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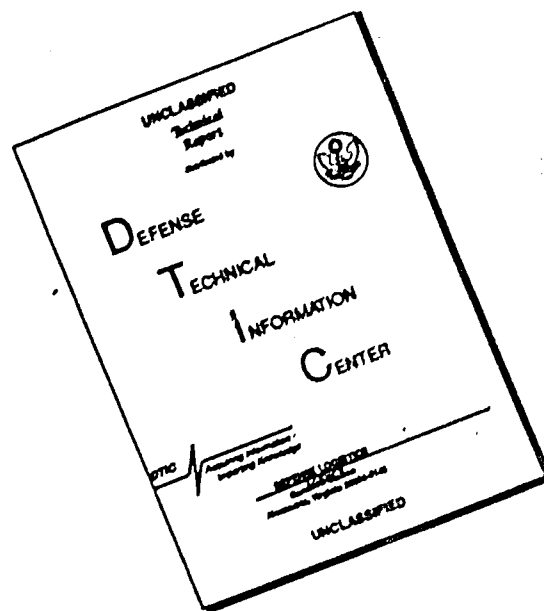
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ABSTRACT

Probabilities of detecting airplanes visually in daylight have been determined in trials conducted by the Naval Air Test Center, Patuxent River, Maryland. Comparison of the results with those predicted by visual-detection theory (OEG 51, 100-100) indicates that the theory adequately describes visual detection in air interception. The agreement between trial results and theory is better when the actual ground plane area of the targets are used in computing the visual range of detection than it is when the assumption is made that these ranges are proportional to the cross section of the ground area. This approximation, suggested in Study No. 100-100, is necessary when actual ground plane area is not known.

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15 August

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VISUAL DETECTION IN AIR INTERCEPTION:
A COMPARISON OF THEORY WITH TRIAL RESULTS
(Revised April 1952)

- Ref: (a) OEG Report 56 Search and Screening Conf 1946
(b) OEG Study No. 368 Visual Detection in Air Inter-
ception Conf 26 Oct 1946
(c) OEG Study No. 430 Addendum to OEG Study No. 368
Computation of Probability of Visual Detection in
Air Interception Conf 21 Nov 1950
(d) OEG Study No. 371 The Problem of Visual and Radar
Sighting in High-Speed, High-Altitude Interception
Secret 3 Dec 1948
(e) CO-NAVARR CC-4 JRA-222 Report 1 Jan 1947
(f) CO-NAVARR Engineering Report No. DE-304 Character-
istics Summary U.S. Navy Aircraft Secret 15 Oct
1948

I. INTRODUCTION

In spite of the improvements that have been made in other detection methods, visual sighting of enemy aircraft remains vital in air interception. C.I.C. information generally is insufficient to guide an aircraft into firing position. Consequently, final detection must often be by visual means.

Interest in visual detection was stimulated by the failure to sight Japanese Kamikaze attackers at ranges sufficient to defeat their mission and by the difficulties in conducting air-sea rescue operations. Attempts were made to obtain information on detection probabilities from detections of scale-model aircraft. These trials proved inconclusive, and no permanent record of them was kept. Some experimental data on vision were available, however, and from them a basic theory of visual detection was constructed (reference (a)).

Reference (a) made special application of this theory to the sighting of surface ships from aircraft. Reference (b) applied this theory to the visual detection of airborne targets, and reference (c) presented a method that enabled one to calculate the probability of visual detection of a target aircraft by an airborne observer for a large number of conditions. Reference (d) undertook special treatment of

3
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high-speed, high-altitude interception. But adequate experimental data by which to judge the theory were needed.

To furnish these data, a series of trials were conducted by the Naval Air Station, Patuxent River, Maryland, from 17 December 1949 to 30 January 1950. These trials yielded the data needed for computing the probabilities of success under different operational conditions. Also, a investigation of the extent to which the visual-interception theory of reference (1) was verified in the trials.

A. 100-111

100-111
(10)

For (1) and (2) ... (1) and (2) ... in de- ... between ... by the ... ground ... back ... under ... difference ... shape ... light ...

(1) ...
(2) ...

... characteristics ... is ... back ... change in ... from ...

a function of the angular distance between the visual axis of the eye and the line joining the object with the eye.

B. DETECTION LOBE

Results of investigation by E.J.W. Craik are used in reference (1) and (2) to derive the following expression connecting brightness contrast C with range of target R , angle θ between line target and the visual axis, and area A of the cross section of the target in the plane perpendicular to the visual axis:

$$C = 1.75 \times 10^{-4} + 45.6(\theta R^2)/A. \quad (1)$$

Here R is in miles, A is in square feet, and θ is in degrees. (If θ is less than 0.8, this equation does not apply, and the value of R is the same as that determined for $\theta = 0.8$.) This equation defines a detection lobe, which can be thought of as a surface of revolution constructed about the eye's visual axis in such a manner that a target within the lobe can be seen and a target outside of the lobe cannot be seen. Actually, of course, visibility of an object is not that precisely determinable; some targets that fall within the detection lobe will be missed and others that fall outside of it will be detected. The lobe is drawn on the assumption that the number of targets detected is the same as though all that fall within the lobe are detected and all that fall outside it are missed.

C. HAZE

Haze in the atmosphere will reduce the apparent contrast of the target and thus reduce the range at which the target can be detected. Reference (3) connects intrinsic contrast C_0 with apparent contrast C by the expression

$$C = C_0 \exp(-2.44 R/V), \quad (2)$$

where V is the meteorological visibility or range at which large targets (such as mountains) can be seen. Substituting this into equation (1) gives

$$C_0 \exp(-2.44 R/V) = 1.75 \times 10^{-4} + 45.6(\theta R^2)/A. \quad (3)$$

D. DETECTION RANGE

Maximum range of detection will be obtained when the target is imaged on the fovea. This will occur when θ is less than or equal to 0.5 degree, which is the approximate angular radius of the fovea. This substitution in equation (1) yields

$$R_m = 0.1655 (C_0 - 1.565)A \quad (4)$$

as an expression for maximum range R_m . The maximum range in the absence of haze, R_0 , similarly becomes

$$R_0 = 0.1655 \sqrt{C_0 - 1.565}A. \quad (5)$$

E. COMPUTATION OF DETECTION LOBE

Equations (3) and (5) connect visual perception angle θ with A , C_0 , V , and R . If, instead of these, the variables R/R_0 , R_0/V , and C_0 are employed, the number of variables is reduced from 4 to 3. When this is done, the following expression is obtained for θ :

$$\theta = F \left\{ \sqrt{G/F + 1} - 1 \right\}^2, \quad (6)$$

where

$$F = 0.49 (R_0/R)^4 / (C_0 - 1.565)^2$$

and

$$G = 0.80 C_0 \exp(-3.44R/V) (R_0/R)^2 / (C_0 - 1.565).$$

Details of a similar substitution involving R_m instead of R_0 can be found in reference (a).

Equation (6) has been used in reference (b) to compute detection lobes for a wide variety of conditions. Two typical lobes are plotted in Figure 1. Curve A shows the

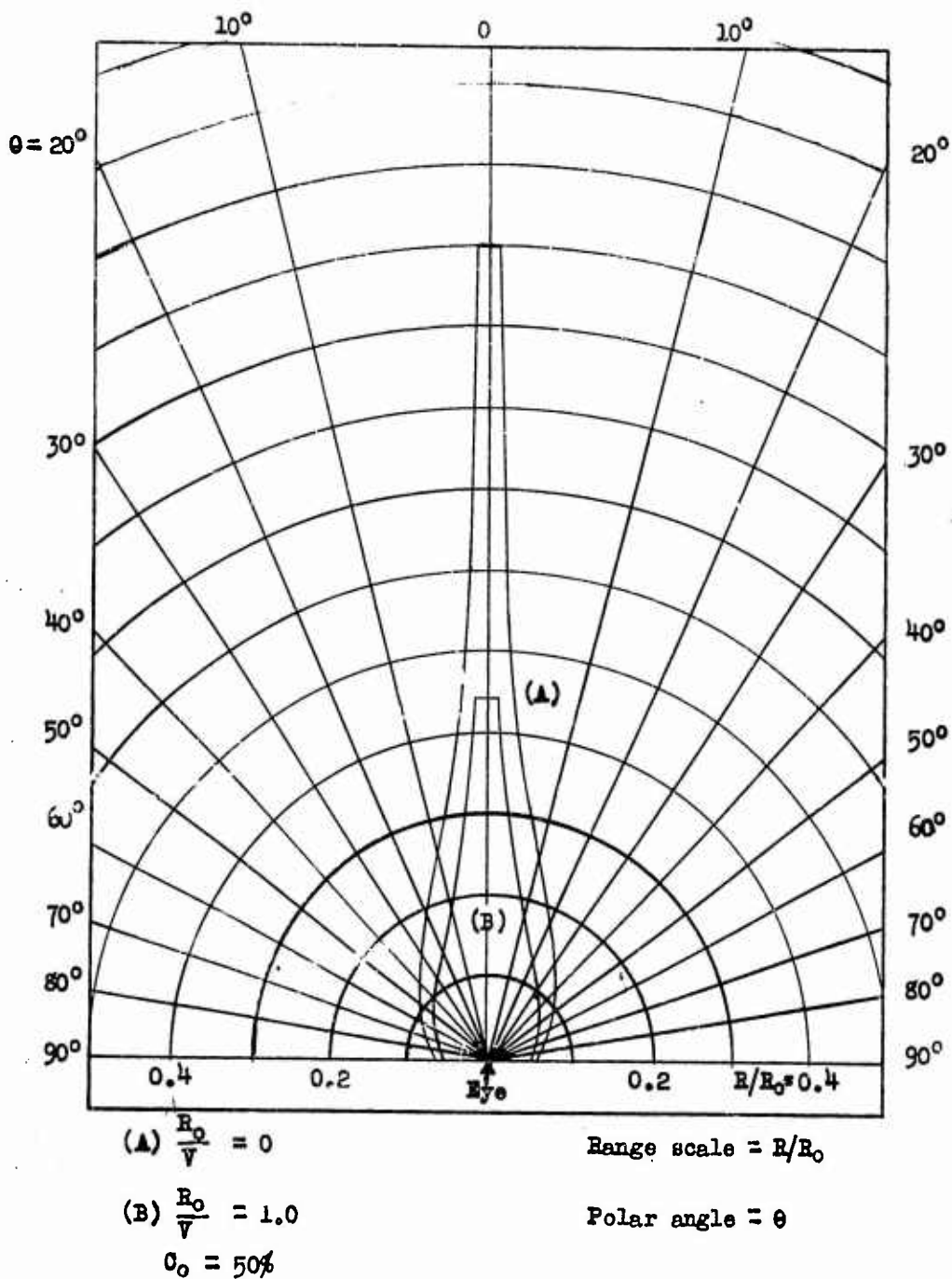


FIG. 1: TYPICAL DETECTION LOBES

F. CLIMPS' PRO A. 12

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$$x^2 + y^2 + z^2 = 1 \quad (7)$$

C. CUMULATIVE PROBABILITIES OF DEATH

initially, the target was not a target.

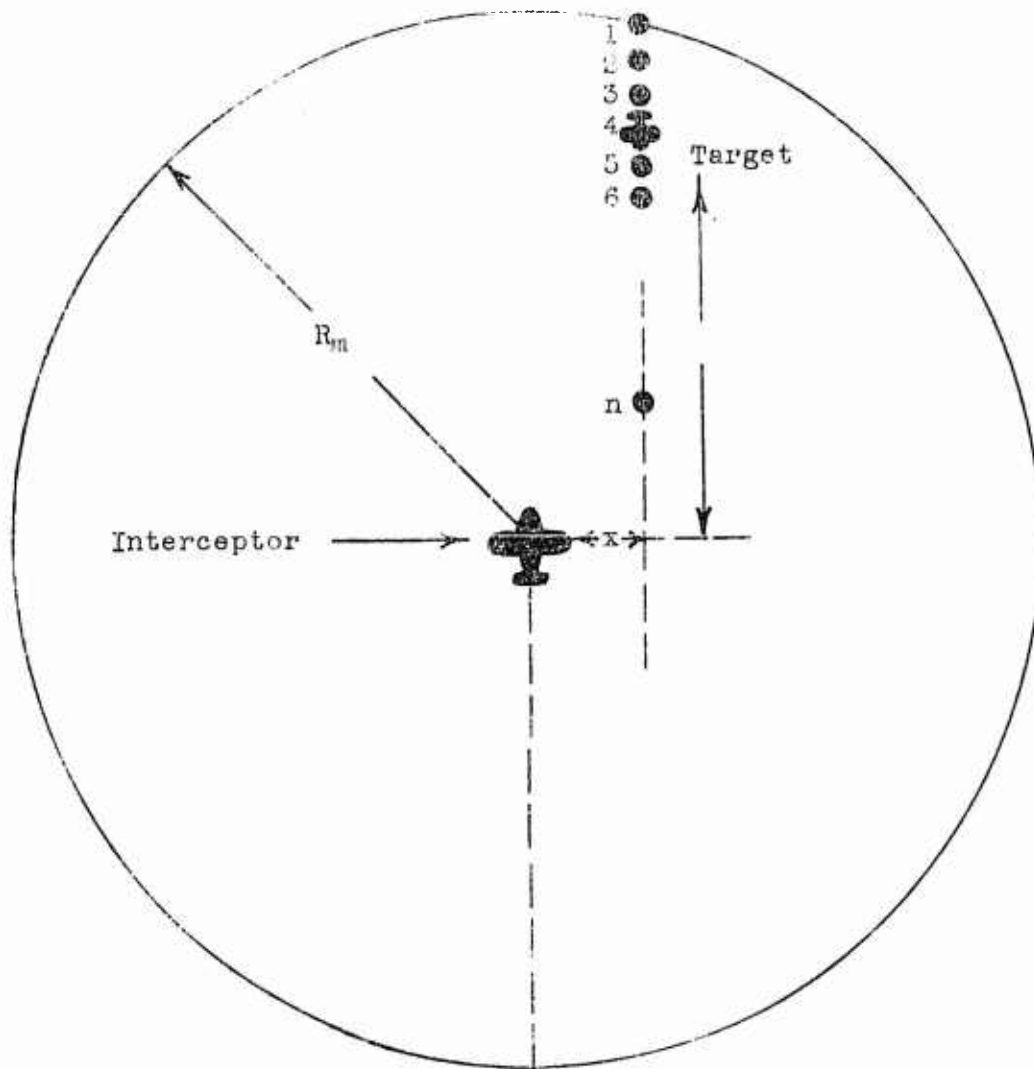


FIG. 2: GLIMPSE PROBABILITIES

The target, however, may be at positions 1, 3, 4, ..., n; so if it is not detected the instant it is at the extreme range, it will not be detected until it has reached some closer range. Let us assume that the probability that the target will be detected at position 1 is g_1 . (See Equation (7).) Then the probability that it will not be detected at position (1) is $(1 - g_1)$, since the probability of successful detection and the probability of failure to detect must equal 1. The probability that the target will fail to be detected at all the points 1, 2, 3, 4, ..., n is $(1 - g_1)(1 - g_2)(1 - g_3) \dots (1 - g_n)$. Then the probability that the target will be detected initially at point n or earlier is

$$P_n = 1 - \prod_{i=1}^n (1 - g_i) \quad (8)$$

where the symbol $\prod$ is used to indicate the product of the $(1 - g)$'s that were given in the preceding sentence, because the sum of the probabilities of initial successful detection at point n or earlier and the probability of failure to detect at any of the points up to and including point n is unity.

Equation (8) may be written in logarithmic form

$$P_n = 1 - \exp\left(-\sum_{i=1}^n \ln(1 - g_i)\right) \quad (9)$$

where $\exp\left(\sum_{i=1}^n \ln(1 - g_i)\right)$ is the antilogarithm of the sum of the natural logarithms, and this is equal to $\prod_{i=1}^n (1 - g_i)$.

Equations (8) and (9) give probabilities of detection for the particular points 1, 2, 3, ..., n. To obtain the average probability associated with all points on the target's course, the logarithm of each failure probability in (9) is converted to unit time by dividing by the average time between contacts, T . The resulting failure

probability per unit time then is integrated over time to give

$$P_n = 1 - \exp \left[(1/v) \int_0^t \ln(1 - g_1) dt \right], \quad (10)$$

which is more convenient if it is expressed in terms of distance

$$P_n = 1 - \exp \left[-(1/vT) \int_y^\infty \ln(1 - g_1) dy \right], \quad (11)$$

where v is the relative velocity in knots.

For the special case in which the interceptor is on a collision course with the attacking aircraft, this equation reduces to

$$P = 1 - \exp(-R_0 I/v) \quad (12)$$

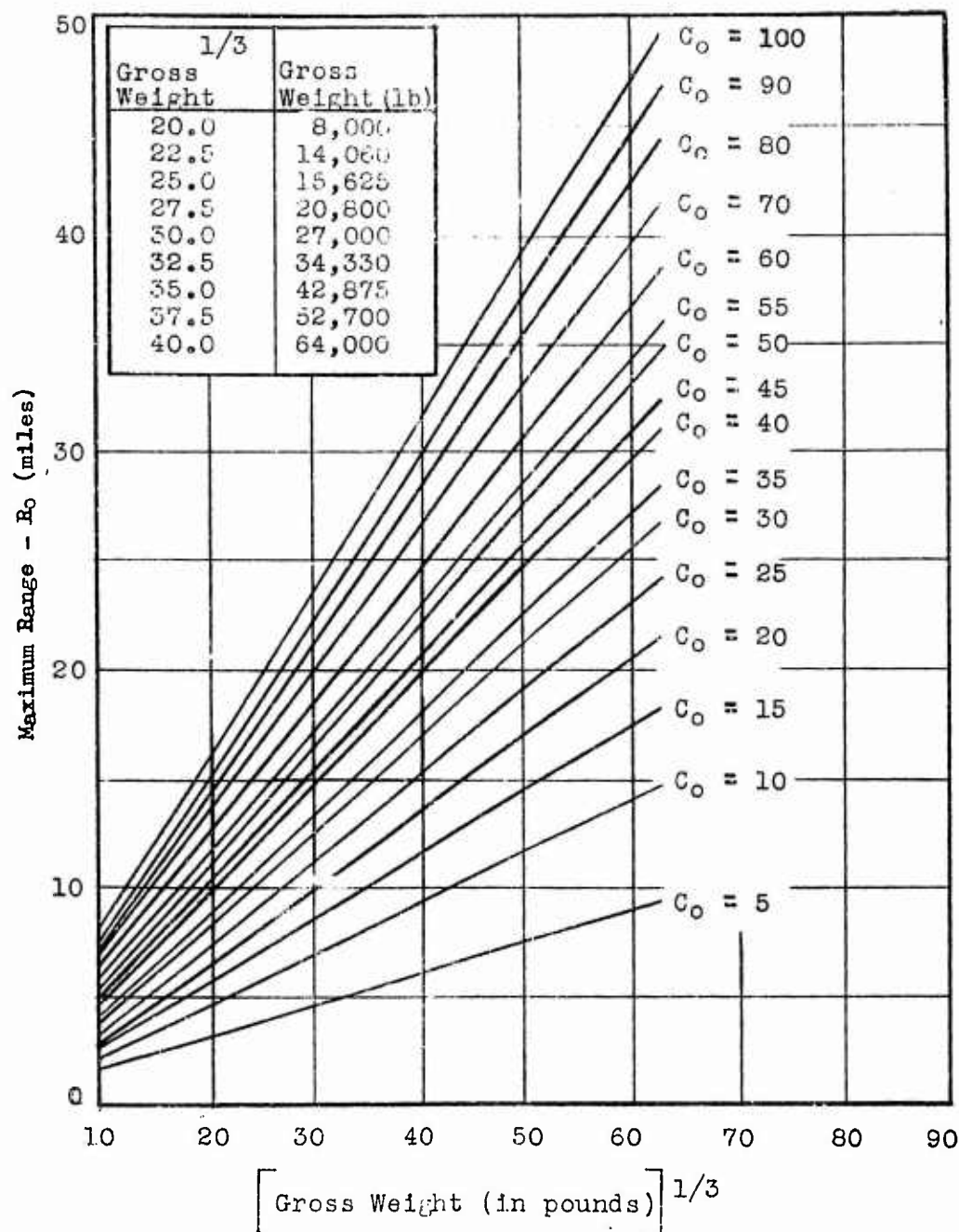
where I is the integral

$$I = \int_{R_2/R_0}^{R_1/R_0} 2.21 (10^3) \ln(1 - g_1) d(R/R_0).$$

Here R_1 is the range at which search begins and R_2 is the range at which the interceptor has closed to obtain the probability of detection P . This special situation corresponds to the one existing during the trials. (See Section III).

H. METHOD OF DETERMINING PROBABILITY

From the formulas given in the preceding paragraphs, it is possible to determine the theoretical probability of detecting an air target if the necessary parameters are known.



* FIG. 3: MAXIMUM RANGE FOR BOW-ASPECT TARGETS

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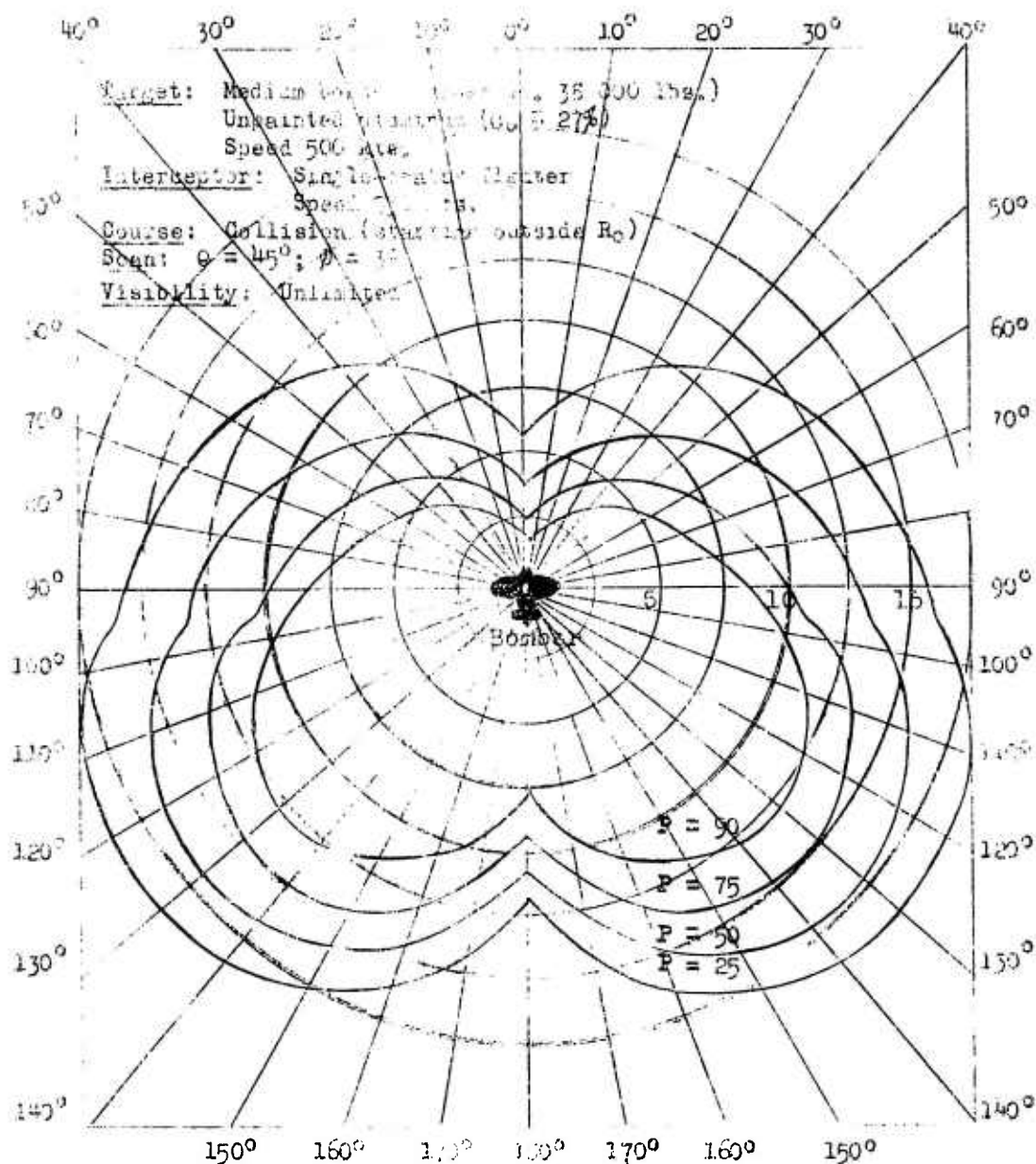


FIG. 4: RANGE (MILES) VS. ASPECT ANGLE

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1.1.1. DESCRIPTION OF TESTS

Tests to determine the probabilities of visually detecting aircraft in various conditions were performed at the Naval Air Station, Patuxent River, Maryland from 1 December 1948 to 10 September 1949. Aircraft participants were the F4U, the F7F-3N, and the TO-1. Results are presented in Appendix A.

Each trial consisted of a tracking run and a detection run. The tracking run provided data from which could be determined the size and shape of the detection lobe associated with the target and atmosphere condition. The detection run provided data from which could be determined the cumulative probability of detection at or above a given range. Aircraft were observed on SX radar and on the ground; reasonably accurate measurements of the distance between the aircraft could be made at any time.

During the tracking run, two aircraft flew at approximately equal speeds in two positions abreast of one another at the "start" (Figure 5) on courses diverging by 60 degrees. Each pilot functioned as observer, and reported to the operator of the SX radar when, after looking away from the target aircraft for a moment, he could not immediately find it when he looked toward it again. The operator of the SX radar measured the separation of the two aircraft at this point to give the quantity $R_{m,120}$ (the maximum detection range under prevailing haze conditions of a target aircraft viewed from an aspect angle of 120 degrees off the bow).

When one aircraft was out of sight of the other, the tracking run was ended and the detection run begun (Figure 5). The aircraft were vectored to turn in such a manner that they were heading back toward one another from beyond maximum detection range of both aircrafts. Their speeds were so regulated that the closing speed v was a predetermined quantity. During the detection run each observer scanned systematically through angle $(H) = 30$ degrees right and left of the airplane and through angle $(\phi) = 3$ degrees above and below the horizon. Each observer reported to the SX radar operator when he detected the target aircraft, and the detection range was recorded.

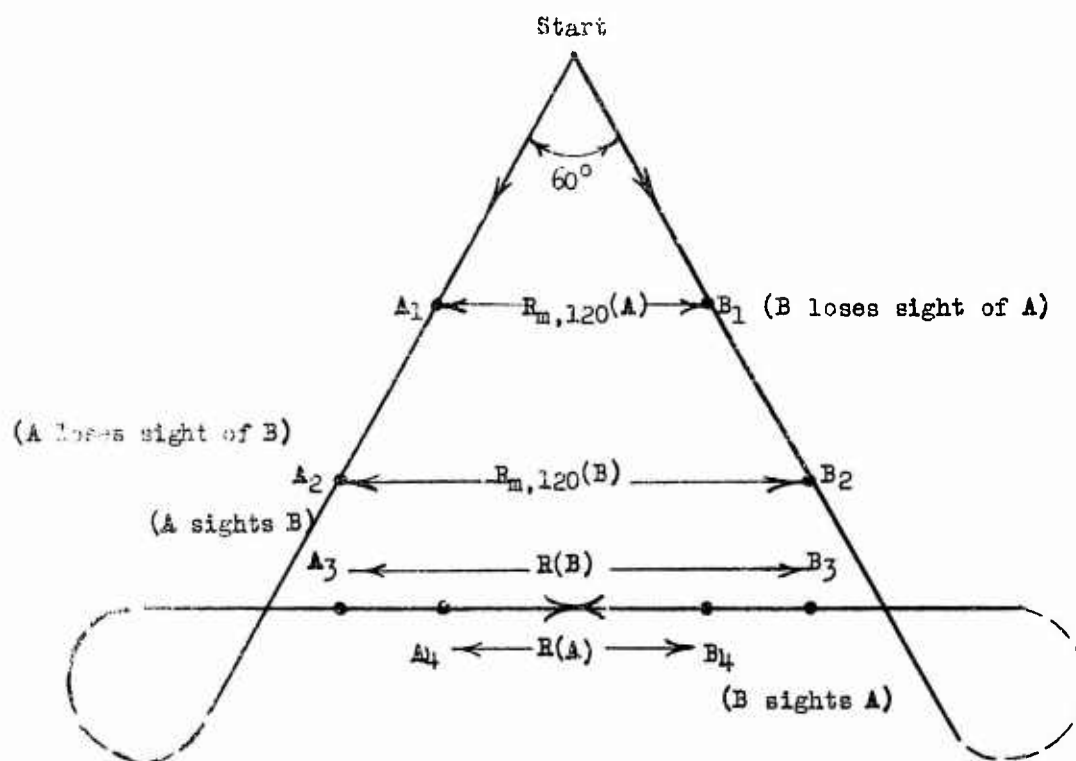


FIG. 5: DIAGRAM OF FLIGHT PATHS USED DURING TRIALS

17. DETERMINATION OF THEORETICAL DETECTION PROBABILITIES

A. DETERMINATION OF PARAMETERS

Quantities necessary for calculation of the theoretical probabilities of detection can be determined from the results of trials described in Section III. From these same trial results it is also possible to determine the observed probabilities of detection. (See Section V below.) The theory can be tested by comparison of these theoretical and observed probabilities.

This section of the study describes the manner of determining the quantities needed for calculating the theoretical probabilities of detection. The method of using these values to determine these probabilities is described in Section II-H.

B. DETERMINATION OF SCAN ANGLES (Θ AND Φ)

Θ is the number of degrees that the observer scans to the left or right of the expected position of the target. Φ is the number of degrees that the observer scans above or below the expected position of the target. These quantities were specified as 30 degrees for Θ and 3 degrees for Φ for all detection runs in these trials.

C. DETERMINATION OF INTRINSIC CONTRAST (C_0)

Reference (b) gives 27 percent as the intrinsic contrast against a sky background of an unpainted aluminum aircraft (TO-1) and 97 percent for the intrinsic contrast of an aircraft that was painted Navy blue. These values of C_0 are used for the aircraft employed during these trials.

D. DETERMINATION OF MAXIMUM RANGE ($R_{0,\alpha}$)

$R_{0,\alpha}$ is the maximum range in the absence of haze at which the target can be detected if it is headed at an angle α off the line from observer to target. There are two methods of determining it. An "exact" method determines bow-aspect area A_0 and beam-aspect area A_{90} from scale drawings

of the target aircraft and uses these figures in the following equations:

$$R_{0,0} = .1655 \sqrt{(C_0 - 1.565) A_0} \quad (\text{equation (5), Section II})$$

$$R_{0,\alpha} = R_{0,0} \sqrt{|\cos \alpha| + (A_0/A_{90}) |\sin \alpha|}$$

This assumes that $A_{0,\alpha}$, the apparent area at aspect angle α , is the sum of the projections of the bow and beam areas.

In the "approximate" method, the maximum range at zero degrees aspect angle is assumed to be proportional to the cube root of the gross weight of the aircraft. (See Section II-I.) Then $R_{0,0}$ for any contrast can be found in Figure 3, and $R_{0,\alpha}$ can be determined from

$$R_{0,\alpha} = (\sqrt{|\cos \alpha| + 2.4 |\sin \alpha|}) R_{0,0}$$

Here the additional assumption that $A_0/A_{90} = 2.4$ also is made.

Calculations of $R_{0,0}$ and $R_{0,120}$ have been made using both of these methods. The results of these calculations are shown in Tables I and II. Justification of the two methods can be found in Section II and in reference (b). Weights and areas for the F8F-2 and the F7F-3N were obtained from reference (c). For the TO-1, these were determined from reference (f).

TABLE I
MAXIMUM RANGES DETERMINED BY "EXACT" METHOD

Aircraft	$C_0(\%)$	$A_0(\text{ft}^2)$	$A_{90}(\text{ft}^2)$	$R_{0,0}$	$R_{0,120}$
F8F-2	97	62.5	147.5	12.8	20.5
F7F-3N	97	132	280	18.5	28.4
TO-1	27	53	158.6	6.1	10.7

TABLE II

MAXIMUM RANGES DETERMINED BY "APPROXIMATE" METHOD

Aircraft	C _o (%)	W(lb)	W ^{1/3}	R _{o,o}	R _{o,120}
F8F-2	97	11,500	22.5	17	27.2
F7F-3N	97	23,900	29	22.5	36.0
T0-1	27	14,300	24.5	10	16

E. DETERMINATION OF METEOROLOGICAL VISIBILITY (V)

Meteorological visibility, the range at which large targets can be detected in the absence of haze, is not as directly determinable as the other visual detection parameters. It is a property of the atmosphere and not of the particular aircraft. Its connection with the range at which a target can be detected was given in equation (2), which may be rewritten in the following form:

$$V = (3.44 R_{m,120}) / (\log C_o - \log C_{m,120}),$$

where C_o is the intrinsic contrast in absence of haze and $C_{m,120}$ is the actual contrast of the object at a maximum range and aspect angle 120°. This latter can be obtained from $R_{m,120}$ by equations (4) and (5), which combine to give

$$C_{m,120} = (C_o - 1.565)(R_{m,120}/R_{o,120})^2$$

$R_{m,120}$, the maximum range at which a target with an aspect angle of 120 degrees can be detected, is furnished by the trial data. It was noticed that the values thus determined during each of the two periods 17 January - 8 August 1949 and 16-31 August 1949 fluctuated very little. It was therefore decided to consider the meteorological visibility constant within each period. The value of $R_{m,120}$ used to determine V for each of the two periods was the largest $R_{m,120}$ of the period. The justification for this choice is that the observers were also acting as pilots, and consequently were forced to make their observations of

maximum range with less efficiency than could have been expected if they had been acting as observers only. Disturbing factors such as the need for looking at flight instruments, the absence of reference points to facilitate relocation of the target after glancing away from it, and the irregular motion of the aircraft carrying the observer caused the observer to lose sight of the target sooner than he would under normal conditions. Consequently it was felt that the longest range at which the target was visible was close to the value that would in fact obtain under normal operating conditions.

Values of $R_{m,120}$ that were used in the computations are given in Table III. Values of V are also given in that table.

TABLE III
RANGES AND METEOROLOGICAL VISIBILITIES

Aircraft	Period	$R_{m,120}$	$C_{m,120}$		V	
			Exact	Approximate	Exact	Approximate
F8F-2	17 Jan- 8 Aug	17	65.5	37.3	147.7	60.7
F8F-2	16 Aug- 31 Aug	20.3	95.1	53.2	3535.4	116.4
F7F-3N	17 Jan- 8 Aug	18.5	42.0	40.5	76.5	73.2
T0-1	16 Aug- 31 Aug	14.3	27.0	21.9	∞	176.3

F. GROUPING OF PARAMETERS

Examination of the raw test data disclosed that the visual detection parameters would be constant over each of eight groups of trials. Each group may be characterized by the period during which the runs of the group took place, the target aircraft, and the speed with which the target aircraft closed toward the observer. The eight groups are

(LO)1548-52
15 August 1952

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Data Group Number	Periods	Target Aircraft	Closing Speed
1	17 Jan - 8 Aug 1949	F8F-2	300 knots
2	17 Jan - 8 Aug 1949	F8F-2	500 knots
3	16 Aug - 31 Aug 1949	F8F-2	500 knots
4	16 Aug - 31 Aug 1949	F8F-2	700 knots
5	17 Jan - 8 Aug 1949	F7F-3N	300 knots
6	17 Jan - 8 Aug 1949	F7F-3N	500 knots
7	16 Aug - 31 Aug 1949	TO-1	500 knots
8	16 Aug - 31 Aug 1949	TO-1	700 knots

Certain trials were excluded from these groups, as explained in Appendix A. Values of the various parameters, determined for the different periods as described in this section, are summarized in Table IV. These values were used in computing the theoretical cumulative probabilities of detection. (See Section II-H and Section VI.)

23
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TABLE IV
VISUAL DEFLECTION PARAMETERS DURING TRIALS

Data Group Number	Period	Aircraft	θ°	ϕ°	V (knots)	00(%)	Box Calculation	$R_{0.0}$ (n.m.)	V (n.m.)
1	17 Jan to 8 Aug 49	F8F-2	30	3	300	97	exact	12.8	147.7
							approx	17.0	60.7
2	17 Jan to 8 Aug 49	F8F-2	30	3	500	97	exact	12.8	147.7
							approx	17.0	60.7
3	16 Aug to 31 Aug 49	F8F-2	30	3	500	97	exact	12.8	3535.4
							approx	17.0	116.4
4	16 Aug to 31 Aug 49	F8F-2	30	3	700	97	exact	12.8	3535.4
							approx	17.0	116.4
5	17 Jan to 8 Aug 49	F7F-3A	30	3	300	97	exact	18.5	76.5
							approx	22.5	73.2
6	17 Jan to 8 Aug 49	F7F-3A	30	3	500	97	exact	18.5	76.5
							approx	22.5	73.2
7	16 Aug to 31 Aug 49	F0-1	30	3	500	27	exact	6.1	∞
							approx	10.0	176.3
8	16 Aug to 31 Aug 49	F0-1	30	3	700	27	exact	6.1	∞
							approx	10.0	176.3

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15 August 1952

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V. DETERMINATION OF OBSERVED CUMULATIVE
DETECTION PROBABILITIES

Section IV described the method of obtaining theoretical probabilities of detection from the trial results. The present section gives means of calculating the cumulative probabilities of detection that actually were observed in the trials. Section VI will compare the two sets of probabilities.

Observed cumulative probabilities of detection for each group of trials (Section IV-F) are determined from the detection ranges that occur during the detection runs (Section III). The n runs of the group are arranged and numbered in decreasing order of the detection ranges observed on each run, so that

$$R_1 \geq R_2 \geq R_3 \geq \dots \geq R_i \geq \dots \geq R_n,$$

where R_i is the detection range observed on the i th run. Failures to detect are recorded at range zero.

Then the observed cumulative probability of visual detection associated with the i th run is i/n at range R_i .

25
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VI. COMPARISON OF OBSERVED AND THEORETICAL
PROBABILITIES OF DETECTION

The validity of the theory of visual detection that was outlined in Section II can be assessed by comparing the cumulative probabilities of detection that were observed during the Patuxent trials with the corresponding probabilities that were determined by the theory.

To make the comparison, an 80-percent cumulative frequency belt was drawn around the curve of theoretical probability that had been determined from each group. These belts are defined as those within which 80 percent of the observations can be expected to lie. They were determined with the assistance of the theory of binomial distributions, as described in Appendix B. A sample curve with its belt is shown in Figure 6.

After these belts were drawn, the observed probabilities of detection for each group of trials were plotted on the corresponding graphs of the theoretical probabilities and 80-percent belts. For each graph, a count was made of the number of observed cumulative probabilities plotted above the 80-percent belt, within the belt, and below the belt. Failures were counted as occurring below the belt.

If the theory adequately described the detection process, 10 percent of the observed probabilities should lie above the theoretical 80-percent belts, and 10 percent of them should lie below the 80-percent belts. The actual percentages in each belt are shown in Table V.

TABLE V
PERCENTAGES IN FREQUENCY BELTS

Method	Percentage of Observed Probabilities				
	Above 80% belt	Within 80% belt		Below 80% belt	Total
		upper half	lower half		
Exact	19 59	40 68	28 41	13	100
Approximate	44 79	35 55	20 21	1	100

Table V demonstrates the close agreement between the results of the exact theoretical method and the observed test results. Agreement is not as close for the results of the approximate theoretical method. It was not expected, of course, that it would be. It is unlikely that the approximate method will be used if the required information (size of the aircraft (See Section IV-D)) is available. In many actual cases, unfortunately, the size and shape of the target aircraft will not be known. Then the approximate method, which utilizes the gross weight of the aircraft will be useful.

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15 August 1952

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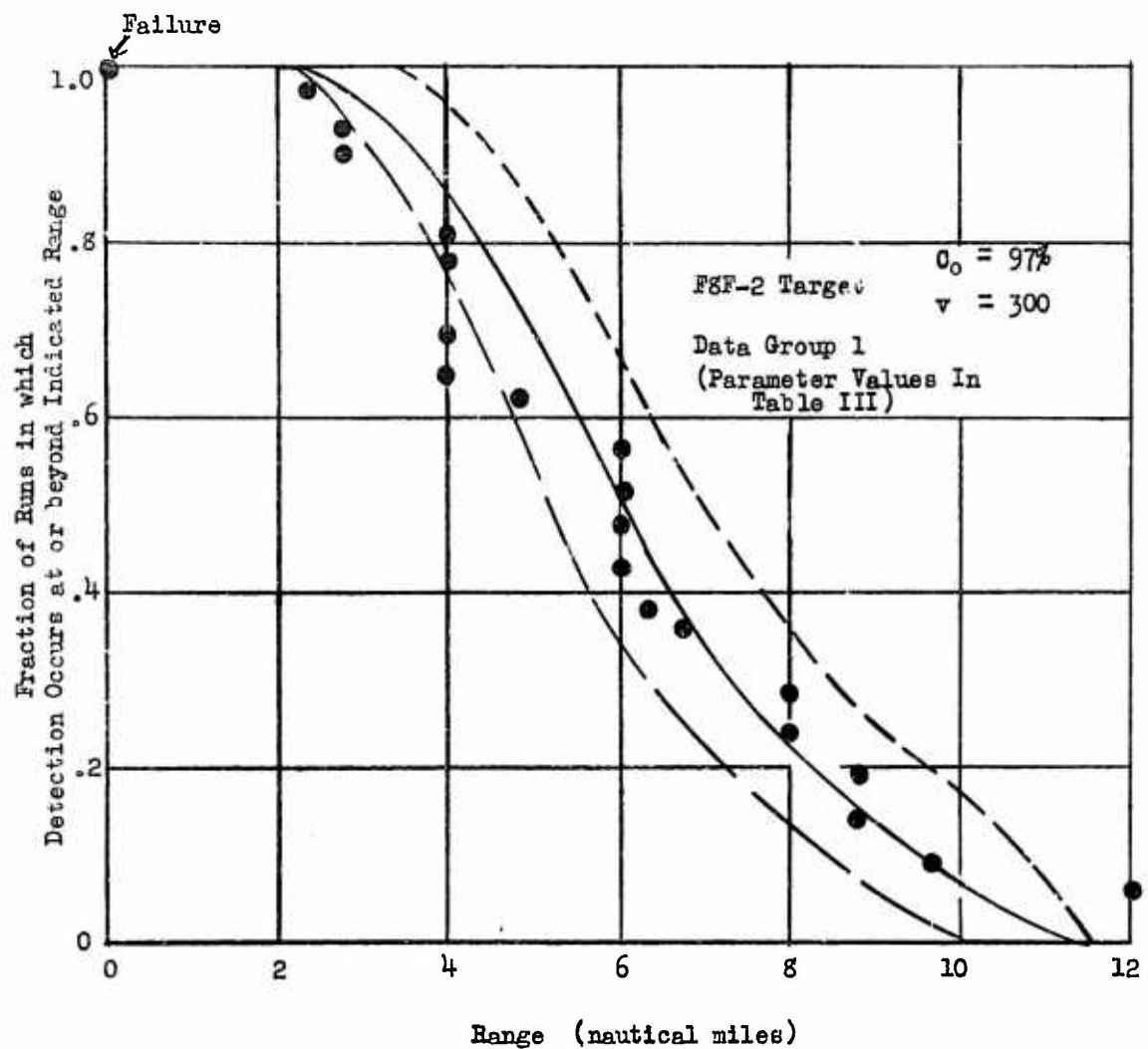


FIG. 6: COMPARISON OF THEORETICAL AND EXPERIMENTAL CUMULATIVE PROBABILITIES OF DETECTION

29
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VII. CONCLUSIONS

On the basis of the trial results, it can be concluded that the visual detection theory presented in reference (b) satisfactorily predicts cumulative probabilities of detection when the so-called "exact" method is used. In this method the maximum range in absence of haze is determined from the aspect area of the target. However, when this range is determined from considerations of the weight of the airplane, the so-called "approximate" method, agreement between theory and experiment is not as satisfactory.

Examination of the relatively small number of trials analyzed in this study reveals that the "exact" method gives slightly smaller detection probabilities than are observed in practice. This conservatism is not extreme, and may be accounted for by two conditions:

(1) Specular reflection aids detection, and is not considered in the theory. Although detections that obviously were facilitated by sunflash have been excluded from the computations, it is possible that some detections might have been assisted by sun reflections that were not recognizable as such. This would give a large detection range and so increase the observed detection probability.

(2) Since there were no reference points, it was difficult to enforce the scanning procedure. A tendency for observers to scan the center of the field more thoroughly than the edges was noted on the data sheets. This would reduce the horizontal scanning angle, which would tend to produce detections at greater ranges than those predicted by a theory using the erroneous larger horizontal scanning angle.

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(LO)1548-52
15 August 1952

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APPENDIX A

TRIAL DATA AND REASONS FOR OMISSION OF CERTAIN TRIALS

Tables A-1 to A-5 present the data from trials conducted at the Naval Air Test Center, Patuxent River, Maryland, from 17 December 1948 to 20 September 1949. These trials were conducted to determine the probabilities of visually detecting aircraft under operational conditions, and from the basic data from which the worth of the visual detection theory was assessed. Certain of the data listed in these tables were not used in making this analysis. Enumeration of the rejected data and reasons for their omission follow.

Data taken on 17 December 1948 and 1 and 6 September 1949 were not used. On 17 December 1948 no tracking turns were made, and no experimental determination of meteorological visibility was possible. Consequently there existed no basis for making a comparison with the results obtained on the detection runs.

On 1 and 6 September 1949, seven sets of observations of a P2B-1S were made. Because this aircraft was painted black on the underside and was of unpainted aluminum above, it was not possible to determine a logical value of C_0 for use in calculating the theoretical probabilities of detection. Calculations with $C_0 = 97$ percent have been made. These give a good fit of observed and theoretical probabilities of detection (all points fall within the 80-percent frequency belts) and also give close agreement between observed and theoretical haze-free maximum ranges. However, the results are not considered significant and have not been used.

In each of the periods, 17 January - 8 August 1949, and 16 - 31 August 1949, the observed values of $R_{m,120}$ for each aircraft fluctuated in general between fairly narrow limits independent of the closing speed. It was decided therefore to consider that the meteorological visibility was constant within each period. On this basis, the results of the runs made on 17 May have not been included in this analysis, since for both participating aircraft the observed values of $R_{m,120}$ were all considerably lower than the values generally observed on the other runs made during the same period.

A-1
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Results of tracking run 4(TO-1) on 17 August 1949 and tracking runs 10 and 12 on 31 August 1949 are attributed to sunflash and hence are not included since they represent maximum visual ranges obtained under atypical conditions.

The results of detection runs made on 17 May have not been included, since, as has been pointed out earlier, they were conducted under different visibility conditions than the other runs in that period, and there were not enough of these runs to warrant their separate analysis.

During the detection runs made on 17, 18 May, 29 July and 3 August, instead of being vectored directly toward each other (as was the case in all other detection runs) the participating aircraft were vectored on anti-parallel courses passing some small distance (called flight-path separation) abeam of one another. Although, under such conditions, detections would ordinarily occur at slightly smaller ranges than on head-on detection runs, the data from these runs have been handled in the same manner as the data obtained from the other detection runs (except runs on 17 May which have already been excluded from consideration for reasons discussed earlier). The inclusion or exclusion of these runs should not materially affect any of the results since in most cases the flight-path separation was quite small.

Detection runs 5 and 6 on 23 August have not been included. On these runs detections were reported as having occurred at an unspecified range and outside the field of scan. Since the manner of handling such data is highly questionable, these results have been excluded from further consideration.

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TABLE A-1
RESUME OF EVNS 300 KNOTS CLOSING SPEED
10,000 FEET ALTITUDE

400 SQUAD	DATE	Flight	Position on FFF-IN	Signatures	Remarks
		Param	with Drop Tank	FEET	
		Separation	Max. Vis. Intercept	Max. W/S	
1	17 Dec 42	---	9.0	---	5.0 Accurate clock code information. Minimum scan angle.
2		---	8.0	---	5.0
3		---	9.0	---	8.0
4		---	10.0	---	5.0
5		---	14.0	12.0	4.0 Minimum scan angle. (etc.)
6	17 Jan 49	---	18.0	12.0	4.0 Clock code informa-
7		---	17.0	15.0	12.0 tion had direct
8		---	12.5	12.0	6.0 bearing on intercept
9		---	14.0	10.5	no run range.
10	18 Jan 49	---	9.0	6.0	3,000 ft. altitude
11		---	14.0	11.0	due to weather.
12		---	13.0	11.0	Minimum scan angle.
					Poor clock code information.
13	27 Jan 49	---	14.0	12.5	5,000 ft. altitude.
14		---	15.0	15.0	Minimum scan angle.
15		---	14.5	13.8	
16	13 May 49	---	16.0	14.0	
17		---	15.0	10.0	Controlled controlled
18		---	15.0	14.0	scan limits and scan
19		---	11.5	11.0	procedures. All
20		---	16.0	11.0	intercepts directly
21		---	12.5	16.0	on 12:00 clock code Tends to discourage scanning. Suggest flight path separa- tion to enforce scanning.

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TABLE A-1 (CONTINUED)

Run No.	Date	Flight Path Separation	Sighting on F7F-3N with Drop Tank Max. Vis.	Intercept Max. Vis.	Sighting on F8F-2 Max. Vis.	Intercept	Remarks
22	17 May 49	3.0	7.0	Miss	8.0	3.6	Flight path separation of over 1.5 miles appears to cause very erratic results. This limit will be utilized in later runs to enforce scanning. Misses here are not believed indicative.
23		1.5	8.5	5.9	7.5	5.7	
24		3.0	8.5	Miss	7.0	5.0	
25		2.5	7.5	Miss	7.0	Miss	
26		2.0	9.0	Miss	9.0	4.0	
27		1.0	9.0	4.6	7.0	3.2	
28		3.0	7.5	3.1	7.0	4.0	
29	18 May 49	.50	18.0	7.0	14.5	6.0	Flight terminated due to radar difficulty.
30	29 Jul 49	1.0	12.0	7.0	11.0	5.0	
31		2.5	15.0	12.0	12.0	3.0	
32		0.0	16.0	7.0	9.0	4.0	
33		1.0	16.0	4.0	9.5	2.5	

TABLE A-2

SOURCE: U.S. AIR FORCE
2, 1949

Ref. No.	Date	Separation	Mar. Vis. Intercept		Mar. Vis. Intercept		Intercept
			Mar. Vis.	Intercept	Mar. Vis.	Intercept	
1	17 Dec 48	---	---	4.5	---	---	3.5
2		---	---	10.0	---	---	7.0
3		---	---	12.0	---	---	Miss
4	27 Jan 49	---	14.0	13.0	12.5	---	3.5
5		---	15.0	4.5	15.0	---	3.0
6		---	None	4.0	None	---	10.0
7	3 Aug 49	---	17.5	4.0	14.0	---	3.0
8		---	None	7.0	None	---	3.0
9		---	16.0	6.0	14.0	---	3.0
10		---	14.0	7.0	13.0	---	3.0
11		---	16.0	7.0	14.0	---	7.0
12		---	12.0	7.0	5.0	---	7.0
13	4 Aug 49	---	16.0	4.0	12.0	---	5.0
14		---	16.0	6.0	12.0	---	1.0
15		---	18.0	11.0	13.0	---	11.0
16		---	15.0	3.0	8.0	---	4.0
17		---	12.0	7.0	9.0	---	3.0
18		---	10.5	6.0	12.0	---	5.0
19		---	16.0	None	8.0	---	None
20		---	16.0	11.0	11.0	---	4.0
21	8 Aug 49	---	14.0	7.0	16.0	---	3.0
22		---	16.0	9.0	13.0	---	5.0
23		---	17.0	13.0	12.0	---	7.0
24		---	17.0	8.0	11.0	---	5.5
25		---	16.0	6.5	9.0	---	8.0

These were killed
by aircraft and
prisoners.

Many thunder
storms cause
erratic results.

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(LO)1548-52
15 August 1952

TABLE A-3
RESUME OF RUNS 500 KNOTS CLOSING SPEED
30,000 FEET ALTITUDE

Run No.	Date	Sighting Max. Vis.	Intercept	Sighting on T.O. Max. Vis.	Intercept	Region Intercepted
1	16 Aug 49	19.0	4.5	12.0	4.0	
2		16.0	3.5	12.0	1.0	
3	17 Aug 49	18.0	5.0	14.0	3.0	
4		20.0	8.0	*16.0	2.0	
5		16.0	7.5	12.0	3.0	
6		14.0	7.0	7.0	4.0	
7		16.0	8.0	11.0	5.0	
8		None	8.0	None	0.5	
9	19 Aug 49	16.0	2.5	10.0	5.0	
10		19.0	8.0	13.0	1.5	
11		None	8.0	None	4.0	

* Extreme range due to sunflash

A-6
CONFIDENTIAL
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TABLE A-4

RECONSTRUCTION OF SIGHTING DATA
 (10000 FEET ALTITUDE)

Ref. No.	Date	Sighting as Reported (Range)		Sighting as Reported (Altitude)		Intercept	Max. Vis.	Intercept	Max. Vis.	Intercept	Max. Vis.
		Max. Vis.	Intercept	Max. Vis.	Intercept						
1	22 Aug 49	19.0	None	12.0	None	None	12.0	None	12.0	None	12.0
2		None	8.5	None	8.5	None	None	None	None	1.5	1.5
3		15.0	5.0	11.0	5.0	11.0	11.0	11.0	11.0	3.0	3.0
4	23 Aug 49	17.0	8.0	13.0	8.0	13.0	13.0	13.0	13.0	1.5	1.5
5		14.0	Out of Scan	10.0	Out of Scan	10.0	10.0	10.0	10.0	Out of Scan	Out of Scan
6		None	Out of Scan	None	Out of Scan	None	None	None	None	Out of Scan	Out of Scan
7	30 Aug 49	16.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	1.5	1.5
8		15.0	5.0	6.0	5.0	6.0	6.0	6.0	6.0	1.5	1.5
9		12.0	3.0	7.0	3.0	7.0	7.0	7.0	7.0	2.0	2.0
10		16.0	1.5	**14.0	1.5	**14.0	**14.0	**14.0	**14.0	3.0	3.0
11		18.0	8.5	8.0	8.5	8.0	8.0	8.0	8.0	2.0	2.0
12		19.0	3.5	**16.0	3.5	**16.0	**16.0	**16.0	**16.0	3.5	3.5
13	31 Aug 49	18.0	7.0	10.0	7.0	10.0	10.0	10.0	10.0	1.5	1.5
14		14.0	11.0	None	11.0	None	None	None	None	1.5	1.5

** Extreme ranges due to sunflash

A-7
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TABLE A-5

RESUME OF RUNS 500 KIOTS CLOSING TIME
20,000 FEET ALTITUDE

Run No.	Date	Sighting in F22-1S		Sighting in F22-1S		Sighting in F22-1S		Sighting in F22-1S	
		Max. Vis.	Intercept	Max. Vis.	Intercept	Max. Vis.	Intercept	Max. Vis.	Intercept
1	1 Sep 49	36.0	40.0 (On Contrails)	None	None	None	None	None	None
2	6 Sep 49	35.0	16.0	"	"	"	"	"	"
3		37.0	22.0	"	"	"	"	"	"
4		32.0	11.0	"	"	"	"	"	"
5		35.0	18.0	"	"	"	"	"	"
6		33.0	24.0	"	"	"	"	"	"
7		37.0	24.0	"	"	"	"	"	"

APPENDIX

CONFIDENTIAL FREQUENCY BELTS

1. The purpose of this appendix is to provide a method for determining the probability of a given result being observed during those trials in which the observed results are within the confidence belt.

2. The confidence belt is defined as the region between the observed results and the theory. The theory of confidence belts is based on the theory of normal distributions (see reference (1), footnote page 336, and reference (2)). The theory of confidence belts has been utilized, as follows:

3. The confidence belt is defined as the region between the observed results and the theory. The theory of confidence belts is based on the theory of normal distributions (see reference (1), footnote page 336, and reference (2)). The theory of confidence belts has been utilized, as follows:

4. The confidence belt is defined as the region between the observed results and the theory. The theory of confidence belts is based on the theory of normal distributions (see reference (1), footnote page 336, and reference (2)). The theory of confidence belts has been utilized, as follows:

5. The confidence belt is defined as the region between the observed results and the theory. The theory of confidence belts is based on the theory of normal distributions (see reference (1), footnote page 336, and reference (2)). The theory of confidence belts has been utilized, as follows:

6. The confidence belt is defined as the region between the observed results and the theory. The theory of confidence belts is based on the theory of normal distributions (see reference (1), footnote page 336, and reference (2)). The theory of confidence belts has been utilized, as follows:

the probability of not less than a nor more than b occurrences of the event on n trials ($0 \leq a \leq b \leq n$) is

$$\sum_{i=a}^b P(i,n) = \sum_{i=a}^b \frac{n!}{i!(n-i)!} p^i (1-p)^{n-i}$$

The limits of the 80-percent frequency belt for a given probability p , and a given number of trials, n , are obtained by choosing values of a and b located as symmetrically as possible about np (the expected number of occurrences) in such a manner as to yield a value for $P(a \leq x \leq b, n)$ as close to .80 as possible.

It is by this procedure (or approximations to it, in which the incomplete Beta Function is used) that the curves in Figure 10.4 of reference (a) have been obtained.

(LO) 1548-52
15 August 1952

CONFIDENTIAL
SECURITY INFORMATION

APPENDIX C

COMBINING STATISTICS FROM RUNS MADE UNDER DIFFERENT CONDITIONS

One of the desirable characteristics of a useful visual detection theory is the ability of the theory to combine the results of runs made under different conditions. In this appendix a method is described for combining results in testing any detection theory that predicts cumulative probability of detection by any given range as a function of the various conditions under which the detection was made, no specific reference to the exact nature of the theory need be made. With such a procedure for combining data from runs made under different conditions, the operational validation of a given theory may be made more quickly and economically than might be possible, if it were necessary to run large numbers of carefully controlled trials and vary the pertinent parameters one by one.

Let P_i be the theoretical cumulative probability of detection obtained during run i , and number the runs in such a manner that

$$P_1 \leq P_j \quad \text{whenever} \quad i < j \quad (1 \leq i \leq n)$$

Let

$$\begin{aligned} d_i &= 1 \text{ if a detection occurred by the end of run } i \\ d_i &= 0 \text{ if no detection occurred during run } i \end{aligned}$$

Then the observed cumulative probability of detection corresponding to the theoretical cumulative probability of detection

$$P_o = \frac{\sum_{i=1}^k d_i}{n}$$

C-1
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A graph of observed probability of detection (P_{obs}) versus theoretical probability of detection (P_{th}) is shown in Figure C-1 together with the 90-percent frequency belts for 131 runs.

A similar graph in which the scale of course from the origin is proportional to $-\log(1 - P)$ along each axis (the graph is an $1 - P$ hyperbola) is shown in Figure C-2.

On both graphs the 90% line runs up from the origin representing a line along which observed probabilities in perfect agreement with the corresponding theoretical probabilities would be obtained.

Both graphs show that for small and intermediary probabilities, the theory is slightly pessimistic, i.e., yields slightly smaller results than are observed in practice, and that for high probabilities the theory is slightly optimistic.

The graph shown in Figure C-2 has an additional property which can be useful. A straight line through the origin which provides a good fit to the plotted observations shown has a slope which can be thought of as a correction factor to be applied to T , the time between successive glimpses stated in reference (a) to be 1.63 seconds. Since the slope of such a line is

$$\frac{-\log(1 - P_{obs})}{-\log(1 - P_{th})}$$

and since

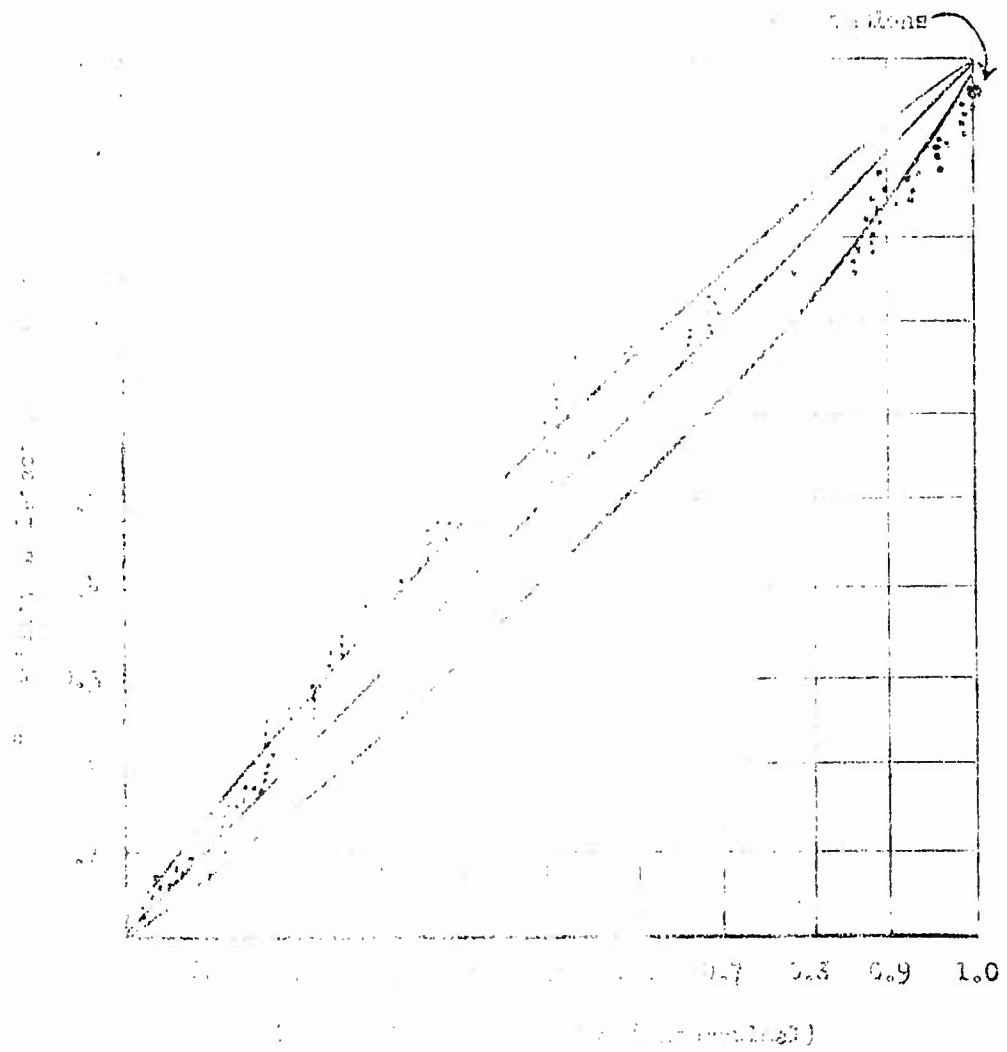
$$P = 1 - \exp\left(-\frac{t}{T}\right) \approx (1 - e^{-t/T})$$

it follows that

$$-\log(1 - P_{obs}) = \frac{t}{T} \approx (1 - e^{-t/T})$$

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15-10

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6-3
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(LO)1548-52
15 August 1952

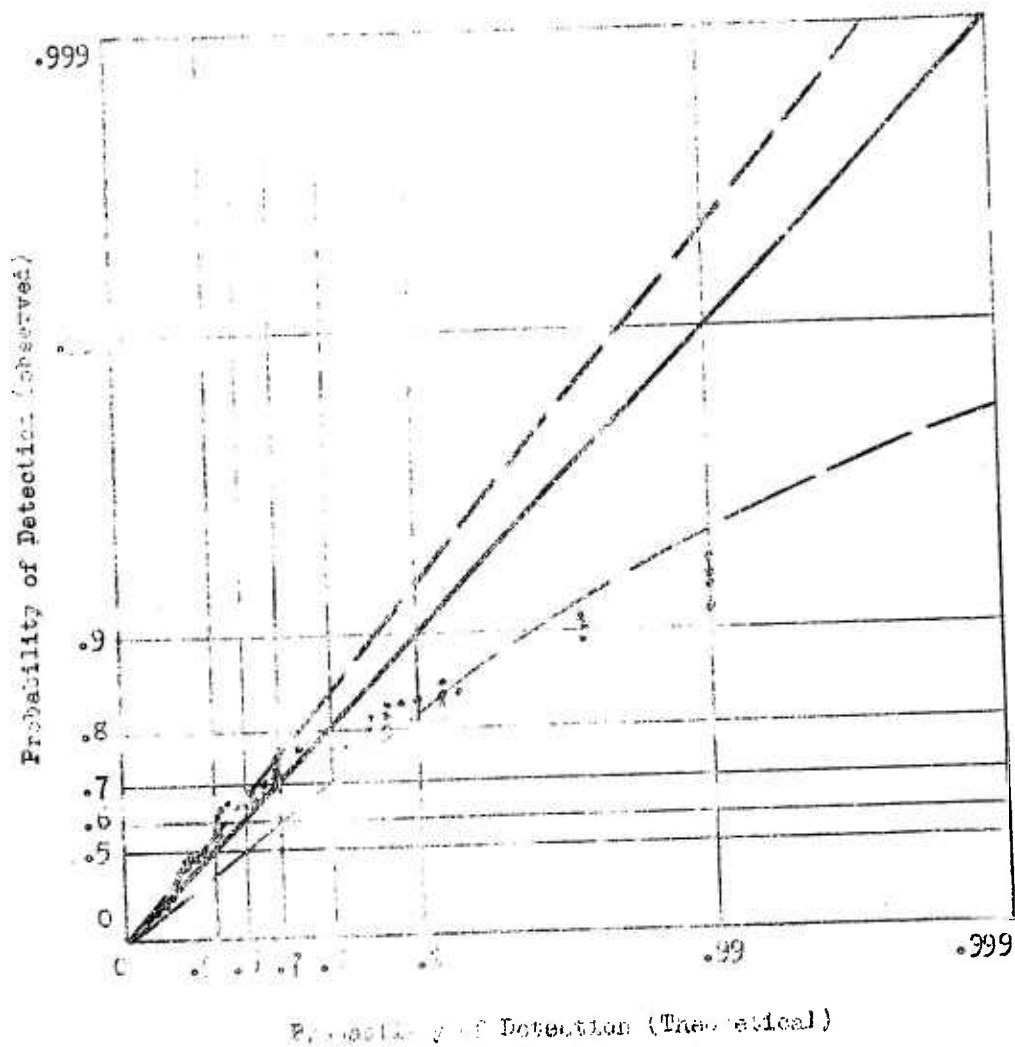


FIG. C-2: COMPARISON OF OBSERVED AND
THEORETICAL PROBABILITIES

(Continued from page 1)

C-4
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Thus, if T is the time that all other
 particles have to travel to the right
 half of the circle, then T , the time
 half of the circle, has a value
 along any path. The number of points
 along any path is $2\pi R$, and the uncer-
 tainty in the path length is ΔL , so
 we have $\Delta T = \Delta L / c$. It is
 small, but it is not zero.

C-5
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