, and no feedback was provided concerning actual or estimated aircraft range at any time during the test.

The most obvious differences between the three offset sites concerned the different distances to terrain mask. The center offset site was located on top of a slight knoll and had an unobstructed view of the terrain to the mountains, which were from 40 to 90 miles distant. The 1,400-meter offset site was located in a shallow bowl, and although the distant mountains were not masked, only about 2,000 meters or less of the intervening terrain was visible. The 650-meter offset terrain mask depended upon the aircraft flight path. The uninterrupted terrain view was seldom as long as the center group's and seldom as short as that of the 1,400-meter group.

These data indicate that underestimates of aircraft range are associated with near terrain mask, correct estimates at an intermediate, mask range, and overestimates associated with very far masks. The data obtained by Frederickson, Follettie, and Baldwin (1), when analyzed in terms of distance to terrain mask, also show underestimates as a function of near mask and correct estimates at intermediate (in terms of the mask ranges available in this study) mask ranges.

Kaufman and Rock (14) and Rock and Kaufman (15) have found that terrain effects are related to the magnitude of the "moon illusion" phenomena of classical studies in perception. Hamilton (16) has found that factors influencing the "moon illusion" also influence range estimates to objects on the terrain. These data suggest that such factors (terrain and terrain restriction by binoculars) may also affect aircraft range estimation.

CONCLUSIONS

The most interesting aspect of the study appears to be the relatively long detection and recognition ranges obtained and the high percentage of correct recognition responses.

The large detection and recognition range are attributed to the excellent meteorological and terrain conditions and the near optimum conditions of observation. It appears that the probability of detection and recognition as a function of target range is dependent upon observer training, the type and accuracy of early warning, vigilance factors, observer offset from the aircraft flight path, and aircraft characteristics.

The value of binoculars for low-altitude aircraft detection depends, in part, on aircraft smoke characteristics and accuracy of early warning. The latter is determined by:

(1) Observer offset from the flight path
(2) Speed of the aircraft
(3) Warning interval
(4) Accuracy of the initial bearing estimate

The recognition data indicate that both binoculars and observer offset from the flight path tend to increase recognition range.

Correlations obtained between a test of training proficiency and field performance indicate that filmed simulation of the recognition task appears promising, both as a training and a research tool.

The data concerning range estimation performance indicate that large range estimation errors occurred. These errors, which appear to be related to the offset groups in some manner, indicate that the relatively unsophisticated range estimation training program was ineffective. The biases in range estimation performance as a function of observer offset may be related to terrain differences between the offsets; however, this hypothesis remains to be tested.

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13. ABSTRACT

The purpose of this test was to determine man's capability to visually detect, recognize, and estimate range to low-altitude aircraft. Twenty-seven Army enlisted men served as observers. The results indicate that man can detect and recognize low-altitude aircraft at a considerable range under near-optimum field conditions. The value of binoculars for aircraft detection was found to be dependent upon (a) observer offset from the aircraft flight path, (b) accuracy of early warning, (c) aircraft speed, and (d) exhaust smoke trail characteristics of the aircraft. Under the test conditions employed, binoculars reduced the detection range on the most potentially threatening targets, high-speed, head-on jet aircraft. The data show that large range estimation errors occurred. Filmed simulation of the recognition task appears promising as a training tool. ( )

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