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FIELD AND SIMULATOR STUDIES OF AIR-TO-GROUND VISIBILITY DISTANCES

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SUMMARY

A coordinated program of field tests and simulator measurements is reported in which visual detection and recognition ranges for ground targets viewed from aircraft were obtained. Flight speed was fixed at 130 knots. Flight altitude was varied between 2,000 and 7,500 feet. Flight attitude with respect to the position of the sun was varied between 3 and 177 degrees. The target was a vehicular complex consisting of a jeep, a 1/2 ton panel truck, and a 2-1/2 ton stake truck. Nine pilot-observers were used, all of whom were commissioned officers of the U.S. Navy and Marine Corps on active duty. The flight tests were made in an SNB-5P aircraft, operating from the Grosse Isle Naval Air Station. The simulator measurements were made in a terrain model facility constructed by personnel of the Vision Research Laboratories at The University of Michigan. In all, 109 flight passes were made in the field test program, and 840 passes were made in the simulator program.

Analysis of the data revealed important similarities and differences between the results obtained in the field and in the simulator. The combined sets of data were used to construct probability curves for target recognition as a function of slant range in the field. The primary curves represent vehicular targets painted battleship gray, viewed against roadway backgrounds. Curves are available for five individual flight attitudes at each of four individual flight altitudes. These curves are directly relevant to practical problems in which a particular flight altitude and attitude is of interest. Curves are also available for various combinations of flight altitudes and attitudes, to represent practical problems in which flight attitude or altitude must be considered to vary. Data are presented which allow predictions of detection ranges to be made. In addition, data are presented which allow corrections to be made in the recognition data for the effects of target paint, and terrain background characteristics.

I. INTRODUCTION

Since February 1, 1957, the Vision Research Laboratories have been studying the general problem of the visibility of ground targets viewed from aircraft. The problem of predicting the visibility of all targets of interest, viewed against all possible terrain backgrounds through all possible atmospheres is indeed a formidable one. Accordingly, a variety of different technical approaches have been utilized.

In the beginning, it was believed that the use of accurate scale model simulation was the most promising approach. Accordingly, considerable effort has been devoted to development of a large terrain scale model simulator constructed at a scale of between 1:500 and 1:1000. Considerable progress has been made in the development of technology for the production of terrain contours and simulator surface details. Plans have been completed for construction of a large terrain model at a scale of 1:600 to be installed in a facility to be supplied by the Bureau at the Grosse Isle Naval Air Station. Sample terrain areas have been constructed and all plans have been made for production of the final model.

A small effort has also been devoted to the development of a theoretical understanding of the characteristics of visual detection and identification for targets of non-uniform luminance viewed against backgrounds of non-uniform luminance. Preliminary experiments were reported in our quarterly progress report A-2643-2, dated November 1, 1957. Final experiments are reported in our final reports 2643-1-F and 2643-2-F. Although we have learned something of the characteristics of detection and recognition under simplified and stylized conditions of target and background luminance non-uniformity, we are not as yet able to predict the visibility of actual targets and backgrounds.

In order to obtain some accurate information on visibility distances of particular interest to the Bureau in as short a time period as possible, we conducted a coordinated program of flight tests and simulator measurements during the summer of 1958. The flight tests were conducted through the cooperative efforts of our technical personnel and Naval personnel and facilities supplied by the Grosse Isle Naval Air Station. The simulator tests were conducted in Hangar 2 of the University's Willow Run Laboratories. A terrain model simulator was constructed especially for these measurements, utilizing all aspects of the technology developed during the entire period of the contract.

The coordinated program was designed to utilize the special features of both flight tests and simulator measurements to advantage, so as to maximize the information obtained in the time available to us for study of this problem. Incidentally, the coordinated program provided us with an excellent opportunity to evaluate the extent to which flight tests and simulator measurements yield equivalent results, and to establish the advantages and limitations of each technique.

The present report contains a detailed summary of the results of the coordinated program of flight tests and simulator measurements. Together with the quarterly progress reports and final reports 2643-1-F and 2643-2-F, it represents final reporting of all phases of our work under the contract.

II. PROCEDURES AND APPARATUS

A. GENERAL RESEARCH PLAN

The coordinated program of flight tests and simulator measurements was intended to provide quantitative information on the visibility ranges of a vehicular target complex viewed against asphalt, grass, and dirt backgrounds at each of a number of flight altitudes and flight attitudes with respect to the sun. Aircraft speed was set for convenience at approximately 130 knots. The conditions of observing were to be as realistic as possible. The observers were given considerable pre-briefing concerning the nature of the target and its probable location.

Nine trained U.S. Navy and Marine Corps pilots were used as observers in both phases of the experiment, so as to insure that the visual searching techniques utilized by the observers were realistic. A site within Kensington Park, near Ann Arbor, Michigan was selected for the flight tests and a terrain model simulator was prepared of this area.

Due to the expense and logistic problems involved in flight tests, most of the data were collected in the simulator. The flight test data, although comparatively few in number, were taken under the same variety of conditions as the simulator measurements. Thus, it is possible to evaluate the extent to which the two sets of data exhibit similar functional relations with respect to the two operational variables: flight altitude, and flight attitude with respect to the sun. Insofar as the same relations are found, it is possible to use the more extensive simulator data as a means of extending the value of the limited number of flight test data.

In the following sections, the procedures utilized in the flight tests and the simulator measurements will be described, and the data from the two phases of the study will be evaluated with respect to similarities and differences. Finally, data from both phases will be used to produce visibility data possessing the greatest possible accuracy for the immediate use of the Bureau.

B. FLIGHT TESTS

A standard SNB-5P aircraft was utilized for all flights. This aircraft was generously made available to Grosse Isle N.A.S. by the Glenview N.A.S. All service and normal flight support was provided by Grosse Isle N.A.S. Without the excellent cooperation of these two Naval Air Stations, the flight test program could not have been completed.

All flights were made at 130 knots indicated air speed. No attempt was made to correct for winds aloft, since a flight pattern was used (see below) which equalized the use of the four major compass directions during each series of four flights over the target. All altitudes were read from the aircraft altimeter, then corrected to give true height above the terrain. The pilot and co-pilot seats were used equally as observation stations in an effort to average out any peculiarities of flight pattern or windshield distortions.

The terrain site used for the tests is shown in the aerial photograph presented in Figure 1. This site was selected for the following general reasons:

(a) The site was located in a county park. This meant that, to a considerable extent, the traffic was constant from time to time and moved at a relatively uniform low speed of some 20 miles/hour. Since no large trucks were permitted in the park, there were normally only scattered individual automobiles moving randomly about. There were no convoy-like groupings which would resemble the vehicular target used. This situation resembles the military situation in which miscellaneous staff cars are moving about the battle area at random, with an occasional convoy which is of particular military interest.

(b) The park had houses, barns, sheds, and such terrain features as trees, grass and planted fields in average numbers. It also had a variety of road surfaces, including new concrete, new asphalt, quite old asphalt, and gravel.

(c) The park was located midway between two major airports (Willow Run and Wayne Major) so that all flights were made in the control zone established between these two. This meant that the observer had to make all the normal flight observations in addition to searching for targets. This feature of the test added realism to the tests, since pilots under military conditions must be concerned about other aircraft as well as targets on the ground.

It was originally planned that the target to be used would be a U.S. medium tank, and indeed such a target was obtained for use in the flight tests. However, prior to the conduct of the flight tests, instructions were received from the Bureau that a small convoy should be used as the target. The convoy actually used consisted of a 1/4 ton jeep with canvas top up and in place, a 1/2 ton Chevrolet panel pickup truck, and a 2-1/2 ton GMC stake truck with racks on the sides but without a tailgate. The vehicles were all painted with standard Navy battleship gray paint, and were in moderately used condition as far as fading and dust were concerned. The convoy always consisted of all three vehicles, parked on the right-hand edge of the roadway, with approximately 2 to 3 vehicle lengths between each two vehicles. The relative positions of the three vehicles were varied randomly among flight passes. The convoy was placed in each of ten target positions on different flights, with the convoy headed in each direction equally often.

The ten target positions used are shown in Figure 1. These positions were selected at various points within the target area, which measured 1 nautical mile on a side to give the pilot-observers a clear view of each target unobstructed by either terrain or vegetation. However, the target positions varied from very easy ones (positions 3 or 7), in which the targets were essentially placed in the middle of a field with little or no vegetation around them, to more difficult ones (positions 1 or 8) in which there were houses and vegetation in the area immediately surrounding the convoy. The ten positions were also selected to give approximately equal numbers of East-West and North-South orientations of the convoy. Thus, the observers were equally likely to see the target convoy placed parallel with, or perpendicular to the line of flight.

On each series of flights, the pilot followed the standard cloverleaf pattern shown schematically in Figure 2, always beginning at the North starting position. The pilot made a N-S pass over the target area and attempted to make a target interception. Whether he succeeded or not, he continued on the cloverleaf pattern and next made an E-W pass. The target was moved to a new position before the E-W pass was made. The flight pattern continued in this way until four passes were made. Since the cloverleaf pattern extended over a square approximately six miles on a side, there was usually sufficient time for the convoy to be moved. In the event that the convoy was not in place when the pilot came to the beginning of a pass path, he was instructed to make a 360 degree turn so as to delay his pass over the target area. All flights were made under conditions of essentially clear air, with the meteorological visibility equal to 15 miles or more. Scattered clouds were present on some flights. All flights were made between the hours of 1400 and 1700. These hours were selected so that the sun's elevation varied only between the limits of 33 and 57 degrees, with an average value of 45 degrees. The sun's azimuth from true north varied from 244 to 290 degrees, with an average value of 267 degrees.

Before each series of flights, the pilot made several low-level passes over the convoy from each direction so as to familiarize himself with the general appearance of the target. The aircraft then flew off to a position well beyond the limiting visibility range and the convoy was moved to the first target position. After the convoy was stopped in position on the edge of the roadway, the aircraft was directed by two-way radio to begin the cloverleaf pattern.

It was originally intended that the pilot would use both a detection and a recognition criterion. Detection was defined by the pilot having sufficient information to alter his normal flight pattern in order to verify the existence of a target better. Recognition was defined by the pilot having located the target correctly, and being willing to state the order in which the vehicles were positioned. (It is to be emphasized that the pilot did not have to be entirely correct in identification of the location of the vehicles in the convoy, but he had to be substantially correct.) Because of the flight control needed at the moment of detection, use of the double criterion proved to be impracticable in practice, and so the pilot only indicated the moment of recognition of the target's location and the order of its components.

When the pilot believed he had detected the target, he would verbalize the information he had such as "I think I see you in the Southwest corner heading North, with the jeep first, the 2-1/2 ton truck second, and the panel truck last." If the identification was approximately correct, the pilot was given credit for an interception at the slant range then separating him from the target. If the pilot made essential errors in his identification of the target location, or the order of the vehicles in the convoy the pass was scored as a miss. The target locations were sufficiently separated so that it was always quite clear whether or not the pilot had correctly located the position occupied by the convoy. The pilot was required to identify correctly the positions within the convoy occupied by the panel truck and the stake truck. These vehicles were usually correctly located whereas the jeep was not always seen.

The aircraft was guided in its flight pattern by radio information supplied by the ground crew located at the target. It was possible for the ground crew to instruct the pilot as he approached a target pass so as to make small adjustments in the flight pattern.

Each flight pass was originally intended to pass close to the center of the flight pattern, as shown in Figure 2. However, it was found that the pilot's visibility was cut off badly on the opposite side of the cockpit. Accordingly, the flight pattern was adjusted so that when the left seat was used the passes were made to the right of the flight pattern center. Correspondingly, when the right seat was used, the passes were made to the left of the flight pattern center. In terms of the test area shown in Figure 1, these passes were made approximately midway between the center of the flight pattern and each edge of the test area.

The slant range at which detection was made was determined in two separate ways. In one method, the pilot photographed the ground immediately under his aircraft at the moment he believed he had recognized the target. In the second, a ground observer tracked the aircraft through a transit, stopping the tracking procedure when the pilot gave his recognition of the target.

The aircraft camera was a standard K-17 aerial camera, belly-mounted. It could be triggered by either the pilot or co-pilot by means of a "pickle switch" especially installed at Grosse Isle N.A.S. for the purposes of our test. The aircraft was put into flight trim and the camera was carefully leveled. Thus, a photograph of the ground could be used to establish the ground coordinates of the aircraft position at the moment the photograph was taken. Subsequently, the point in the center of each photograph was located on a master photo-mosaic of the test site, and the ground separation between the target position and the aircraft position established. The slant range is readily computed from the known flight altitude.

The ground method was based upon continuous tracking of the aircraft through the telescope of a standard high quality surveyor's transit, located at the target site. When the pilot correctly identified the target, tracking was stopped and the transit elevation was read. In this case, the slant range may be computed from the elevation angle of the transit and the known flight altitude.

It is apparent that the two methods used to determine slant range are only approximate, but they do involve different sources of error. Thus, average values of slant range derived from the two methods should not be subject to systematic bias. For those cases in which both measurements were made successfully, there was no significant difference between the two methods. The average difference between the two measurements amounted to 13%. It was felt that the average values derived from the two methods had reasonable precision.

The nine pilots participating in the tests were all Navy pilots on active duty, temporarily assigned to the University as students. All had the rank of Lt. or higher. The enthusiastic performance of these pilots, and the outstanding support given our flight tests by Captain Mothersill of the University's NROTC program were of inestimable value. The pilots were highly motivated and most conscientious in carrying out the specified flight routine and in reporting target interceptions.

In all, there were 109 flight passes.

C. SIMULATOR MEASUREMENTS

1. General Description

The apparatus used in these experiments consisted of a scale model of the selected terrain, scale models of target vehicles and non-target vehicles, a simulated sun, and an observation platform which could be mounted at several heights above a dolly which traveled along a track. Figure 3 is a photograph taken from the rear of the experiment room. In the foreground the motor for moving the dolly and the track for the dolly can be seen. The observation platform and dolly are at the opposite end of the track. The terrain model is at the foot of the track. On the left and behind the model is the sun-simulator mounted at the top of a tower.

The terrain model was a replica at a scale of 1:600 of the terrain over which the field tests were flown. Since the ground area measured approximately 1 nautical mile on a side, the model measured approximately 10 feet on a side.

In simulating the actual terrain of the field test, every effort was made to produce exact correspondence of terrain and model. Aerial photographs and contour maps were used to reproduce both the topography and detail of the field. Also, the craftsmen and artists made direct visual inspection of the terrain to be duplicated. The detail built into the model included duplicates of all dirt, asphalt, and concrete roads.

Figures 4 and 5 are photographs of the simulated terrain taken at simulated altitudes of 2,000 and 7,500 feet, respectively. These photographs illustrate the difference in appearance of the model when it is approached from the two altitude extremes investigated in this experiment.

Models of the three vehicles in the target complex used in the field test were constructed at the scale of 1:600. These vehicles were painted a battleship gray which was a visual match to the paint on the actual vehicles.

In addition to the target vehicles, non-target automobiles were constructed at the same scale and painted various colors to simulate the paint of civilian automobiles.

The simulation of the sun was provided by a 5000 watt incandescent lamp mounted slightly inside the focal length of a 60-inch reflector. The reflected light rays diverged just enough to cover all four corners of the model. The simulated sunlight was provided both by the direct light rays from the source falling upon the model and by the re-directed light rays from the reflector.

The sky light illumination was provided by two sources, overhead incandescent lights ordinarily used to illuminate the room, and the multiple reflection of these lights and those rays from the sun-simulator which did not fall on the model, from the white walls and ceiling of the experimental room. The outside windows of the room were blacked out. The sky-light illumination on the model measured at 13 different positions over the surface of the model was relatively constant. Illumination values with the sun rays excluded ranged from 23 to 28 lumens/ft^2. The illumination on the model from the sun varied as a function of the distance from the model area to the lamp. The ratio of sun illumination to sky-light illumination was 10:1 at the corner of the model nearest the sun, 4:1 diagonally across the center of the model from corner to corner perpendicular to the sun, and 2:1 at the corner of the model farthest away from the sun. However, at about the center of the model this ratio was only about 3:1 because of a slight shadow cast by the light bulb and its supporting arm in the sun simulator. This shadow did not cover any target positions used in the experiment.

An observation platform could be mounted at four heights above a dolly which moved along a track. The four heights could be produced by either one, two, three, or no scaffolding sections between dolly and platform. The appropriate number of scaffolding sections under the platform, plus the appropriate adjustment of the height of the chair and chin rest provided for the observer, produced simulated altitudes for the observers' eyes in relation to the typical height of the simulated terrain, of 2000, 4000, 5700, and 7500 feet.

The observation dolly was moved by a chain and sprocket attached to a motor which produced a maximum simulated speed for the observation platform of 134 knots. This motor could be controlled from the dolly by the observer or by the experimenter. Next to the observer's chair there were two switches controlling two response-indicator lights. The response lights were located next to a pointer, which was attached to the dolly, directly over a numbered tape on the floor. Marked at three-inch intervals, the numbered tape extended from the front edge of the model along the entire length of the dolly track.

Microswitches at either end of the track were activated when the dolly passed over them and prevented the dolly from running off either end of the track. The positions of the observer and experimenter are shown in Figure 6.

Ten locations of the target complex were used, which were essentially identical to those used in the field experiments. Of the 10 target positions, two (2 and 8) appear on dirt roads, two (6 and 10) fall on the concrete main highway, and the rest (1, 3, 4, 5, 7, and 9) are asphalt locations.

In a run of 20 observations, a target complex appeared twice at each of the 10 target positions. In the two appearances of the target at a given location, the direction in which the vehicles were pointed was once one way and once the opposite way. The sequence in which the target vehicles were placed varied from observation to observation according to no set pattern.

The reflector behind the sun-simulating lamp was always tilted about 45° downward and was directed toward the center of the model. The tower supporting the sun could be moved about the model. For a single session for one observer the sun appeared at three azimuths from (simulated) true north. These azimuths were 58°, 148°, and 238°. The sequence of testing sun azimuths in a given daily session was haphazard, except that an attempt was made to equate the number of times a given sun position appeared in a given order.

The sun remained at a given azimuth for a run of 20 observations in which each target location and convoy heading appeared once.

In a single session only one simulated altitude of the observer was used. The altitude employed for a given observer was chosen primarily to provide the most direct comparison with the field test data for the same observer. For those observers who served for more than one session, different sequences for presentation of altitudes were used.

Before the simulated flight toward the terrain, the observation dolly was moved sufficiently far down the track away from the model so that there was no likelihood that the targets were inside the detectability range for that observer and experimental condition. This distance was also far enough to allow the observer to scan the complete model before the target was seen. When the observer detected what he thought was a target with sufficient certainty that he would have to alter his flight path in an airplane to investigate it more closely, he threw a switch to one of the lights mounted next to the pointer over the markers on the floor. The experimenter recorded the scale reading. This distance to the target, when converted into slant range between observer and target, was called the detection threshold. Whenever the observer changed his mind about the possible target at which he was looking (i.e., he decided that it was not a target after all), then he turned the light off. Later when he detected another possible target, he again turned that light on. The light remained on until the recognition threshold was reached.

When the observer felt that he could report the correct sequence in which the three target vehicles appeared, he threw a second switch which turned on another light by the pointer. This was recorded and later converted into slant range for the recognition threshold. When this recognition threshold was achieved, the observation trolley was stopped, and returned to the opposite end of the track. Although the observer was required to report the target vehicle sequence, this report of sequence was not required to be correct. If the sequence was incorrect the experimenter quizzed the observer about where he saw the target, in order to be sure the observer was actually looking at the target complex. On rare occasions in which the observer was not regarding the target when he reported a recognition, a false positive was recorded, and the observation was dropped from further data analysis.

Sometimes, the observer felt he could report the sequence of vehicles as soon as he could detect them. In this case he threw both the detection and recognition switches simultaneously.

If the observer had failed to detect the targets by the time the microswitches at the forward end of the track were activated, then the target was considered not seen and preparations were made for the next observation.

An experimental session usually lasted between 3-1/2 and 4 hours. Rest pauses were taken between blocks of 20 observations while the sun's position was being changed.

A green curtain of simulated grass was draped behind the model to provide a background for the model other than the wall of the room which was disturbing to the observers, particularly in simulated low altitude flights.

A total of 840 simulator passes was made in all.

2. Limitations of the Experiment

Although for convenience in this report a distinction has been made between the detection and the recognition threshold, obviously what is here called detection involves a large element of recognition. Specifically, to achieve a "detection threshold" the observer must discriminate between the target complex and a varied assortment of automobiles, trees, houses, and miscellaneous lights and shadows. Therefore, a detection threshold may occur when the observer decides that the spot that he has seen for some time is actually a target and not something else. On the other hand, a detection may mean that the observer suddenly notices a target which is clearly suprathreshold as far as visibility factors are concerned. If he had known where the target was he could have seen it easily. As a matter of fact, it was obvious to the experimenters that every case of failure to see the target on a given observation was due to a failure of search rather than to the target being below the basic "detection threshold."

The criterion for recognition used in this study was arbitrary. Naturally a criterion which required more information about the target would have produced shorter slant ranges for the recognition threshold, and a criterion which would have produced longer slant ranges at threshold could have been devised.

The fact that the observers knew that the targets would always appear on roads with unobstructed view from the aircraft was unquestionably an important factor influencing the slant ranges obtained. This factor influenced what might be called the search component of the visual task rather than the visibility component as such. Reduction of the relevant number of target positions increased the amount of time which could be spent on search of the remaining positions.

In this connection, it seemed to the experimenters that the observers quickly became familiar with the 10 target positions used in the study and then tended to search those 10 areas almost exclusively. If a target position was scanned and the observer decided there was no target there, he tended to eliminate this position from subsequent search. This factor probably made the slant ranges in the first session for each observer somewhat less than they would have been after practice. The observer could, of course, wrongly decide there was no target at a given position and, hence, his slant range detection threshold would be greatly decreased.

There were two fundamental deficiencies of the simulated sun. The light intensity was less than desirable, and the rays were not collimated. Our understanding of the relations between general visual functions and luminance level strongly supports the belief that the reduced light level of the simulator had no appreciable effect upon the data. Lack of collimation was also probably not significant. The elevation and azimuth of the simulated sun were calculated from the center of the lamp to the center of the model and are accurate, strictly speaking, for the center of the model only.

III. COMPARISONS BETWEEN THE FIELD AND SIMULATOR DATA

A. COMPARISONS OF RAW DATA

The initial data analysis consisted of averaging the slant range values obtained on the various passes in which a target was recognized successfully, both for the field and the simulator data. Mean values of these slant ranges are presented in Tables I and II, for the simulator and the field tests respectively. The number of passes at each altitude is tabulated in the column labeled "N."

The values of probability that the target was recognized were also tallied, with the results given in Tables III and IV.

TABLE I

MEAN SLANT RECOGNITION RANGES: SIMULATOR DATA

Altitude (feet)	θ 45°	θ 122°	Average	N
2,000	11,430	12,210	11,820	180
4,000	13,390	15,610	14,500	240
5,700	16,030	17,160	16,600	240
7,500	18,710	22,610	20,600	180
Averages	14,890	16,897		
		Grand Average 15,895 feet		

TABLE II

MEAN SLANT RECOGNITION RANGES: FIELD DATA

Altitude (feet)	θ 3°	θ 90°	θ 177°	Average	N
2,000	6,677	6,832	10,980	8,160	44
4,000	7,376	9,767	11,014	9,390	50
5,700	8,273	12,901	16,292	12,490	12
7,500		10,380	17,600	13,990	3
Averages	7,442	9,970	13,972		
		Grand Average 11,008 feet			

TABLE III

RECOGNITION PROBABILITIES: SIMULATOR DATA

Altitude (feet)	θ 45°	θ 122°	Average
2,000	.75	.90	.825
4,000	.91	.94	.925
5,700	.89	.90	.895
7,500	.91	.93	.920
Averages	.865	.918	
		Grand Average .891	

TABLE IV

RECOGNITION PROBABILITIES: FIELD DATA

Altitude (feet)	θ 3°	θ 90°	θ 177°	Average
2,000	.45	.54	.64	.543
4,000	.54	.46	.54	.513
5,700	.67	.67	.67	.670
7,500	.00	1.00	1.00	.670
Average	.415	.668	.712	
		Grand Average	.599	

It is immediately apparent that the field test data differ significantly from the simulator data both with respect to the values of mean slant range and recognition probability. It also appears quite clear that mean slant range depends both upon flight altitude and flight attitude with respect to the sun, for both the field and the simulator data. There is also fairly convincing evidence that the value of recognition probability depends both upon flight altitude and attitude, for both the field and the simulator data.

The next analysis was undertaken, therefore, to establish the dependency of mean slant range and probability upon flight altitude and attitude. This analysis had as a first objective to demonstrate to what extent the field and simulator data exhibited similar trends. If such similarity was demonstrable, then relations derived from the more extensive simulator data could be used to describe the field data with respect to these relationships. Such descriptions could be used to work back from the complete field data to obtain estimates of what the field data would have shown for individual conditions of flight altitude and attitude, had there been sufficient data.

B. ANALYSIS OF THE EFFECT OF FLIGHT ALTITUDE UPON SLANT RECOGNITION RANGE

The analysis of the effect of flight altitude was first made upon the values of mean slant recognition range. First, each average value in Table I representing a given simulator flight altitude was divided by the grand average to yield values of relative slant range for each altitude. The same operation was performed on the values from Table II, to give relative slant ranges for each altitude from the field data. These values are tabulated in Table V so that the similarity of the effect of flight altitude upon slant recognition range can be compared for the two sets of data. It is apparent that the field and simulator data yield very similar values.

The data from Table V are presented graphically in Figure 7. It is apparent that log relative slant range is linearly related to flight altitude.

TABLE V

VALUES OF RELATIVE SLANT RANGE: ALTITUDE VARIATION

Altitude (feet)	Field Tests	Simulator Measurements
2,000	.74	.74
4,000	.85	.91
5,700	1.13	1.04
7,500	1.27	1.30

C. ANALYSIS OF THE EFFECT OF FLIGHT ATTITUDE WITH RESPECT TO THE SUN'S POSITION UPON SLANT RECOGNITION RANGE

The analysis of the effect of flight attitude upon slant recognition range was performed in a manner similar to that used in the analysis of flight altitude reported in Section III B above. Values of relative slant range were computed from the values presented in Tables I and II. Since the earlier analysis had demonstrated that slant range depends upon flight altitude, the relative slant range values for various attitudes were expressed in terms of the average slant range for each altitude. In the case of flight attitude, different values of the angle θ between the line of flight and the sun's position were involved in the field and simulator tests, due to limitations imposed by each method of study. The field tests involved flights along all four major compass directions in the clover-leaf flight pattern (Figure 2). In terms of the angle θ with respect to the average sun's position, these directions of flight involve $\theta = 3$, 87, 93, and 177 degrees. For convenience, the values of $\theta = 87$ and 93 were averaged so that the values of θ obtained from the flight tests were taken as 3, 90, and 177 degrees. The simulator measurements involved values of $\theta = 32$, 58, and 122 degrees. The first two values were averaged, so $\theta = 45$ and 122 degrees.

The relative slant range values for the field and simulator studies are presented in Table VI and in Figure 8.

TABLE VI

VALUES OF RELATIVE SLANT RANGE: ATTITUDE VARIATION

Field θ 3°	Simulator θ 45°	Field θ 90°	Simulator θ 122°	Field θ 177°
.75	.94	.97	1.06	1.37

There is a regular trend in the values of Table VI, irrespective of whether the data were obtained in the field tests or the simulator measurements. In Figure

8, the two sets of data seem to be reasonably well described by a linear relation between log relative slant range and the angle θ.

D. ANALYSIS OF THE PROBABILITY DATA OBTAINED IN THE FIELD AND SIMULATOR STUDIES

The analyses of Sections III B and III C have been concerned entirely with the slant recognition range values obtained on the passes in which the target was recognized. It is apparent from Tables III and IV that the field and simulator data differ also with respect to the recognition probability, and that the recognition probability values obtained both in the field and the simulator tests vary with respect to both flight altitude and flight attitude with respect to the sun's position.

The interpretation to place upon these values of recognition probability was not immediately apparent. It was decided that the significance of different recognition probabilities could only be ascertained in terms of the characteristics of probability curves expressed in terms of slant range. Accordingly, the simulator data were tallied as a body, as were the field test data. The tally involves counting the number of slant ranges falling within each of a large number of intervals along the scale of slant range. Each tally was assigned to a value of slant range corresponding to the midpoint of the interval used. In making the tally, passes in which the targets were never recognized were not assigned arbitrary values of slant range, but were scored as misses.

The second step involves obtaining cumulative tallies, representing the number of values of slant range equal to or greater than a given interval. The final step involves computing the probability that an interception occurred with a slant range equal to or greater than a given value, considering the total number of passes including those in which the target was missed.

The summary probability data for the field and simulator measurements are presented in Table VII and in Figure 9. These data should be used in those problems of interest to the Bureau in which it is not meaningful to specify either the flight altitude or the flight attitude with respect to the sun's position. Theoretical curves to be constructed in Section V should be used whenever the operational conditions of flight are known.

From examination of the data in Figure 9, it is apparent that there is a considerable difference in the data obtained in the two phases of the present study, with the recognition probability values being much smaller for the field test data than for the simulator data.

Detailed examination of the data in Figure 9 reveals that there are three kinds of differences between the two sets of data. The data obviously differ with respect to the general values of slant range for the same probability. This must be the case for the mean slant range values to differ as is apparent from a comparison of Tables I and II. The data also differ markedly with respect to the largest value of probability attained, the simulator data reaching

P = .89, whereas the field data reach only P = .54 as the upper limiting value. These differences correspond to the differences of grand average probabilities in Tables III and IV. (The limiting probability values in Figure 9 do not agree precisely with the grand average values of Tables III and IV because the values of N are not equal for the various flight altitudes studied.)

TABLE VII

RECOGNITION PROBABILITY AS A FUNCTION OF SLANT RANGE: ALL ALTITUDES AND ATTITUDES COMBINED

Slant Range (feet)	Field Data	Simulation Data
2,500	.54	.89
3,500	.52	.89
4,500	.52	.89
5,500	.50	.89
6,500	.46	.88
7,500	.40	.88
8,500	.36	.87
9,500	.32	.84
10,500	.26	.80
11,500	.18	.73
12,500	.09	.65
13,500	.06	.59
14,500	.05	.51
15,500	.05	.43
16,500	.04	.36
17,500	.04	.29
18,500	.02	.24
19,500	.02	.20
20,500	.01	.16
21,500	.00	.14
22,500	.00	.11
23,500	.00	.10
24,500	.00	.07
25,500	.00	.06
26,500	.00	.04
27,500	.00	.03
28,500	.00	.03
29,500	.00	.02
30,500	.00	.01
31,500	.00	.01
32,500	.00	.01
33,500	.00	.00

It is also possible to show that the field test data do not rise as rapidly to the upper limiting value as do the simulator data. That is the probability curve for the field test data is flatter than the curve for the simulator data.

An analytic method is needed to describe the quantitative characteristics of the probability curves shown in Figure 9. Such a method has been found which may be used to describe the differences between the two sets of probability data presented in Figure 9. This method was arrived at after considerable work with the data.

It is first assumed that the probability data represent two statistically separate processes, one of which depends upon the value of slant range and one of which is independent of the value of slant range. The first of these processes is to be expected, since the target would be expected to have higher probability of recognition the shorter the slant range. The second process may be conceptualized in terms of a lack of attention, or distraction, or any process which will make it impossible on a given pass for the observer to recognize the target, no matter how short the slant range. It is obvious that such a process must be at work in the data since the recognition probability does not reach unity for values of slant range equal to zero. It is hypothesized here that this process is statistically independent of the first process. Under these circumstances

$$P' = \frac{P}{\phi}$$

where P' is the recognition probability in the absence of the second process;
P is the recognition probability actually obtained; and
ϕ is the upper asymptotic value of P.

This equation may be used to correct out the effect of the hypothetical second process for each obtained value of P. Once corrected, the values of P' may turn out to be more readily described than the raw values of P, containing as they did the two separable processes.

The field test data were corrected for the role of the hypothetical second process, utilizing $\phi = .54$. The simulator data were likewise corrected, utilizing $\phi = .89$. The resulting values of P' were plotted in various ways to see if an analytical expression could be found to describe them. It was found that both sets of data were adequately described by a normal ogive when the values of P' were plotted against the logarithm of the slant range. The ogive has two parameters, corresponding to the median value of the slant range and the standard deviation of the frequency distribution from which the ogive may be derived. These parameters are expressed in terms of a logarithmic scale of slant range. (It must be emphasized, that these parameters do not describe the data directly, because they refer to the curve fitted through values of P' rather than P.) The median log slant range for the field data is 3.978 and σ is .163. The corresponding values for the simulator data are 4.188 and .135. These median values might be taken to mean that the average slant range for the field tests was 9,510 feet and 15,400 feet for the simulator data. Such an interpretation ignores the very real differences in ϕ and has no direct meaning. The proper description of the field and simulator data is in terms of the three parameters, median log slant range, σ, and ϕ.

To verify the adequacy of this analytic treatment of the data, we may construct theoretical probability curves with the three parameters selected and ascertain to what extent these theoretical curves do indeed fit the data. From the values of median and σ, we define values of log slant range corresponding to various values of P', utilizing standard tables of the ogive function. We obtain values of slant range for each value of P'. Finally, we obtain values of P from the relation

$$P = P' \phi$$

The solid curves plotted through the data in Figure 9 were obtained in this manner. The theoretical curve fitted through the simulator data provides an excellent fit of these data. The theoretical curve put through the field test data probably fits the data as well as any regular function. The field test data represent only one-eighth the number of simulator data and, of cource, there are a considerable number of additional experimental uncertainties present in the field test data, so that the general erraticness of the field test data is probably not surprising.

E. GENERAL COMMENTS ON THE DIFFERENCES BETWEEN THE SIMULATOR AND FIELD DATA

It is important to evaluate the rather large difference between the simulator and field data. Since the complexity of the terrain and target configurations was presumably simulated, we must look for other differences. It is true that there was no atmosphere present in the simulator, whereas the atmosphere present in the field tests reduced target contrast to some extent. However, since the slant ranges were considerably less than 50% of the minimum meteorological visibility, it is unlikely that the presence or absence of the atmosphere was very significant. There are a host of factors related to the task of flying the aircraft which were not simulated. For example, the pilots had to devote considerable time which might have been spent searching for the target watching the flight controls, listening to radio instructions, etc. There was the vibration and turbulence of the aircraft, and the optical imperfections and distortions of the windscreen. Unquestionably, these factors contributed greatly to the difference between field and simulator data.

In commenting upon the field tests and simulator measurements, the pilots emphasized that the cockpit configuration of the aircraft made forward viewing virtually impractical and that field observations had to be made therefore from the side to a point nearly forward. Furthermore, visibility was very poor on the side opposite from the seat occupied by the pilot-observer. Of course, visibility was unlimited in the simulator.

It is perhaps significant that the difference in ϕ is a very important contributer to the differences between the simulator and the field. As noted above, the values of median slant range for the theoretical curves in Figure 9 are 9,510 and 15,400 feet. Thus, the "field factor" is 1.62 when we ignore the difference in ϕ. The considerable importance of the difference in ϕ emphasizes the importance of such general factors as inattention and distraction which would be expected to reduce performance in the statistical manner of the ϕ factor.

IV. EVALUATIONS OF THE EFFECTS OF FLIGHT ALTITUDE AND FLIGHT ATTITUDE UPON THE SIMULATOR PROBABILITY DATA

The next step in our analysis involves investigating the effects of flight altitude and flight attitude with respect to the sun's position upon the values of ϕ and σ obtained in the simulator. The basic problem is that the Bureau wished to have continuous curves indicating the probability that target recognition would occur in the field at each of various values of slant range. Such probability curves were desired at each of various values of flight altitude and of flight attitude with respect to the sun's position. There were clearly only sufficient flight test passes (109) over the targets to enable us to prepare a summary probability curve representing all the data. The problem is therefore to obtain probability curves for sub-divisions of the field test data. This is to be accomplished by examining various aspects of the probability data obtained in the simulator measurements for various flight altitudes and attitudes, and employing internal relations in these data to estimate the characteristics of the probability data to be expected in field tests for different flight altitudes and attitudes.

A. EFFECTS OF FLIGHT ALTITUDE FOR ALL ATTITUDES COMBINED

First, we evaluate the extent to which values of ϕ derived from the simulator data depend upon flight altitude. The simulator data were tallied separately for each flight altitude, all values of Θ being included in each case. Values of ϕ were obtained which have been plotted in Figure 10, relative to the average value ϕ. There appears to be a variation in ϕ as a function of altitude which is reasonably well fitted by the empirical curve drawn through the points.

Next, we evaluate the simulator data to ascertain whether on not σ varies with flight altitude. We must begin by correcting the raw values of P at each altitude into values of P', utilizing the appropriate values of ϕ obtained from the data at each altitude. Values of P' are plotted against log slant range on probit paper. This paper rectifies a normal ogive into a straight line.

It is possible to fit a straight line to the data plotted on probit paper by visual inspection. The value of σ may be read off directly from the slope of the straight line. There was no evidence that σ varied as a function of altitude. However, the value of σ obtained with the simulator data for the separate altitudes is .105, which is smaller than the value of .135 obtained with all the simulator data. (Of course, the value of σ should be larger when the data from different flight altitudes are combined, since there is a systematic difference in the mean slant range as a function of flight altitude. Combining non-homogeneous data samples must of necessity increase the value of σ.)

B. EFFECTS OF FLIGHT ATTITUDE FOR ALL ALTITUDES COMBINED

As in the analysis reported in Section IV A above, we begin by evaluating the extent to which values of ϕ derived from the simulator data depend upon flight attitude. The simulator data were tallied separately for each flight attitude, all values of flight altitude being included in each case. Values of ϕ were obtained from those tallies. These values are plotted as a function of ϕ in Figure 11, expressed relative of the average value of ϕ. The line fitted through the two points in Figure 11 is of necessity quite uncertain, but it is our simplest assumption in the absence of other information.

Next, the simulator data were examined with respect to a possible variation in the value of σ as a function of flight attitude. As before, values of P were converted to P' by means of the appropriate values of ϕ. Plots were made on probit paper of P' versus log slant range, and values of σ were determined by visual fit. The value of σ was found to be the same for the two values of Θ. However, the average value of σ for samples separated in terms of Θ but combined in terms of altitude is .130, to be compared with a value of .135 for all the combined simulator data. Again, this difference is to be expected since mean slant range varies with Θ; the combining of sets of non-homogeneous data should increase the value of σ.

C. FLIGHT ATTITUDE FOR EACH FLIGHT ALTITUDE TAKEN INDIVIDUALLY

Finally, an analysis was made of the simulator probability data in which the effects of flight attitude were investigated on data for each altitude taken separately. The first step involved tallying the simulator data into separate sets for individual values of Θ at each flight altitude.

It was found that the values of ϕ obtained from each set of data varied with respect to Θ in accordance with the line plotted in Figure 11, obtained from data combined from all altitudes. Similarly values of ϕ obtained from each set of data varied with respect to altitude in accordance with the line plotted in Figure 10, obtained from data combined from all values of Θ. Thus, the lines of Figures 10 and 11 may be considered to describe the data obtained with individual values of Θ and altitude. Furthermore, this analysis indicates that the effects of attitude and altitude are independent of each other, and that the value of ϕ for a particular set of data involving a single value of Θ and a single altitude may be computed by multiplying a factor obtained from Figure 10 by a factor obtained from Figure 11.

Finally, an analysis was made of possible variations in the value of σ for sets of simulator data representing single values of Θ at each altitude. Values of P were converted to values of P' by appropriate values of ϕ. Values of P' and log slant range were plotted on probit paper and values of σ determined by visual fits. It was found that σ varied as a function of Θ, but not as a function of flight altitude. The variation in σ as a function of Θ is shown by the two points plotted in Figure 12. The straight line fitted through the points is our simplest assumption in the absence of other information. The average value of σ obtained in the sets of data for individual values of Θ and altitude was .100, as compared with .135 for all the simulator data combined. This large difference is to be expected since our analysis has made it clear that both Θ and altitude influence mean slant range. The combining of such non-homogeneous data must increase the value of σ considerably.

V. CONSTRUCTION OF THEORETICAL PROBABILITY CURVES FOR FIELD DATA UNDER VARIOUS OPERATIONAL CONDITIONS

The analyses of Sections III and IV have laid the foundation for the construction of theoretical probability curves, intended to represent the form the field test data would have taken under various operational conditions had there been ample data. These theoretical curves are based upon the actual probability curve for all the field data combined, with modifying factors used to represent the probable characteristics of subdivisions of the data representing different conditions of flight altitude and flight attitude with respect to the position of the sun. The modifying factors are based upon the characteristics of both field and simulator data when possible (Section III), and upon the characteristics of the simulator data alone when necessary (Section IV). Theoretical probability curves have been constructed for three operational situations, involving different conditions of flight altitude and attitude with respect to the sun's position.

A. FLIGHT ALTITUDE FOR ALL ATTITUDES COMBINED

We have established that mean slant range varies with flight altitude, as shown in Figure 7. Factors were derived from the line of Figure 7 at each flight altitude. These were multiplied by the median slant range for all field data combined, and logarithms taken to yield values of median log slant range to use at the various flight altitudes. The following values were obtained;

Altitude (feet)	Median log slant range (feet)
2,000	3.841
4,000	3.927
5,700	4.003
7,500	4.082

We have also established that ϕ varies with flight altitude, as shown in Figure 10. We obtained values of relative ϕ corresponding to the various flight altitudes from the smooth curve of Figure 10, and, using an average value of $\phi = .54$ for all the field test data, computed the expected values of ϕ for the field test data as follows:

Altitude (feet)	ϕ
2,000	.49
4,000	.55
5,700	.56
7,500	.56

We have previously established that σ does not vary with altitude. However, the value of σ for simulator data for separate altitudes, but combined with respect to Θ, is .105 as compared with .135 for all simulator data combined. We assume that the value of σ for field data at individual flight altitudes will be reduced in the same ratio as was the value of σ in the simulator data. Hence, from the fact that σ for all the field data combined is .163,

$$\sigma = .163 \times \frac{.105}{.135} = .127$$

A value of $\sigma = .127$ is used to describe each set of field data at a particular flight altitude.

The foregoing analysis has established the values of median log slant range, σ, and ϕ to utilize in constructing theoretical probability curves to represent likely values of the field data at the various flight altitudes. The final step involves construction of the theoretical curves. As before, values of P' and log slant range are obtained from the standard tables of the ogive function, based upon values of median log slant range and σ. Values of P are computed utilizing values of ϕ, and values of slant range are obtained by the antilogarithmic process.

Theoretical curves for the four flight altitudes are presented in Figure 13. It is to be emphasized that each curve represents average data for all attitudes with respect to the sun's position. These data are directly suitable for the solution of practical problems in which it must be assumed that any or all flight attitudes between 3 and 177 degrees may be involved in aerial reconnaissance.

B. FLIGHT ATTITUDE FOR ALL ALTITUDES COMBINED

The construction of theoretical probability curves for various flight attitudes with respect to the sun's position, for all altitudes combined, proceeds in a manner analogous to that used in the last section. We begin by defining values of median slant range for various flight attitudes based upon the line fitted to the mean slant range data in Figure 8. Factors are read from the line at each value of θ of interest. These are multiplied by the median slant range for all field data combined, and logarithms are taken to yield values of median log slant range to use at the various flight attitudes. The following values were obtained:

θ (degrees)	Median log slant range (feet)
3	3.841
45	3.907
90	3.973
122	4.027
177	4.108

Values of ϕ for the field data at various flight attitudes were computed from relative factors read from the line in Figure 11, and the average value of ϕ for all the field data. The values were as follows:

θ (degrees)	ϕ
3	.51
45	.52
90	.54
122	.56
177	.58

The average value of σ for data samples separated in terms of θ but combined in terms of altitude is .130. Thus, the average σ to be used in the present analysis of field data,

$$\sigma = .163 \times \frac{.130}{.135} = .157 \ .$$

With the values of median log slant range, σ, and ϕ, it is possible to derive theoretical probability curves for the field data to be expected at different values of θ. These curves are presented in Figure 14. There are directly relevant to any practical problems in which flight attitude is determined, but in flight altitude may assume any or all values between 2,000 and 7,500 feet.

C. FLIGHT ATTITUDE FOR EACH FLIGHT ALTITUDE

Following the method described in Section V A above, theoretical probability curves are constructed for each of various flight attitudes at each of various flight altitudes taken separately.

The first step involves determining the values of median log slant range for each value of Θ at each flight altitude. Factors relating relative slant range to Θ are presented in Figure 8. Analysis demonstrated that these factors are equivalent for various flight altitudes. Factors relating relative slant range to flight altitude are presented in Figure 7. Analysis demonstrated that these factors are independent of Θ. Under these circumstances, values of median log slant range may be computed by multiplying together the factors derived from the smooth lines in Figures 7 and 8. These combined factors are then multiplied by the median slant range for all field data combined. The following median log slant values were obtained:

	Flight Altitude (feet)			
Θ (degrees)	2,000	4,000	5,700	7,500
3	3.704	3.790	3.866	3.944
45	3.771	3.856	3.932	4.011
90	3.837	3.922	3.998	4.077
122	3.890	3.976	4.052	4.130
177	3.972	4.058	4.134	4.212

Finally, it has been shown that σ varies with Θ but does not vary with altitude. Factors representing the change in σ with Θ may be read from the line in Figure 12. The average value of σ for individual sets of simulator data is .100, as compared with .135 for all simulator data combined. Thus, the average value of σ for the field data is

$$\sigma = .163 \times \frac{.100}{.135} = .121$$

The factors from Figure 12 are applied to this value of average σ, with the following results.

Θ (degrees)	σ
3	.146
45	.133
90	.118
122	.109
177	.091

We have now defined values of median log slant range, σ, and ϕ for each value of Θ at each altitude. Theoretical probability curves are constructed from standard tables of the normal ogive, utilizing the values of median log slant range and σ. Values of P are computed, utilizing the appropriate value of ϕ in each case. Values of P and slant range are plotted for each value of Θ at each altitude taken separately in Figures 15-19. These curves are directly applicable in practical problems in which a particular flight attitude is to be flown at a particular altitude. Presumably, these curves will have the greatest practical value to the Bureau.

VI. DIFFERENCES BETWEEN DETECTION AND RECOGNITION RANGES

As indicated in Section II above, it was considered impractical to determine both detection and recognition ranges during the flight tests. However, detection and recognition ranges were determined during the simulator measurements. These data have been analyzed to give some concept of the extent of difference in the ranges obtained with these two visibility criteria.

It has not seemed worthwhile to subject the detection ranges to the extensive analysis made of the recognition data. The analysis of the detection and recognition ranges proceeded therefore by the determination of values of D/R, a ratio of the detection range divided by the recognition range. Since there was never a recognition made without a detection, nor a detection without a recognition, the probabilities are identical. The values of the D/R ratio were summarized by flight altitude and attitude, with the results shown in Table VIII.

TABLE VIII

VALUES OF THE D/R RATIO FROM SIMULATOR DATA

Altitude (feet)	θ 45°	θ 122°	Average
2,000	1.150	1.259	1.205
4,000	1.188	1.192	1.190
5,700	1.181	1.187	1.184
7,500	1.146	1.090	1.118
Average	1.166	1.182	

It appears that the D/R ratio does not vary significantly with flight attitude, but does show a consistent trend as a function of flight altitude. The fact that the D/R ratio is least for the higher altitudes can perhaps be understood in terms of the fact that the targets exhibit less perspective distortion at the higher altitudes.

If detection ranges are desired, the values in Table VIII may be applied directly to the values of slant range obtained from the theoretical probability curves. This use of the ratios assumes that σ is the same for detection and recognition, an assumption which must be made in the absence of information to the contrary.

VII. SUPPLEMENTARY INVESTIGATIONS OF THE INFLUENCE OF TARGET REFLECTANCE AND OF TERRAIN BACKGROUND

It was not possible to study the influence of either target reflectance or terrain background during the main series of field tests and simulator measurements, due to limitations on the time during which the pilot observers were available. Accordingly, supplementary investigations of these variables were made with a laboratory observer. These investigations were designed to yield comparative data only, so that the use of laboratory observers should be satisfactory.

A. TARGET REFLECTANCE

The targets used in the main experiments were painted battleship gray, which provided rather a good color match against the asphalt roads used exclusively as target backgrounds. A supplementary study was made utilizing targets painted with olive drab paint. A flight attitude of 45° was used since under these conditions the targets produced the least shadow of any value of θ available in the simulator, and hence the color of paint should be of the greatest significance. A flight altitude of 4,000 feet was used as an intermediary value of this operational variable. Twenty observations were first made with the olive drab targets, including a target at each heading at each of the ten locations. Then twenty observations were made with the gray targets. In making the second forty observations, twenty were first made with the gray targets, followed by twenty with the olive drab targets.

The mean slant recognition ranges obtained on all target interceptions were as follows:

Gray paint	15,443 feet
Olive drab paint	16,631 feet

The recognition probabilities were as follows:

Gray paint	P = .925
Olive drab paint	P = .950

It is apparent that the targets were recognized somewhat more often and at somewhat long slant ranges with the olive drab than with the battleship gray paint. However, the effect is very small, being only 2.5% in probability and 7.5% in mean slant range. Thus, we may conclude that our main experimental results apply almost equally well to targets with olive drab as with battleship gray paint. The apparent insignificance of target color seems reasonable in view of the spontaneous reports of the pilot-observers, who believed it was the difference in luminance between target and background rather than color which rendered the targets recognizable.

B. TERRAIN BACKGROUND

The backgrounds against which the targets were viewed in the main experiment were roads, most of which were asphalt. The Bureau wanted information on the slant ranges to be expected when the targets were viewed against grass and dirt backgrounds as well. A supplementary study was conducted utilizing the original targets painted battleship gray, with three terrain backgrounds: asphalt roads, grassy fields, and dirt fields. Because the observer was quite familiar with the target locations used in the main experiment, a new selection of ten roadway locations was made. Locations on grass and dirt were selected which seemed equivalent in difficulty, in terms of the degree of vegetation and man-made structures in the immediate surroundings.

The general procedures of the main experiments were followed, except that when the target vehicles were placed in the grass or dirt backgrounds, they were oriented first parallel and then perpendicular to the observer's line of flight for the two target positions. A flight altitude of 4,000 feet was used throughout, as was a flight attitude of 45°. In the first group of 60 observations, twenty were made with each background condition in the order: asphalt, grass, dirt. In the second group of 60 observations, twenty were made with each background condition in the order: dirt, grass, asphalt.

The mean slant recognition ranges obtained on all target interceptions were as follows:

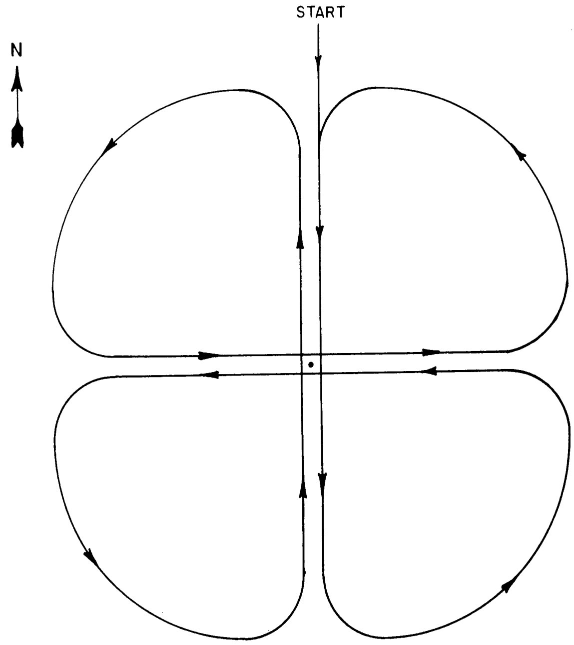
Asphalt background	14,372 feet
Grass background	17,171 feet
Dirt background	19,186 feet

The recognition probabilities were as follows:

Asphalt background	P = .825
Grass background	P = .925
Dirt background	P = .900

There appear to be significant differences in the mean slant ranges for the three terrain backgrounds. The differences in recognition probability are of much less significance. Taking the asphalt background as the standard, the mean slant range is 1.20 times as long for grass background and 1.34 times as long for dirt backgrounds. Presumably, it is appropriate to increase slant range values read from the theoretical probability curves by these factors, when the non-asphalt backgrounds are used. Use of a constant multiplier in this way assumes that the value of σ is the same for the three terrain backgrounds. This assumption will have to be made in the absence of information on this point.

Fig. 1. Aerial photograph of field test site.



ig. 2. Schematic diagram of flight pattern, showing center of flight pattern.

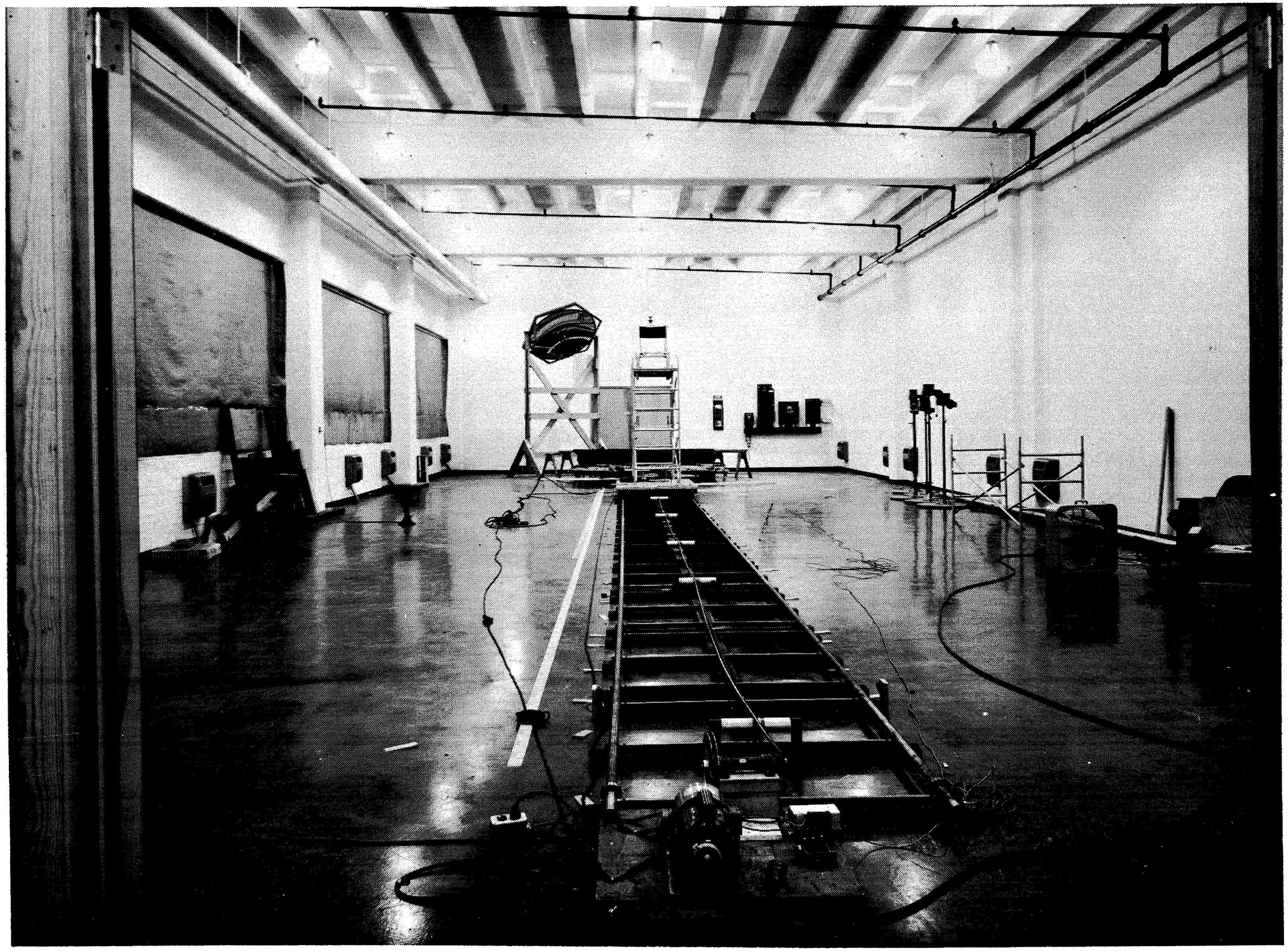


Fig. 3. Photograph of simulator showing track, dolly, model and simulated sun.

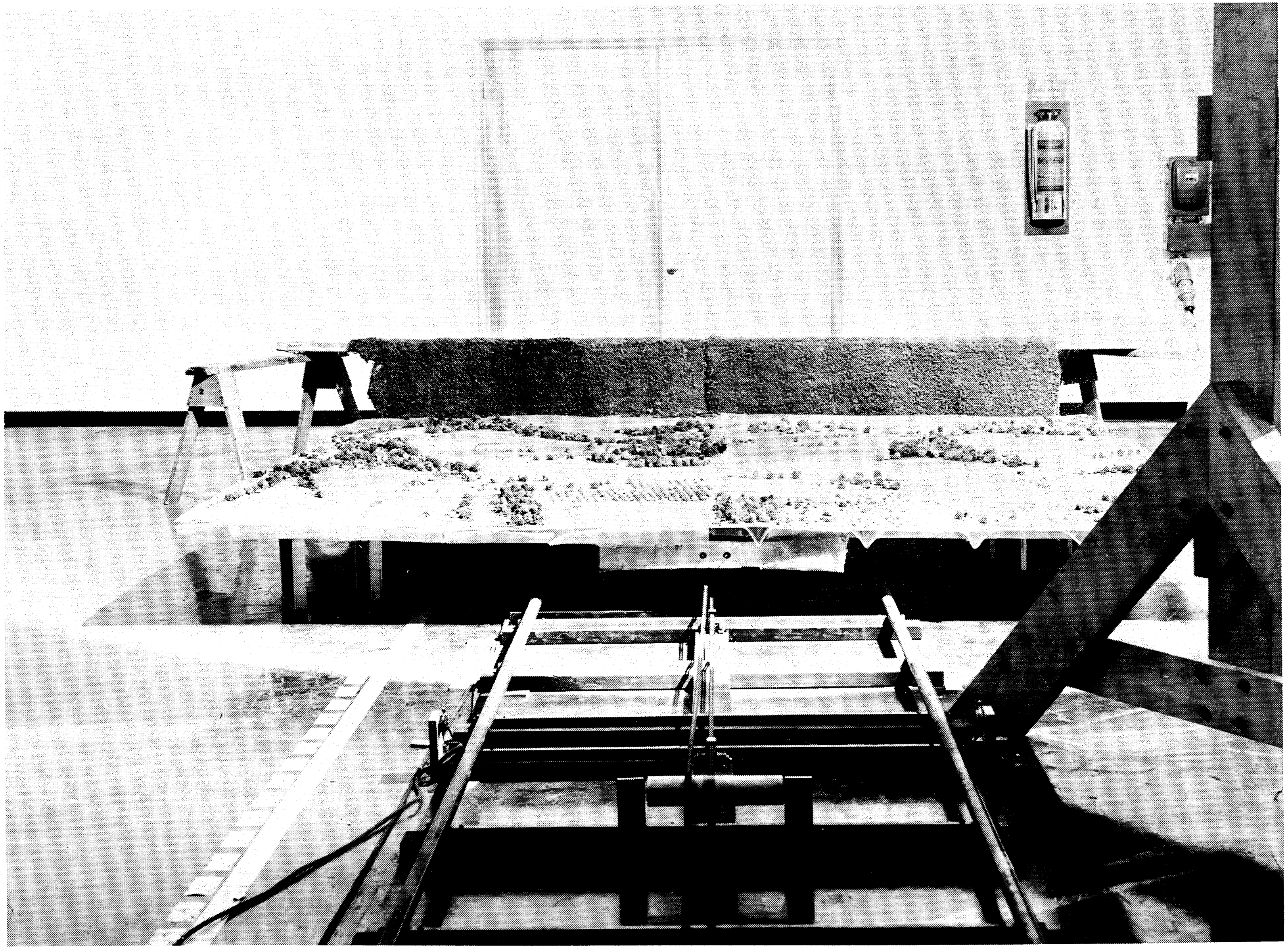


Fig. 4. Photograph of terrain model from simulated altitude of 2,000 feet.

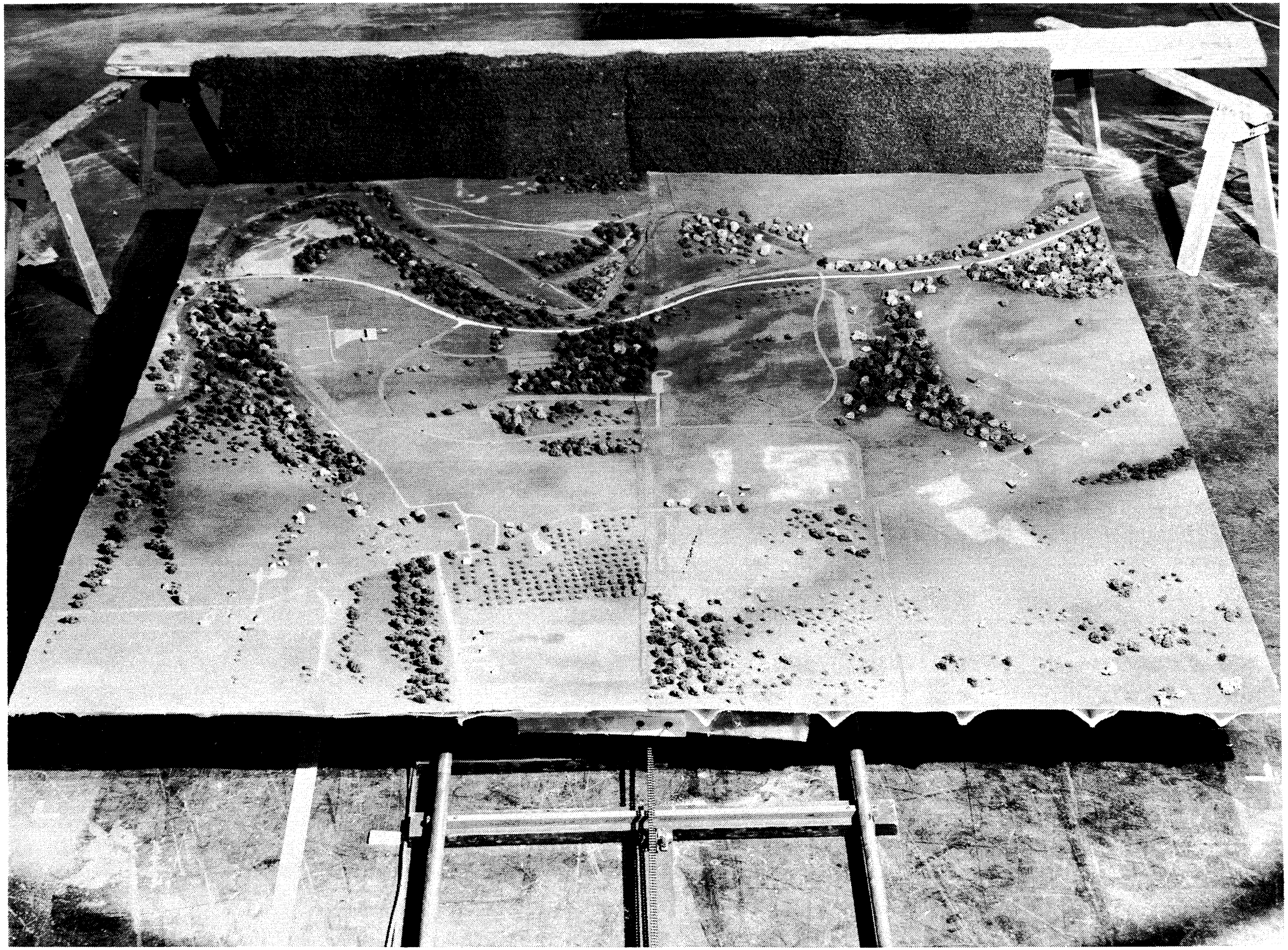


Fig. 5. Photograph of terrain model from simulated altitude of 7,500 feet.

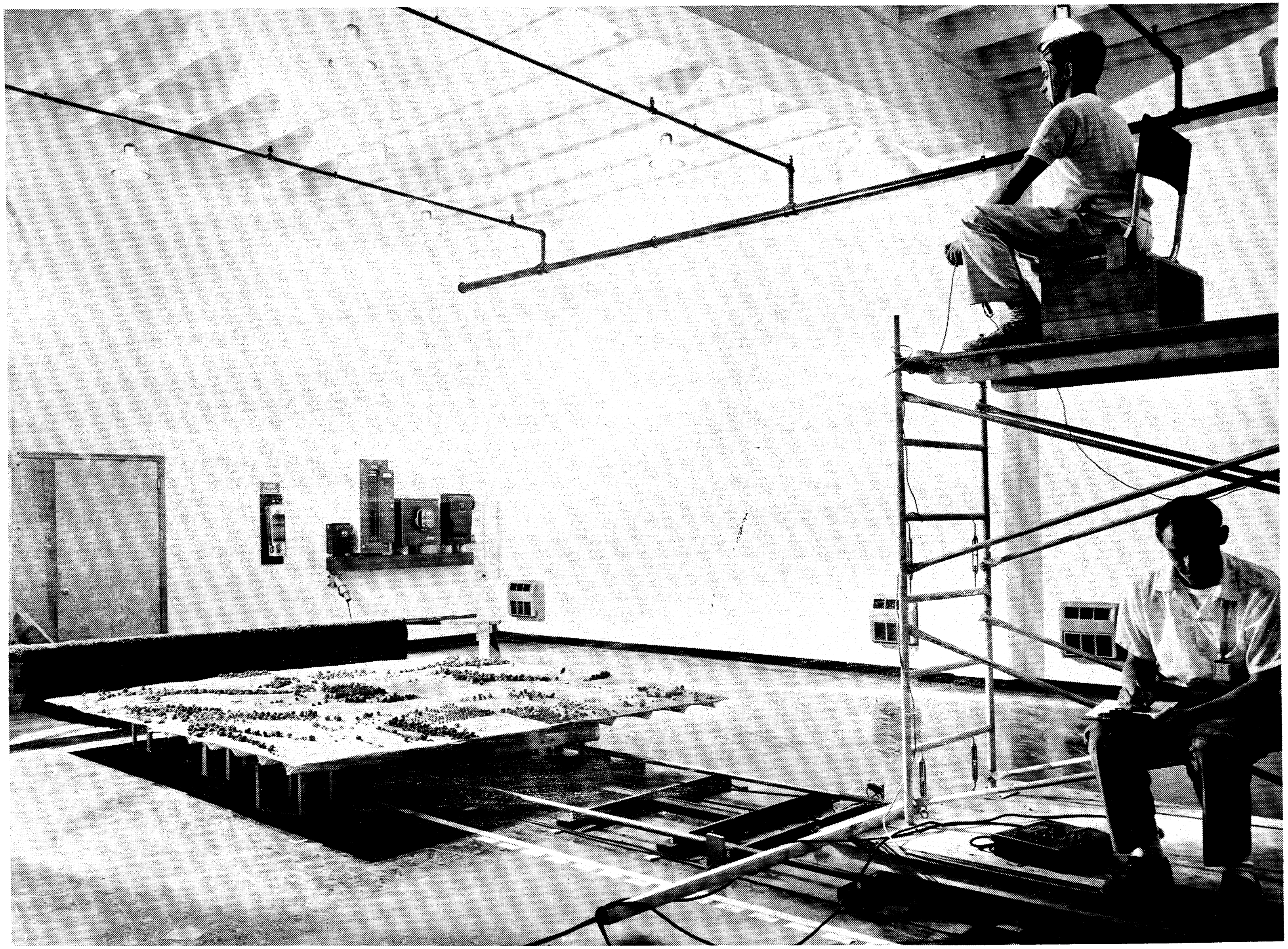


Fig. 6. Photograph of simulator showing observer and experimenter in position.

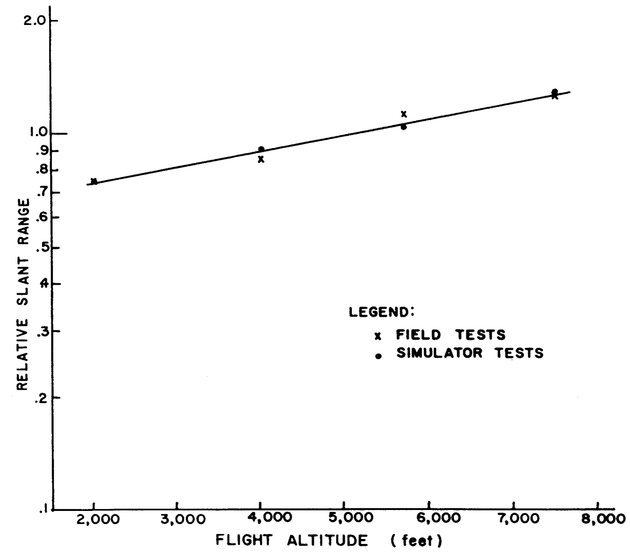


Fig. 7. Log relative slant range as a function of flight altitude.

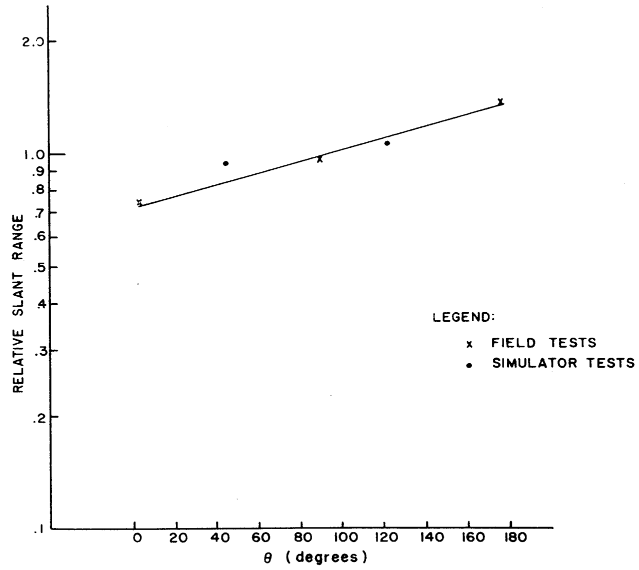


Fig. 8. Log relative slant range as a function of flight attitude.

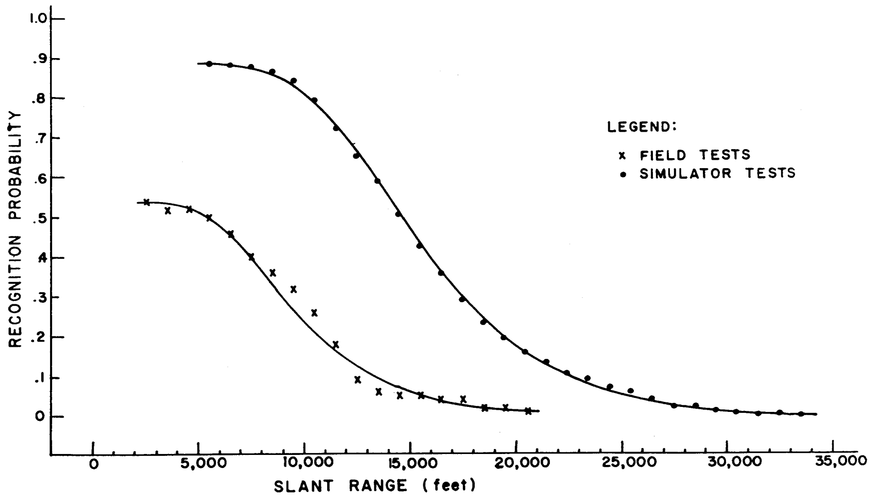


Fig. 9. Data: recognition probability as a function of slant range: field and simulator data.

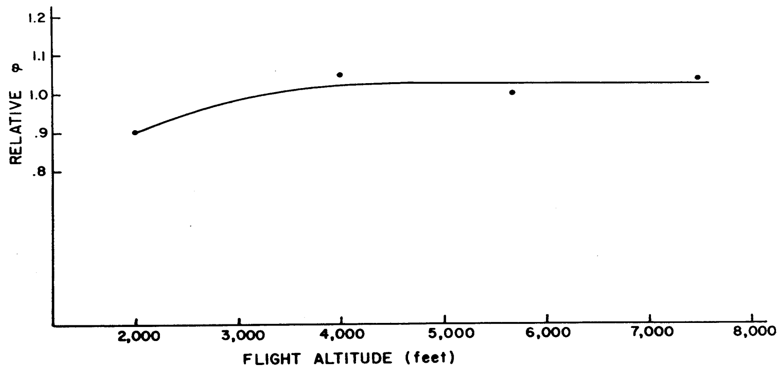


Fig. 10. Relative ϕ as a function of flight altitude.

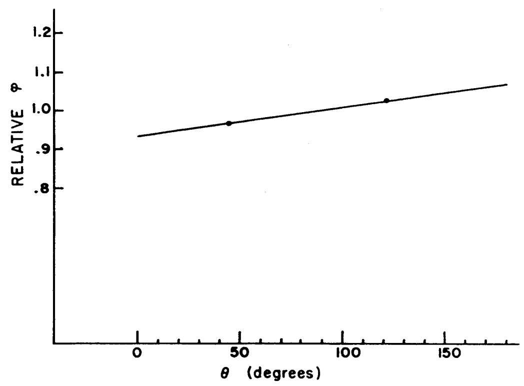


Fig. 11. Relative ϕ as a function of flight attitude angle Θ.

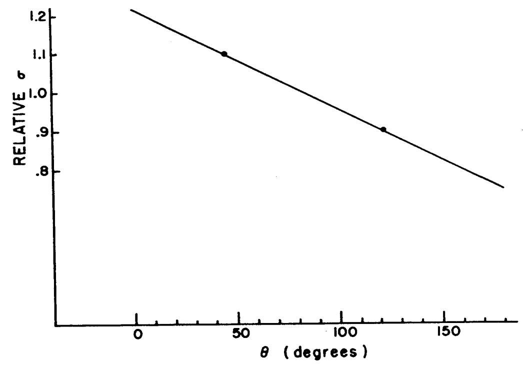


Fig. 12. Relative σ as a function of flight attitude angle Θ.

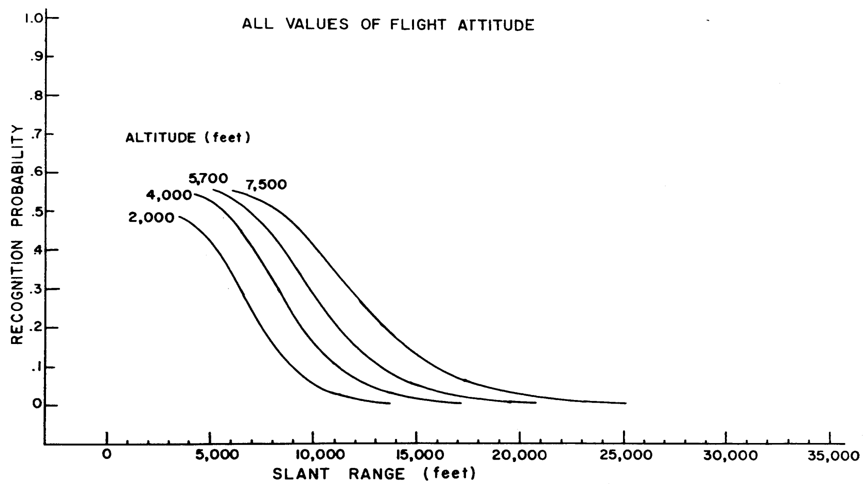


Fig. 13. Theoretical curves: recognition probability as a function of slant range: all values of flight attitude.

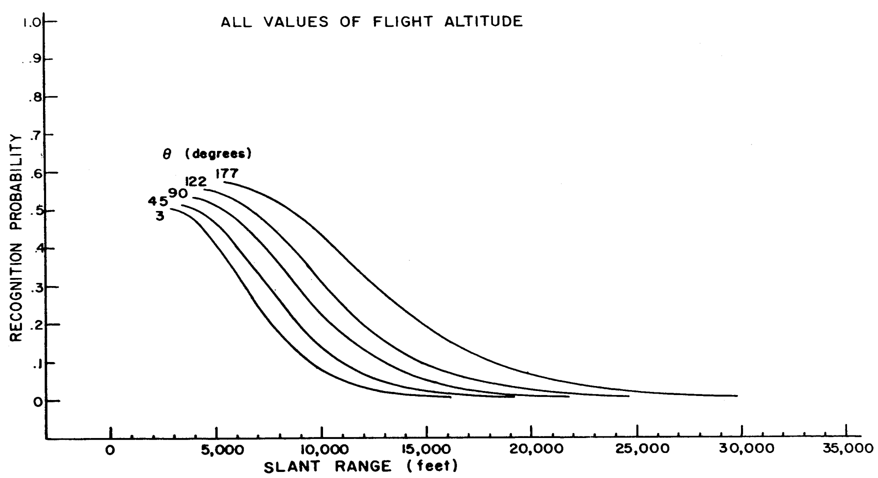


Fig. 14. Theoretical curves: recognition probability as a function of slant range: all values of flight altitude.

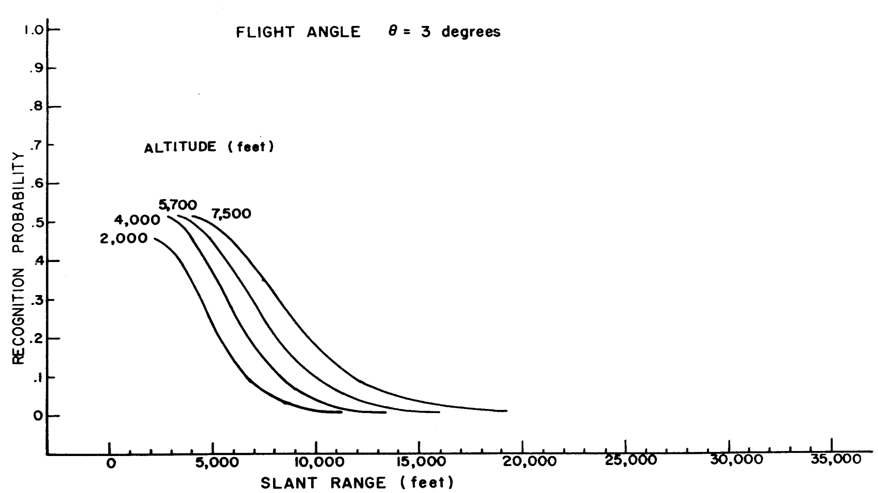


Fig. 15. Θ = 3 degrees.

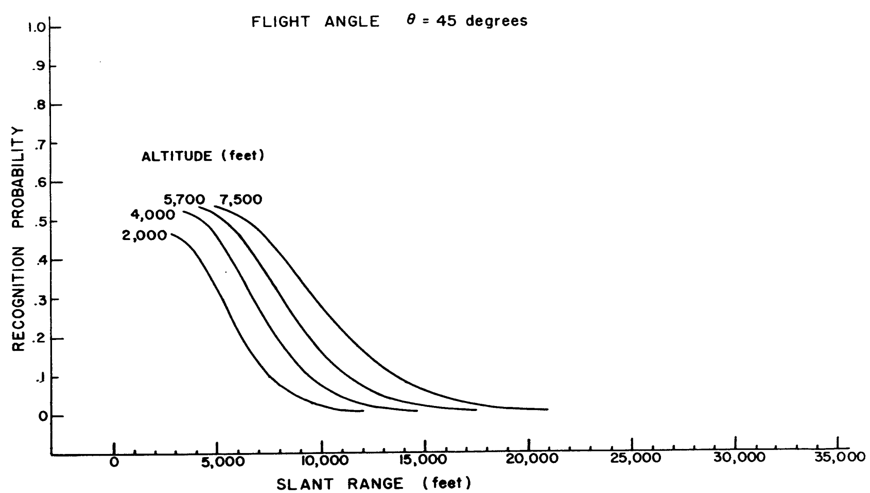


Fig. 16. Θ = 45 degrees.

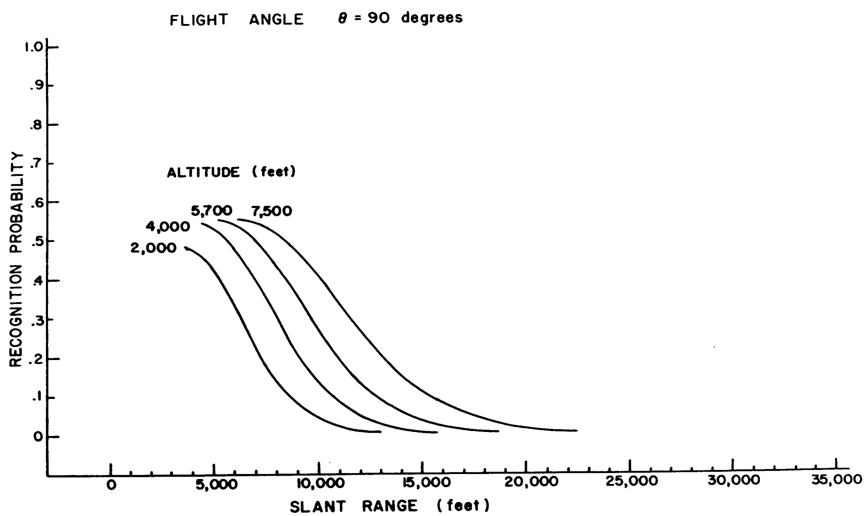


Fig. 17. Θ = 90 degrees.

Figs. 15-17. Theoretical curves: recognition probability as a function of slant range: each of 4 altitudes.

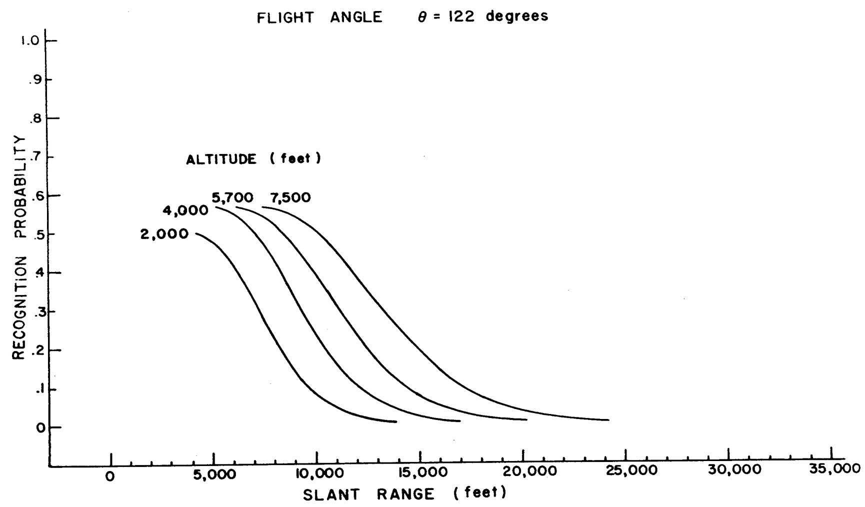


Fig. 18. Θ = 122 degrees.

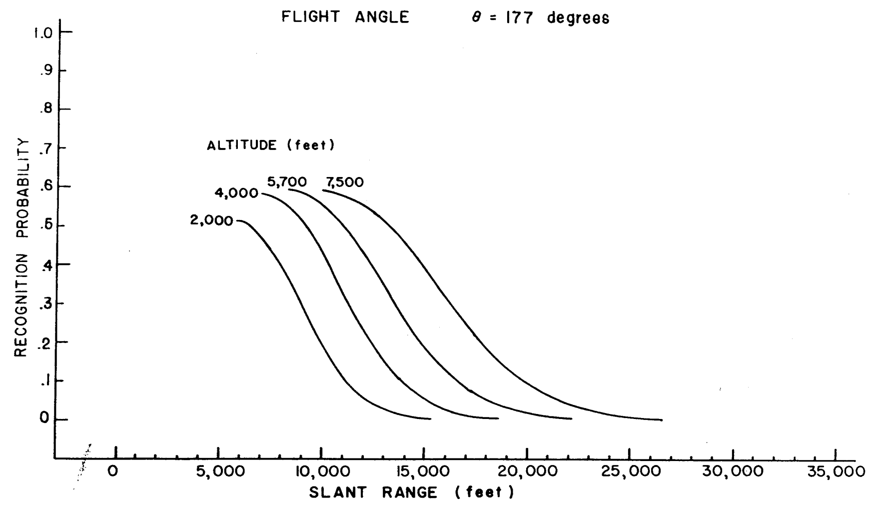


Fig. 19. Θ = 177 degrees.

Figs. 18-19. Theoretical curves: recognition probability as a function of slant range: each of 4 altitudes.