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NWC TP 6005

Launch Opportunity for Air-to-Ground, Visually Delivered Weapons

by
Ronald A. Erickson
and
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Systems Development Department

JANUARY 1978

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Naval Weapons Center
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FOREWORD

This report documents a study conducted in 1977 at the Naval Weapons Center, China Lake, California. The work was carried out under a target acquisition program supported by MIPR RA 0277 from the Joint Technical Coordinating Group for Munitions Effectiveness, U. S. Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, Maryland.

The Joint Technical Coordinating Group for Munitions Effectiveness is sponsoring work on air-to-surface target acquisition under its Joint Munitions Effectiveness Manual for Air-to-Surface Division. The algorithm described in this report was originally devised as part of a Maverick Utility Study (Report No. 61 JTCG/ME-76-12); it has since been generalized, improved, programmed for computer use, and applied to other weapons effectiveness studies.

The method of Target Acquisition Computation was taken from a contract report written by Dr. Charles P. Greening, Autonetics Division, Rockwell International. The authors are grateful to Dr. Greening for his significant contribution of a key item in the launch opportunity algorithm.

The report has been reviewed for technical accuracy by Paul B. Homer, Alan J. Hugo, and William O. Alltop.

Approved by
R. V. BOYD, *Head (Acting)*
Systems Development Department
12 December 1977

Under authority of
W. L. HARRIS
RAdm., U.S. Navy
Commander

Released for publication by
R. M. HILLYER
Technical Director

NWC Technical Publication 6005

Published by . . . . Technical Information Department
Manuscript 2362/MS B0983
Collation . . . . Cover, 30 leaves
First printing . . . . 205 unnumbered copies

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NWC-TP-6005	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) LAUNCH OPPORTUNITY FOR AIR-TO-GROUND, VISUALLY DELIVERED WEAPONS		5. TYPE OF REPORT & PERIOD COVERED Target acquisition study 1977 rept. for period ending 1977
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ronald A. Erickson Carol J. Burge		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Weapons Center China Lake, CA 93555		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS MIPR-RA 0277
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Weapons Center China Lake, CA 93555		12. REPORT DATE January 1978
		13. NUMBER OF PAGES 58
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) 59p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U. S. Government agencies only; test and evaluation; 12 December 1977. Other requests for this document must be referred to the Naval Weapons Center.

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

18. SUPPLEMENTARY NOTES

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

Weapon Delivery
Target Acquisition
Launch Opportunity
Masking

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

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(U) *Launch Opportunity for Air-to-Ground, Visually Delivered Weapons*, by Ronald A. Erickson and Carol J. Burge. China Lake, Calif., Naval Weapons Center, January 1978. 58 pp. (NWC TP 6005, publication UNCLASSIFIED.)

(U) This report presents a method for computing the probability of an aircrew being able to visually locate a ground target and launch a weapon against it. The major factors used in the computations are target acquisition performance, aircraft maneuvering requirements, terrain masking, visibility, and weapon operating time. Estimates of these factors are based on real-world data whenever possible, as opposed to mathematical modeling. The algorithm used to combine these factors is described, the computer program is given, and sample results are presented. The results show that the probability of releasing or launching a weapon on a target is quite low in many situations.

CONTENTS

INTRODUCTION

Most air-to-ground weapons currently in use require that the aircrew make a visual acquisition of the target before the weapon can be employed. Such weapons include bombs, guns, rockets, and guided missiles. The choice of tactics and weapons, and the estimation of the effectiveness of the weapons is currently based upon delivery accuracy and weapons (warhead) effectiveness on specific targets. The probability of finding the target in time to convert to an attack and launch the weapon almost always is ignored.

This report presents a method for computing the probability of an aircrew being able to visually locate a target, convert to an attack pass, and launch, release, or fire a weapon against the target. A computer program that performs these calculations is also described, and example results are given.

OBJECTIVE

The algorithm described here was developed to make it possible to estimate the probability of successfully making a first-pass attack on a ground target with a fixed-wing, high-speed aircraft. The probability that is calculated describes the estimated frequency of use, or *utility*, of a given aircraft/weapon system combination.

Some example questions that might be answered by this probability calculation (or measure of utility) are:

1. What percent of a large number of first-pass attacks would be successful against a column of tanks moving in European terrain during the day in June?

2. How often can we expect to successfully employ a gun, a missile, or a bomb against three tanks in a group in the desert in December?

LIMITATIONS

In addition to the limitation of the algorithm to the utility aspect of weapon delivery, there are other limitations to the algorithm in its present form. These are:

1. The algorithm is limited to weapon delivery by high-speed, fixed-wing aircraft. This limitation is present because the data used

in the algorithm were collected in field tests using such aircraft. Extrapolation to other conditions (e.g., helicopters with a pop-up maneuver) would be risky.

2. The algorithm is limited to weapon delivery involving limited maneuvers by the delivering aircraft. Generally, the data used in the algorithm are derived from straight and level flights toward the target area; pop-ups or roll-ins from high altitude are not included in the calculations. The algorithm best describes the low-level, high-speed delivery tactic.

3. Only a subjective estimate has been made on the limits on the parameters that should be used. These estimates can serve as a guideline to the user, however. They are:

Aircraft altitude - 500 to 2500 feet
Aircraft speed - 350 to 550 knots

4. As mentioned above, the algorithm is statistical in nature, so is not applicable to single, specific situations. Average conditions are used in the computations; the advantages realized by specific mission planning using target photos, etc., are not included.

METHOD

The basic approach used in the development of the algorithm was to use empirical data as much as possible. A means was devised to combine this empirical data, complement it with theoretical calculations when required, and calculate the desired result.

The reliance on empirical data was preferred since it was felt that such data is more representative of the real world than theoretical calculations. Hence, actual ground survey data produced from optical measurements made in the field was preferred to map study results for the computation of a clear line of sight (CLOS). Field test results giving visual detection ranges of ground targets by pilots were used instead of a sophisticated mathematical model of the geometry and the visual search process.

OVERVIEW

The method in which the data are combined in the algorithm is shown in Figure 1. Assumptions as to the time required to operate the weapon system and how the aircraft will be flown are used to calculate the *Required Range*. This range is taken to be the range by which the pilot *must* visually detect the target in order to be able to make a first-pass attack. If the pilot detects the target beyond this required range, he will be able to make the attack; if he detects the target closer than the required range, he will not be able to attack on that pass.

Some general rules have been derived from actual field test data for computing the probability of visually detecting the target. This computation is made as a function of target and background characteristics, unmask range, and atmospheric visibility. The computation is in the form of a cumulative probability as a function of range from the target.

The cumulative probability function is then combined with the required range to produce the probability of acquisition *by* the required range. This probability is given as a function of the range at which there is first a CLOS to the target (unmask range) and visibility (meteorological range).

The last procedure in the algorithm is to combine the acquisition probability with the distribution of unmask ranges and visibility ranges actually expected to occur in the region of interest. Ceiling data can also be used to estimate the percent of the time that particular altitudes could be flown.

This last procedure produces the final output of the algorithm: the expected proportion of the time that a given target can be successfully attacked under a set of specific conditions.

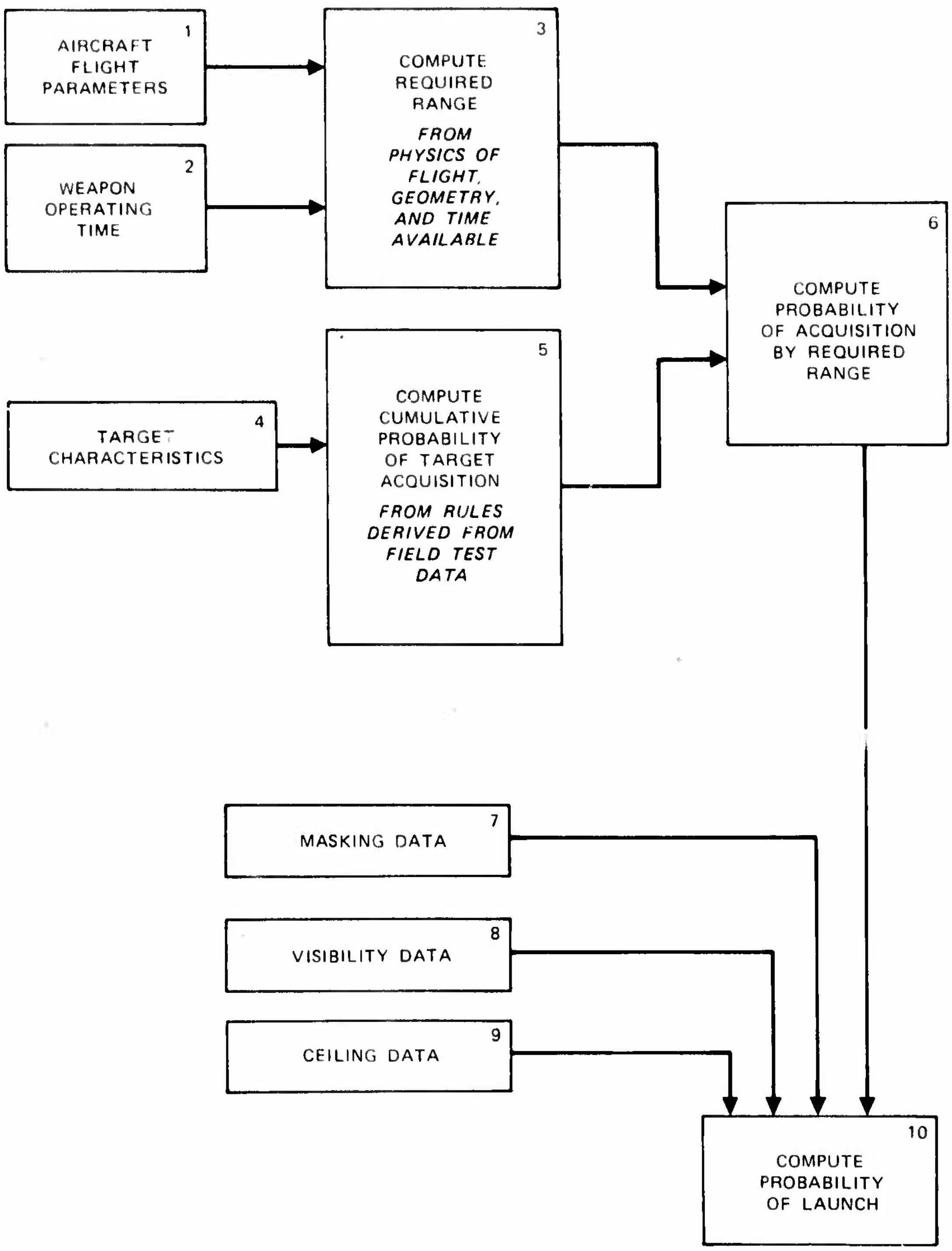

FIGURE 1. Diagram of Launch Opportunity Algorithm.

ALGORITHM DETAILS

AIRCRAFT FLIGHT PARAMETERS

The delivery tactics are, in part, determined by the weapon characteristics. That is, the aircraft must be flown in a particular way in order to successfully deliver the weapon. The use of free-fall bombs, guns, or unguided missiles (rockets) requires that the aircraft be flown directly toward the target. Other weapons with some off-boresight capability have also been used principally in the straight-ahead delivery mode.

Unless exact navigation, or target cueing, is available, most targets should be expected to appear somewhere off the dead-ahead direction. In these cases, the pilot will be required to turn the aircraft toward the target before preparing for weapon release. The geometry describing the entire attack process is shown in Figure 2.

The flight parameters are aircraft velocity, V, and the number of g's pulled in the turn, n. The geometric parameters are the initial range to the target, R, and the angle between the aircraft's initial velocity vector and the direction to the target, α. Some additional factors have been included in the geometry so that they might be included in later calculations.

The range required (actually, the time required) to make the attack decision and roll the aircraft is designated A in Figure 2(c). After the turn is complete, the aircraft must be rolled level, the weapon must be readied for launch, and launched some minimum range from the target. These events are included in the straight segment, B, in Figure 2(c).

From the geometry of Figure 2(c) one can show that

$$R_{RQ} = (A \cos \alpha + r \sin \alpha) \pm [(A \cos \alpha + r \sin \alpha)^2 - (A^2 - B^2)]^{1/2} \qquad (1)$$

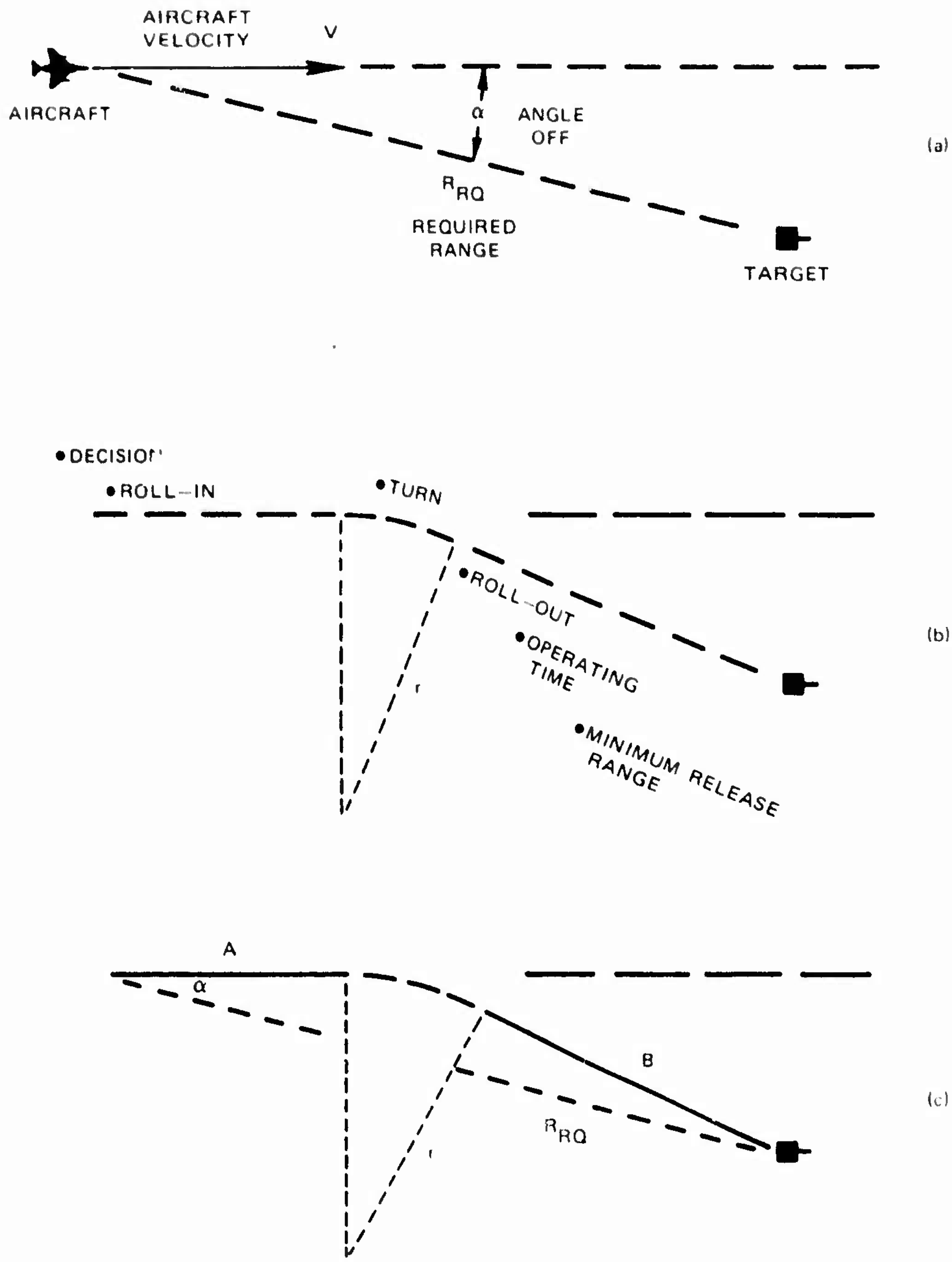

FIGURE 2. Conversion-to-Attack Geometry Used To Calculate the Required Range.

The turning radius of an aircraft is given by

$$r = \frac{V^2}{g\sqrt{n^2 - 1}} \tag{2}$$

where g is the gravitational constant. Other substitutions that can be made in Equation 1 are related to the terms discussed above.

The factors discussed above can be included in Equation 1 by substituting

$$A = V(T_D + T_{RI}) \tag{3}$$

where

T_D = decision-to-attack time
T_{RI} = time required to roll the aircraft into the turn

and

$$B = V(T_{RO} + T_{OP}) + R_{MIN} \tag{4}$$

where

T_{RO} = time required to roll out
T_{OP} = operating time of the weapon
R_{MIN} = minimum release range.

Bank Angle/Dive Angle

The bank angle, ϕ, that an aircraft must attain to pull n g's is given by

$$\phi = \cos^{-1}\left[\frac{1}{n}\right] \tag{5}$$

or

$$n = \frac{1}{\cos\phi} \tag{6}$$

If the aircraft is diving at an angle δ below the horizontal plane at a constant velocity,

$$n = \frac{1}{\cos\phi\cos\delta} \tag{7}$$

Table 1 shows the number of g's pulled (n) at various bank angles for both level flight and a 20-deg dive. The data in the table indicate that dive angle could be ignored in the above formulations for shallow dives, at least up to 20 deg.

TABLE 1. Number of g's Pulled in a Turn.

Aircraft bank angle, deg	Level flight, g	20-deg dive, g
0	1.0	1.0
30	1.1	1.2
50	1.5	1.6
70	2.9	3.1
76	4.1	5.4

WEAPON OPERATING TIME

The weapon operating time, T_{OP} given in Equation 4, is determined by the weapon system characteristics, the aircrew's capabilities, and the environmental operating conditions. Operating times can simply be assumed, derived from manned simulation tests, or from flight tests. The times have been found to vary from 2 sec to as much as 12 sec.

It has been assumed that a tracking time of about 2 sec is used before a bomb is released on a target. Some high-rate-of-fire guns also use a 2-sec firing burst.

Early flight tests with an A-4 aircraft indicated that about 3 sec were required by the pilot to correct a simulated release computer tracking signal.[1] The pilot had to turn the aircraft 17 mrad (1 deg) to replace the pipper on the target. If the deflection increased to 60 mrad, the time required increased to 5 sec.

[1] Naval Weapons Center. *Air-to-Ground A-4 Tracking Accuracy*, by Alice E. Bolstad, George A. Brugnoli, and Ronald A. Erickson. China Lake, Calif., NWC, October 1970. (NWC TP 4992, AD 877309, publication UNCLASSIFIED.)

Some weapon systems require the operator to find the target on a CRT display and either center it in the display or slew cursors to it. Operating time for such a system has been derived from simulator tests[2,3,4] and flight tests. References 2 and 3 describe simulations of a television missile being monitored remotely by an operator. After target acquisition, the operator was required to place a cursor on the target. The results showed that this action took about 5 sec.

A more recent simulation indicated that a similar task took 6 sec.[3] If a missile was added to the system, an additional 2 to 3 sec were required to call up the picture from the missile and lock onto the target, for a total of 9 sec.

The examples of operating times given above illustrate the wide range of times that might be required with different aircraft systems. Another factor that might affect these times is the size of the crew; it is thought that a single pilot would require more time to operate a complicated weapon system than an aircrew of two. The pilot must operate the system as well as fly the aircraft.

Distribution of Times

The times cited above are single times, usually taken to be a mean or median time required to operate the system. The algorithm as originally developed used this single time in the calculation of required range. However, a distribution of times more accurately describes performance in the real world. When the range of times is small, use of a mean or median will suffice. When the spread in the distribution is large and not symmetrical, the distribution itself should be used in the calculations. A sample distribution of operating times from simulator tests[4] is shown in Figure 3. The range is from 2 to over 12 sec, with a peak around 5 sec. The distribution of the aircraft tracking times mentioned earlier[1] is shown in Figure 4.

Such distributions should be used in the algorithm instead of single times. The difficulty is to obtain the data in the first place.

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[2] Naval Weapons Center. *Target Acquisition Performance With an Airborne Television System. Part 1. Flight Profile, Lens Size, and Visibility*, by G. W. Levy, et al, North American Rockwell. China Lake, Calif., NWC, June 1976. (NWC TP 5863, publication UNCLASSIFIED.)

[3] Naval Weapons Center. *Target Acquisition Performance With an Airborne Television System. Part 2. High-Altitude, High-Speed Study*, by G. W. Levy, North American Rockwell. China Lake, Calif., NWC, June 1976. (NWC TP 5863, publication UNCLASSIFIED.)

[4] Naval Weapons Center. *Feasibility Study of a FLIR/Imaging Seeker System*, by Jeffrey D. Grossman. China Lake, Calif., NWC, January 1977. (NWC TP 5909, publication UNCLASSIFIED.)

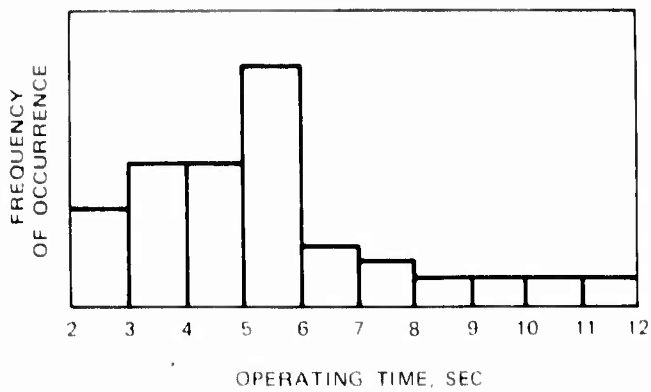

FIGURE 3. Example Distribution of Lock-On Times With TV Missile.

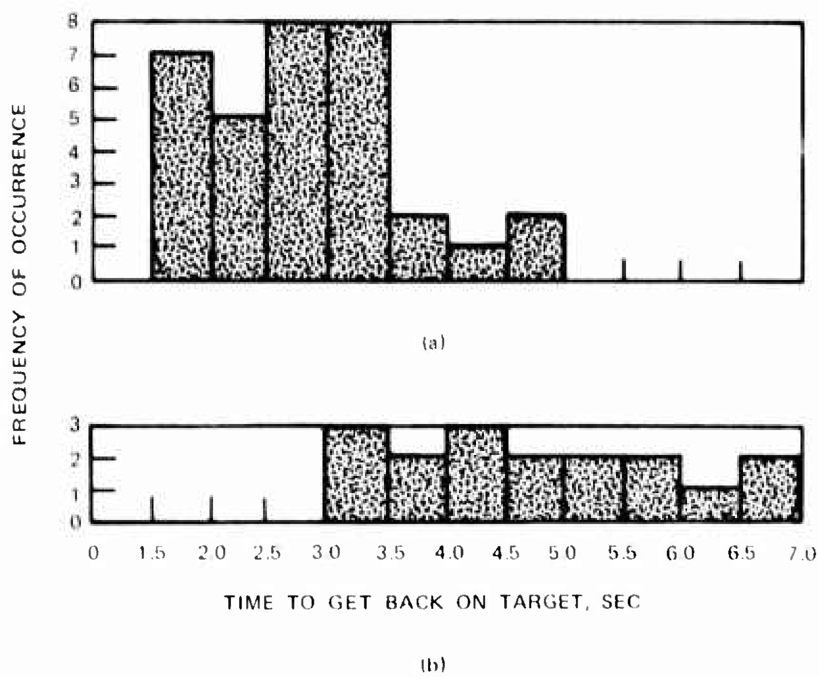

FIGURE 4. Distribution of Times Required by Pilots To Get Back on Target. (a) 17-mil deflection; (b) 60-mil deflection.

REQUIRED RANGE FOR WEAPON DELIVERY

The pilot must sight the target by range R_{RQ} in order to be able to make a first-pass weapon delivery. R_{RQ} is calculated from Equation 1 and uses the following inputs:

V = aircraft velocity

g = gravitational constant

n = number of g's pulled in the turn

T_D = time pilot takes to decide to attack after sighting target

T_{RI} = time required to roll into the turn

T_{RO} = time required to roll out of the turn

R_{OP} = time required to track the target, fire the gun, and/or operate the weapon system

R_{MIN} = minimum release range of the weapon, usually determined by fuzing and warhead considerations (safe separation)

α = initial offset angle to the target

Single values of the parameters listed above are used to compute a required range. The algorithm can currently use distributions of two of those parameters, T_{OP} and α. T_{OP} characteristics have been discussed above.

Angle-Off

The distribution of angle-off is a function of the accuracy of the intelligence information, the aircraft's navigation system, the target's mobility, availability of external target designation (e.g., forward air controller), and many other variables. No data sources have been located to date that could be used to derive angle-off distributions, so assumptions must be made if a distribution is used. Suffice it to say that use of the algorithm does not require the assumption that the target will always appear straight ahead of the aircraft.

Flexibility in Required Range Computation

The parameters in the computation have been named: T_{RI} is called roll-in time, T_D is decision time, etc. Other sequences of operation may require other events to occur, and the formulation given in Equation 1 can be used by setting some values to zero and/or changing the names of events. As long as the situation of interest has a straight-line segment, a curve representing the turning aircraft and another straight-line segment, Equation 1 can be used.

VISUAL TARGET ACQUISITION

The next step in the algorithm is the computation of the probability that the pilot will see the target as he flies toward the target area (see box 5, Figure 1). The result is a cumulative probability as a function of range, for a given target/background combination (Figure 5). The probability curve shown in Figure 5 indicates that the probability is P_1 that a pilot will see the target *by the time he gets to* R_1.

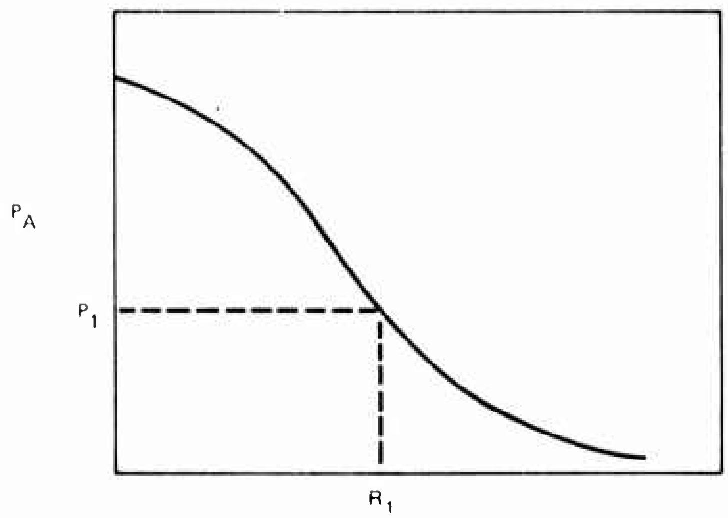

FIGURE 5. Example of Cumulative Probability of Target Acquisition as a Function of Range.

Background

Two separate study efforts led to the development of the technique for computing acquisition probability: evaluation of mathematical models[5,6,7] and summary of field test data.[8] The model evaluation effort illustrated that there are often large differences among the

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[5] Naval Weapons Center. *Target Acquisition Model Evaluation, Final Summary Report*, by Charles P. Greening, Rockwell International. China Lake, Calif., NWC, June 1973. (NWC TP 5536, publication UNCLASSIFIED.)

[6] Naval Weapons Center. *Target Acquisition Model Evaluation. Part 2: A Review of British Target Acquisition Models*, by Charles P. Greening, Rockwell International. China Lake, Calif., NWC, August 1974. (NWC TP 5536, publication UNCLASSIFIED.)

[7] Naval Weapons Center. *Alternative Approaches to Modeling Visual Target Acquisition*, by Charles P. Greening, Rockwell International. China Lake, Calif., NWC, September 1974. (NWC TP 5698, publication UNCLASSIFIED.)

[8] Air Force Armament Laboratory. *Air-to-Ground Visual Acquisition, Summary of Field Test Data* (U), by V. D. Thornton, R. A. Erickson, and R. A. Bruns. Eglin Air Force Base, Fla, AFATL, July 1973. (AFATL-TR-73-140, publication CONFIDENTIAL.)

many models that have been developed. It also showed that the models have not often been validated by field tests, so that one does not know which of the models is the best predictor of target acquisition performance.

The summary of field test data provided a description of over 45 field tests of target acquisition and sample results of the tests. This tabulation of results illustrated that some actual field test data were available for use in making performance predictions.

The result of this effort is a comparatively simple model for computing target acquisition performance.[9] The model is really a data fit, and is based upon actual field test data. In spite of the fact that the model should be subjected to validation (as should all the other models!), it is used in the launch opportunity algorithm.

Target Acquisition Definition

The definitions of target detection, identification, recognition, classification, and acquisition have been discussed and given in many, many reports on the subject. This simplified model is based on data from different field tests, where performance measures were not accurately defined. The target acquisition response seemed to be "I see the target," or "I have the target in sight." It seemed to be the point at which the pilot saw enough, or had enough information, to be willing to begin an attack pass on the object. This very general definition is the one used in the simplified model.

Target Acquisition Probability

The computation procedure uses subjective estimates of the visual appearance of the target as well as physical measurements (or estimates) of the target size, masking, and visibility.

The conspicuousness characteristic of the target is expressed in two ways: "contrastiness" and "associated pattern." The contrastiness of the target is the visual contrast between the most significant, distinctive, target-related feature and its background. The contrasting element may be the target object itself, or a distinctive associated feature.

The associated pattern is the target-related pattern in the target area. The pattern may be made up of target elements (e.g., a straight row of trucks) or of other elements (roads, a river) that can be associated with the target.

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[9] Naval Weapons Center. *A Simplified Air-to-Ground Target Acquisition Model* (U), by Charles P. Greening, Rockwell International. China Lake, Calif., NWC, August 1974. (NWC TP 5680, publication CONFIDENTIAL.)

The maximum probability of target acquisition is taken from Table 2 as a function of the estimates of contrastiness and pattern. More detail on these estimates together with example photos is contained in Appendix A.

TABLE 2. Maximum Sighting Probability, P_{MAX}.

Pattern	Contrastiness		
	High	Medium	Low
Large	1.00	0.75	0.50
Medium	0.75	0.56	0.37
Small	0.50	0.37	0.25

Target Acquisition Range

The probability of acquiring the target as a function of range is assumed to be related to the point at which the target becomes optically available. The point at which the target is unmasked to the observer (where a CLOS exists) and the meteorological range (visibility) are the major variables.

The rules of thumb that were derived from flight test data are as follows:

1. The median range of acquisition will occur at one-half the unmask range, or one-half the meteorological range, whichever is smaller.

2. The probability of acquisition will be 0.2 and 0.8 of the value taken from Table 2 at 0.625 and 0.375, respectively, of the unmask range or meteorological range, whichever is smaller.

These rules of thumb make it possible to construct a curve similar to that shown in Figure 5. For example, assume a target of medium contrastiness and medium pattern. The maximum probability of acquisition will be 0.56 (taken from Table 2). Assume an unmask range of 10,000 ft. The median probability of 0.28 (half of 0.56) will occur at 5,000 ft. At 0.625 x 10,000 ft, or 6,250 ft, the probability of acquisition will be 0.2 x 0.56, or 0.11, and at 0.375 x 10,000 ft, or 3,750 ft, the probability will be 0.8 x 0.56, or 0.45. The resulting curve is shown in Figure 6.

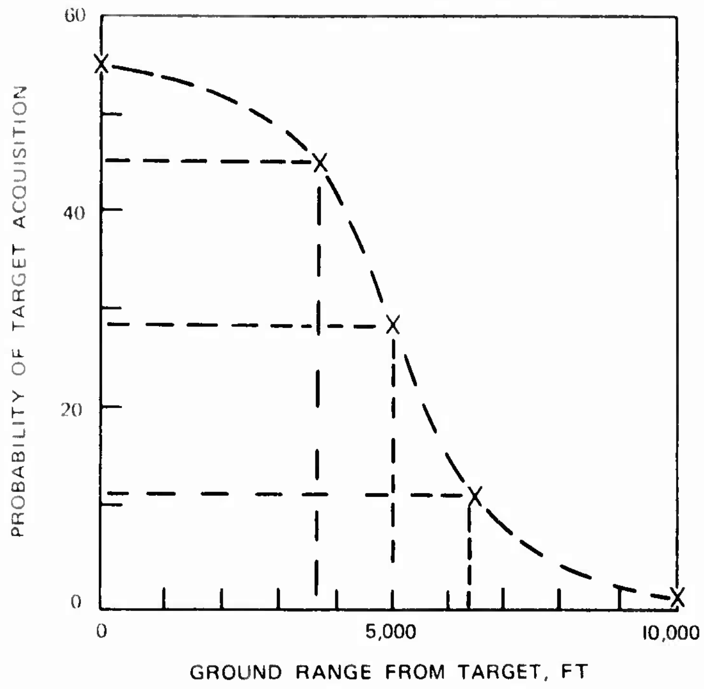

FIGURE 6. Construction of Cumulative Probability of Acquisition Curve.

The algorithm uses the equation

$$P_{ACQ} = P_{MAX}\, e^{-\left(\frac{R_{RQ}}{R_A - 0.75\, R_{RQ}}\right)^2} \qquad (8)$$

to fit the curve, where

P_{ACQ} = probability of acquisition
P_{MAX} = maximum probability taken from Table 2
R_{RQ} = required range (Equation 1)
R_A = meteorological range or unmask range.

Equation 8 and the curve shown in Figure 6 are functions of the unmask range or the meteorological range (visibility). At this point in the computation process, the probability curves are generated for specific distributions or values of target type, weapon type (operating time), aircraft velocity, and initial target angle-off. It remains to modify the calculations by the unmask and visibility data actually expected in the area of interest.

MASKING, CEILING, AND VISIBILITY DATA

The environmental data included in the algorithm tie the probability of launch calculation to a specific time and place by using representative masking and visibility data. The data are used to weight the probability calculation made by Equation 8 by the expected frequency of occurrence of masking, visibility, and ceiling values.

Masking

The masking data used in the algorithm were produced by an actual ground survey, and include both terrain and vegetation effects.[10,11] The survey was done at several sites in each of eight types of terrain. The elevation angle of the skyline above the site was measured along 16 radials extending out from the site; the distance to the skyline (that is, the distance to the obstructing object) was also measured. Masking objects between the skyline and the site were also included in the measurements.

Each radial was considered to be independent of the other radials, resulting in between 50 and 100 independent measurements of masking in each terrain type. These raw data are stored in the algorithm and used to compute probability of unmask for whatever range and aircraft altitude the user chooses. The computer file, called MASKDATA, contains an element for each terrain type; designation of the code name causes the appropriate masking data to be used in the computation. The user may also use other masking data, provided such data are in the form of mask angles and ranges to masking objects.

Visibility and Ceiling

Weather data from the USAF Environmental Technical Applications Center (ETAC) have been found to be the most comprehensive source for algorithm use. The data are usually in the form of cumulative probability curves that show the probability that visibility is equal to or greater than any given value, or that ceiling is at least as high as a given altitude.

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[10] Naval Weapons Center. *Line-of-Sight Handbook*, by Carol J. Burge and Judith H. Lind. China Lake, Calif., NWC, January 1977. (NWC TP 5908, publication UNCLASSIFIED.)

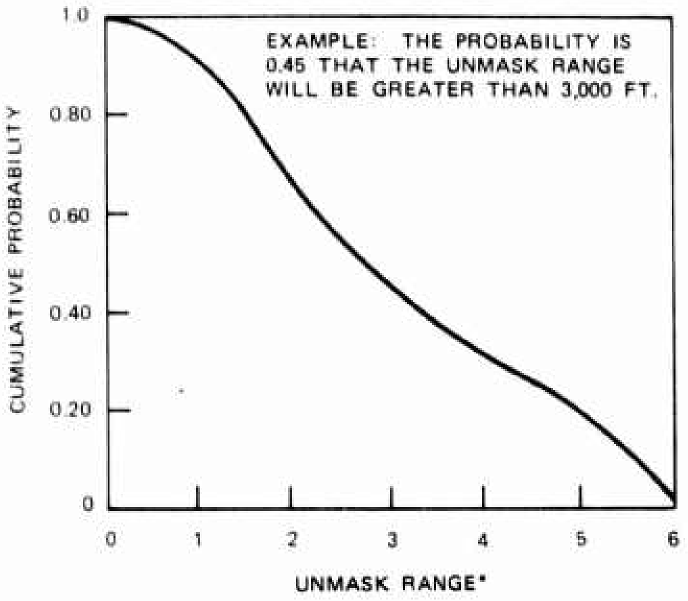
[11] Naval Weapons Center. *A Technique for Measuring Optical Line-of-Sight*, by Carol J. Burge and Judith H. Lind. China Lake, Calif., NWC, January 1977. (NWC TP 5916, publication UNCLASSIFIED.)

Use of the Data

The algorithm converts these cumulative curves into discrete distributions of probability; the concept is shown in Figure 7. The discrete probabilities (Figure 7b) are then each multiplied by the acquisition probability computed from Equation 8 with R_A set equal to the discrete range.

In concept, Equation 8 gives the probability that the aircrew can convert to a launch if the unmask range or visibility is R_A. This probability is then multiplied by the probability of R_A occurring to estimate how often a launch can occur. By summing all these products together, the entire time period is covered (the discrete probabilities in Figure 7b must add to 1.0).

The ceiling data are also entered as a cumulative probability of the ceiling being at least as high as a given altitude. The user may operate the program without ceiling being included (i.e., the assumption of a clear sky), or with a ceiling calculation. The effect of the latter is to multiply the probability of a launch by the probability of being able to fly at the chosen altitude.



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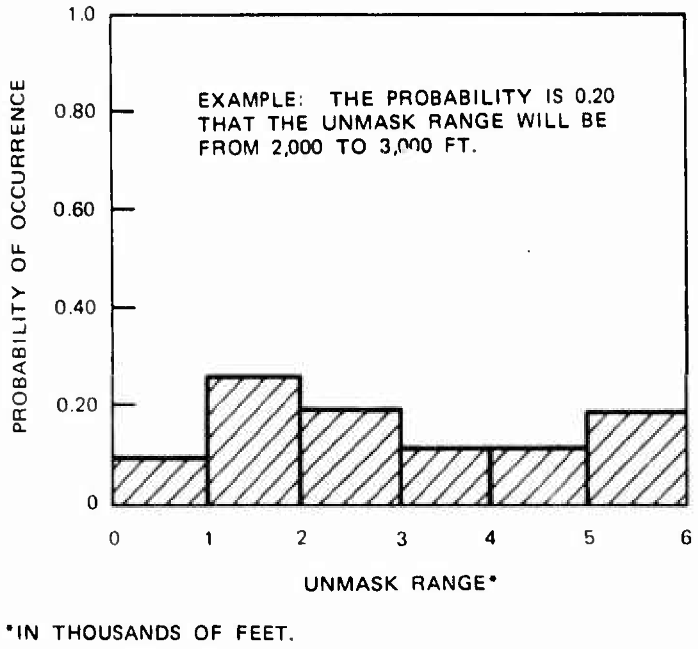

(b)

FIGURE 7. Examples of (a) a Cumulative Probability Distribution and (b) a Discrete Probability Distribution, Describing the Same Data.

SAMPLE RESULTS AND SENSITIVITY

This section of the report presents some sample results from the algorithm. A sample output from the computer program is shown, and the results are shown graphically to illustrate the effects of the variables. Not all of the variables were changed for the sample runs; those held constant are shown in Table 3. Three weather conditions were used in the computations as shown in Figures 8 through 13; for convenience in later referencing they are referred to simply as locations A, B, and C. The weather at locations A and B is similar, and would be judged good flying weather, both winter and summer. The weather at location C is worse, with much lower ceilings and poorer visibility in the winter.

TABLE 3. Variables Held Constant in Sample Results Presented Below.

Decision time, sec	1
Roll-in time, sec	0.5
Aircraft velocity, knots	450
Minimum release range, ft	3,000
Number of g's in turn	3
Roll-out time, sec	1.0

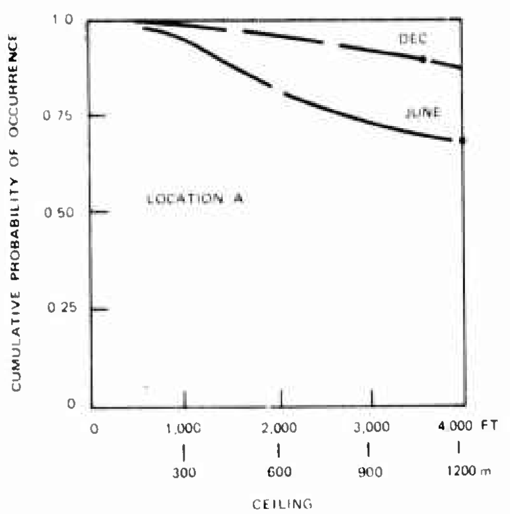

FIGURE 8. Ceiling Assumed for Location A in Sample Results.

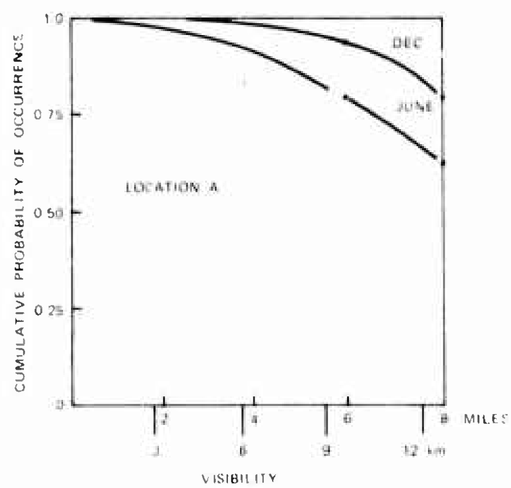

FIGURE 9. Visibility Assumed for Location A in Sample Results.

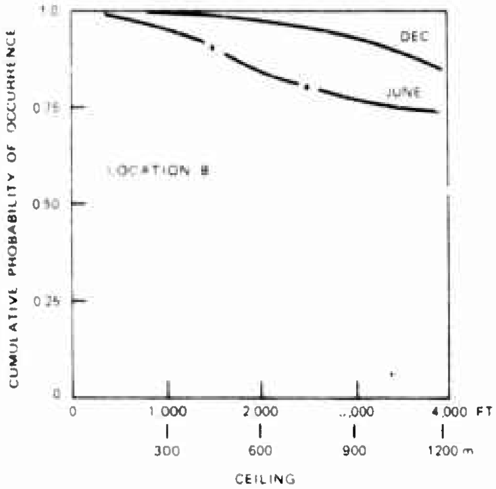

FIGURE 10. Ceiling Assumed for Location B in Sample Results.

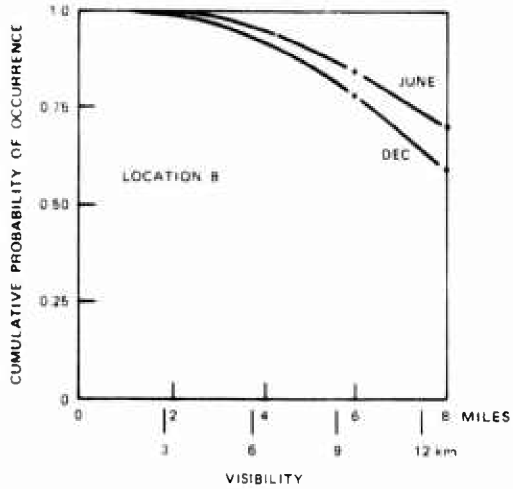

FIGURE 11. Visibility Assumed for Location B in Sample Results.

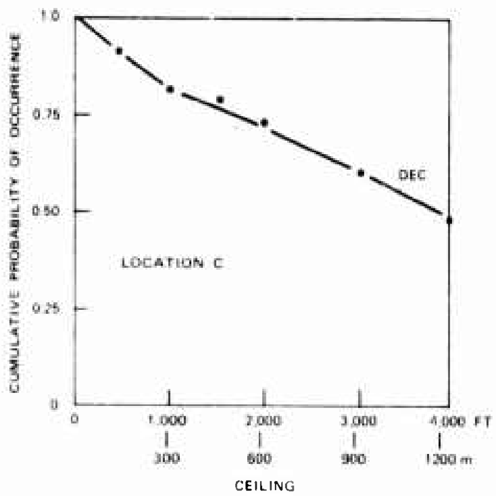

FIGURE 12. Ceiling Assumed for Location C in Sample Results.

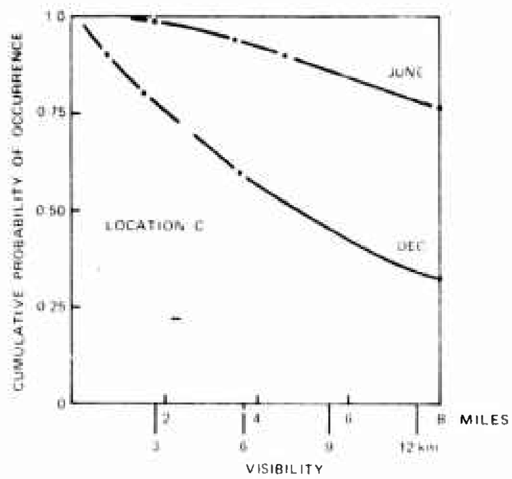

FIGURE 13. Visibility Assumed for Location C in Sample Results.

The terrains chosen for the sample runs illustrate the variety to be expected, from flat, open terrain (Figure 14) to sharply rolling terrain (Figure 15). The descriptive data for these terrains were taken from Reference 10.

TARGET EFFECTS

The algorithm has a large built-in target effect since the user must select the estimated acquisition probability, P_{MAX}, from Table 2; the values range from 0.25 to 1.00. This effect is illustrated in Figure 16, where P_{MAX} values of 1.00, 0.75, 0.37, and 0.25 were selected for running. The resulting probabilities of launch range from 0.75 down to 0.20; there is a direct variation in P_L when there is a variation in P_{ACQ}. This variation is a function of the algorithm user's estimate of how hard it is to find the target.

TERRAIN EFFECTS

Figure 17 illustrates the effect of the type of terrain on the probability of launch. A fairly easy target is assumed (P_{MAX} = 0.75) and the probability of launch is about 0.50 in flat, open terrain. The launch probability is only 0.05 in sharply rolling terrain when the aircraft is flying at low altitude, and increases to only 0.25 at an altitude of 4,000 ft.

This large terrain effect is produced by target masking by the terrain and vegetation. Although the target will be seen on 75% of the passes, it is seen too late to get off a launch on most of the passes. The major factor that interacts with the terrain effect is the aircraft altitude discussed in the next section.

ALTITUDE EFFECTS

Figure 18 shows the probability of being able to fly and launch a weapon from different altitudes under two weather conditions (December and June) in two different types of terrain. A target acquisition probability of 1.0 was assumed.

In flat, open terrain with good weather (June - Figures 8 and 9), the probability increases considerably when the aircraft goes from 500 to 1,000 feet. There is not much improvement above 1,000 feet; and, in fact, there is a slight decrement because some of the time the ceiling will be below the flight altitude.

FIGURE 14. Example of Flat, Open Terrain Used in Algorithm.

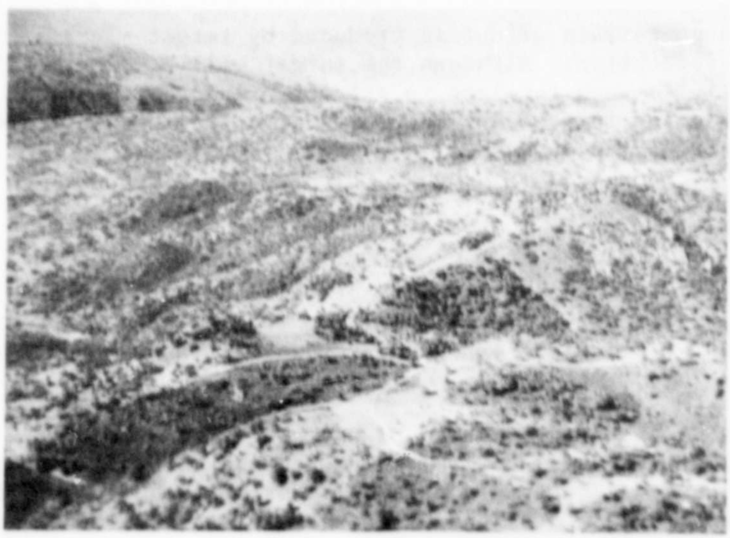

FIGURE 15. Example of Sharply Rolling Terrain Used in Algorithm.

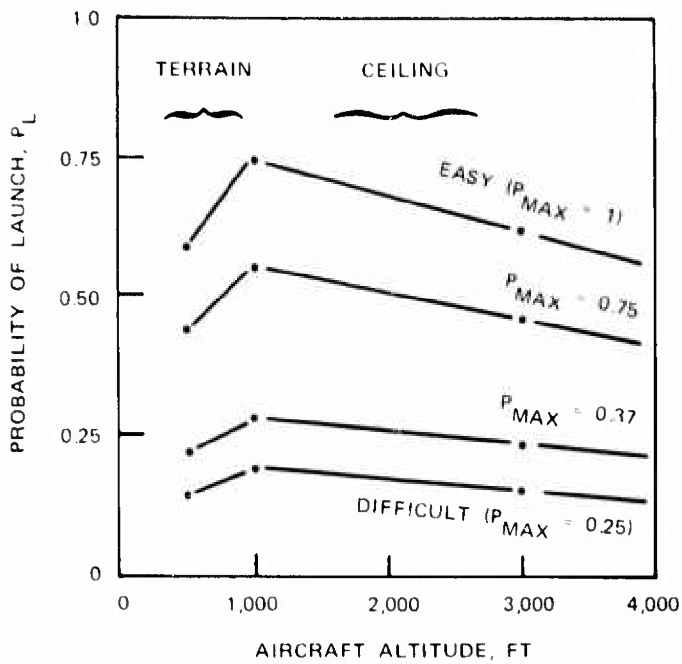

FIGURE 16. Probability of Launch as a Function of Target Acquisition Difficulty for Weather at Location B in June (Figures 10 and 11) With TOP = 7 sec and Angle-Off = 15 deg. Regions of predominant terrain and ceiling effects are shown on the curves.

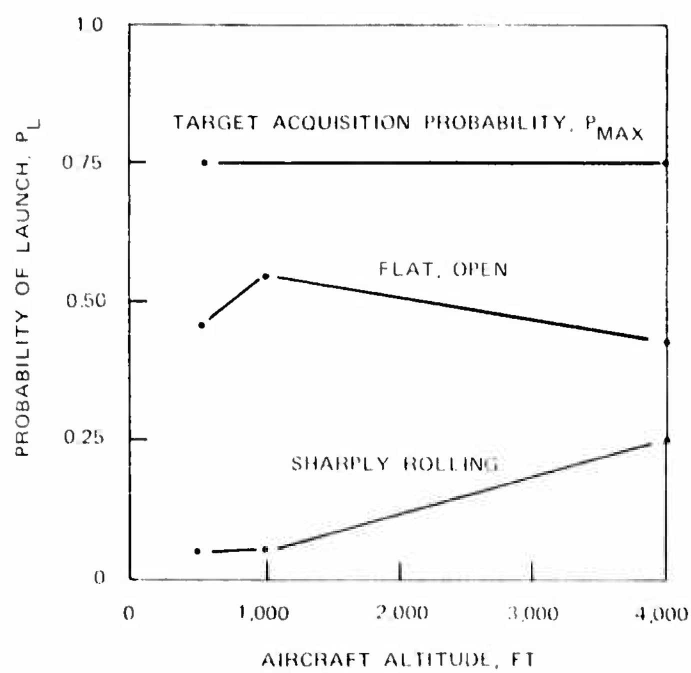

FIGURE 17. Probability of Launch as a Function of Terrain Type for Weather at Locations A or B in June With TOP = 7 sec and Angle-Off = 15 deg.

In the same terrain with poor weather (December - Figures 12 and 13), the probability of launch decreases with altitude. Visibility causes the degradation (not masking), and the probability of a clear sky at altitude gets lower the higher one gets.

The launch probability continually increases with altitude in sharply rolling terrain with good weather; masking is the cause of the degradation in this case, and the higher the aircraft flies, the better the chances of a CLOS.

In summary, increasing the planned attack altitude can either increase or decrease the percent of the time an attack can be made. Increasing the altitude overcomes masking problems, but may put the aircraft in the clouds. The weather and type of terrain must be known to determine the major effect.

OPERATING TIME

The time required by the aircrewman to operate the weapon also affects the probability of launch; the longer the operating time, the lower the launch probability. Figure 19 shows that the launch probability drops from 0.5 to 0.35 when the operating time increases from 2 to 10 sec with a dead-ahead target. A larger effect is illustrated in Figure 20 for sharply rolling terrain. The probability drops from 0.5 to 0.2 for an 8-sec increase in operating time. For other conditions, also shown in Figures 19 and 20, operating time does not have as large an effect as some other variables.

ANGLE-OFF EFFECTS

When the target is first sighted to the left or right of the flight path, the aircraft must be turned to overfly it. This process takes time, uses range, and reduces the probability of a launch. The degradation is shown in Figure 21 for a weapon operating time of 7 sec. The reduction in launch probability is not as large as some of the other effects; the probability drops about 1% for each 3 deg the target is off.

PROGRAM PRINTOUT

The format for the algorithm program printout is shown in Table 4. The input variables are shown in the heading, and the final probability (the smaller of either the masking or visibility calculation) is identified as the limiting factor. The complete program is given in Appendix B.

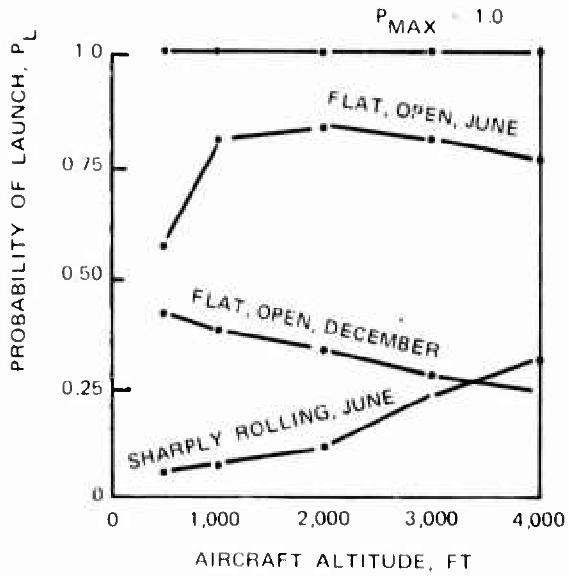

FIGURE 18. Altitude Effect on Probability of Launch in Flat, Open Terrain and Sharply Rolling Terrain. The weather types, December and June, are shown on the curves.

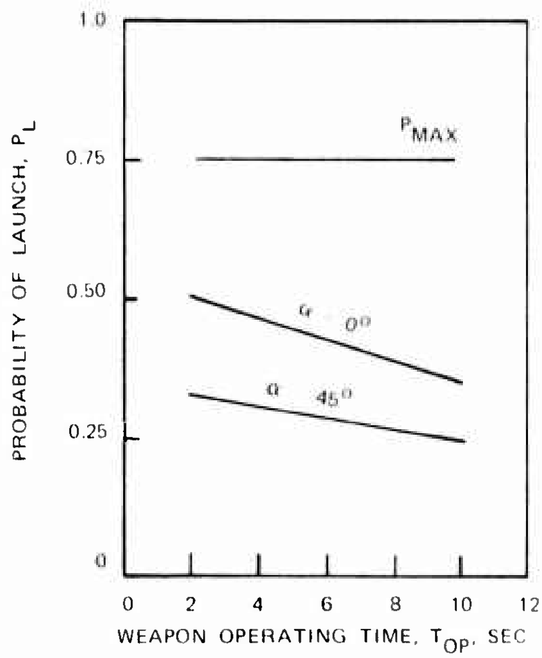

FIGURE 19. Operating Time Effect on Probability of Launch at 500 Feet Altitude or Higher Over Flat, Open Terrain in December. The initial angle off the target is shown on the curves.

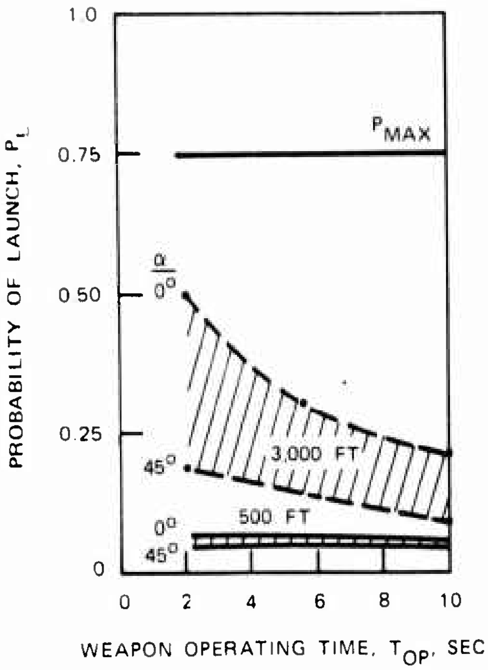

FIGURE 20. Operating Time Effect on Probability of Launch Over Sharply Rolling Terrain. The aircraft altitude and initial angle off the target are shown on the curves.

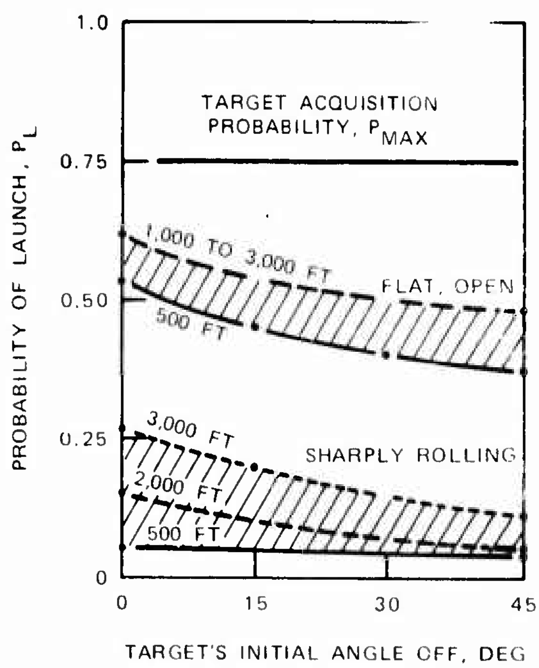

FIGURE 21. Angle-Off Effects on Probability of Launch for a Weapon Operating Time of 7 sec and Good Flying Weather (Location A).

TABLE 4. Sample Computer Program Printout of Algorithm Computations.

WEAPON UTILITY PROGRAM LOCATION A TIME JUNE

DECISION TIME1.0 SEC A/C VELOCITY 450. KNOTS ALTITUDE 500.FT P ALT UNDER CEILING 1.000
ROLL TIME .50 SEC NO. OF G,S 3.0 ROLL OUT TIME 1. SEC MIN RELEASE R 3000. FT

TERRAIN TYPE ROUGH MEAN SKYLINE HEIGHT ABOVE SITE 1506. FT MEAN RANGE TO SKYLINE IS 45353. FT

ANGLE-OFF(DEG) (DISTRIBUTION MEAN)	OPERATING TIME(SEC) (DISTRIBUTION MEAN)	PMAX	P LAUNCH	LIMITING FACTOR	P LAUNCH (WITH CEILING)	LIMITING FACTOR
0.	2.	.250	.025	MASK	.025	MASK
0.	2.	.370	.037	MASK	.037	MASK
0.	2.	.750	.074	MASK	.074	MASK
0.	2.	1.000	.099	MASK	.099	MASK
0.	7.	.250	.015	MASK	.015	MASK
0.	7.	.370	.023	MASK	.023	MASK
0.	7.	.750	.046	MASK	.046	MASK
0.	7.	1.000	.062	MASK	.062	MASK
0.	10.	.250	.013	MASK	.013	MASK
0.	10.	.370	.019	MASK	.019	MASK
0.	10.	.750	.040	MASK	.040	MASK
0.	10.	1.000	.053	MASK	.053	MASK
15.	2.	.250	.016	MASK	.016	MASK
15.	2.	.370	.024	MASK	.024	MASK
15.	2.	.750	.049	MASK	.049	MASK
15.	2.	1.000	.065	MASK	.065	MASK
15.	7.	.250	.013	MASK	.013	MASK
15.	7.	.370	.019	MASK	.019	MASK
15.	7.	.750	.038	MASK	.038	MASK
15.	7.	1.000	.051	MASK	.051	MASK
15.	10.	.250	.011	MASK	.011	MASK
15.	10.	.370	.017	MASK	.017	MASK
15.	10.	.750	.034	MASK	.034	MASK
15.	10.	1.000	.046	MASK	.046	MASK
45.	2.	.250	.012	MASK	.012	MASK
45.	2.	.370	.018	MASK	.018	MASK
45.	2.	.750	.037	MASK	.037	MASK
45.	2.	1.000	.050	MASK	.050	MASK
45.	7.	.250	.011	MASK	.011	MASK
45.	7.	.370	.016	MASK	.016	MASK
45.	7.	.750	.032	MASK	.032	MASK
45.	7.	1.000	.043	MASK	.043	MASK
45.	10.	.250	.010	MASK	.010	MASK
45.	10.	.370	.014	MASK	.014	MASK
45.	10.	.750	.029	MASK	.029	MASK
45.	10.	1.000	.039	MASK	.039	MASK

SUMMARY

This report has presented a method for estimating the probability of an aircrew being able to locate a target and launch a weapon against it on a single pass. The method includes effects of weapon operating time, terrain type, weather, and aircraft maneuvering time.

Sample results show how the launch probability is affected by these variables, and also illustrate that the launch probability can be considerably lower than the probability of sighting the target.

Appendix A
TARGET ACQUISITION COMPUTATION

This section of the report is taken from a contract report written by Dr. Charles P. Greening, Autonetics Division, Rockwell International, Anaheim, CA. It is a user-oriented description of his Simplified Target Acquisition Model (SIMTAC),[9] which is the basic element in the target acquisition computation used in the algorithm.

DESCRIPTION OF THE COMPUTATION

SIMTAC is designed to provide estimates of (1) the likelihood of acquiring a specified target on one pass, and (2) the likely distance from the target at the time of acquisition. The model was based upon flight test data obtained in controlled field studies in the United States.

The model uses subjective estimates of the visual appearance of the target as well as physical measurements (or estimates) of masking and visibility. The reliance upon estimated input quantities in SIMTAC increases the ease of use of the model, but raises questions about the consistency of the estimates. In an effort to reduce this potential source of variability, the following section describes the estimated quantities, and provides graphic examples to help the user "calibrate" his estimates. It is strongly recommended that the prospective user study the examples and text carefully before attempting to use the worksheets to generate predictions.

DIRECTIONS FOR USE

Estimation of Acquisition Probability

An evaluation of the available, relevant flight test data on visual target acquisition indicated that the most important determiners of acquisition likelihood have to do with the conspicuousness of the target complex in its setting. Target size is not as significant, though it can have a substantial effect on the range at which the target is recognized.

The "conspicuousness" characteristic has been split into two separately estimated features called "contrastiness" and "associated pattern." These terms were deliberately coined to avoid confusion with other, existing terms (e.g., contrast) used in target acquisition work.

Contrastiness. This term is intended to signify the visual contrast between the most *significant*, *distinctive*, *target-related* feature and its background. The contrasting element may be the target object itself (e.g., a vehicle parked in a grassy clearing) or it may be a distinctive associated feature (e.g., the symmetrical pattern of pads and roads in an established SAM site).

Examples of target complexes of high, medium, and low contrastiness are shown in Figures A-1, A-2, and A-3. The field hospital (Figure A-1) represents an attempt to provide high contrast so that the complex *will* be found.

The deployed AAA guns (Figure A-2) are located on graded areas which have rather high contrast with the surrounding grass, but the shape and arrangements of the grading are sufficiently irregular that the weapons themselves must be seen in order to recognize the target.

The vehicle park (Figure A-3) has been recently occupied so that it presents no noticeable eroded area. The vehicles against grass present low contrast; even though four large trucks are openly visible, they do not draw attention.

Associated Pattern. This term is intended to signify the extent of *distinctively target-related* pattern in the target area. The pattern may be made up of target elements (e.g., a straight row of trucks) or of incidental elements (such as the pattern of roads and pads in a SAM site).

Figures A-4, A-5, and A-6 show targets of high, medium, and low pattern.

The revetted tanks (Figure A-4) are arranged in a straight line of circular graded areas resulting from building the revetments. This pattern is highly distinctive of some emplaced weapons and would be difficult to overlook.

The antitank missile launchers (Figure A-5) are deployed in a more or less symmetrical pattern and are near a road intersection. However, the existence of other intersections, and the lack of further associated pattern elements (such as revetments) makes the weapon "pattern" an only moderately prominent one.

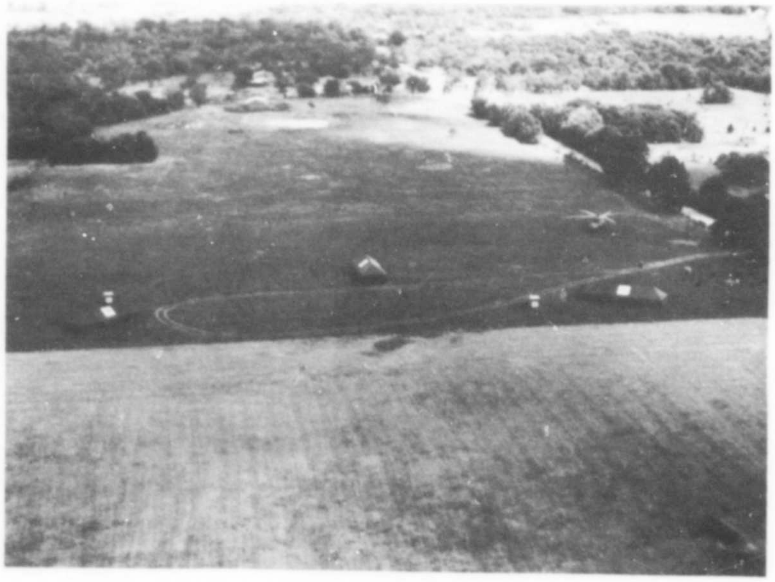

FIGURE A-1. Field Hospital With High "Contrastiness" Rating.

FIGURE A-2. Deployed AAA Guns With Medium "Contrastiness" Rating.

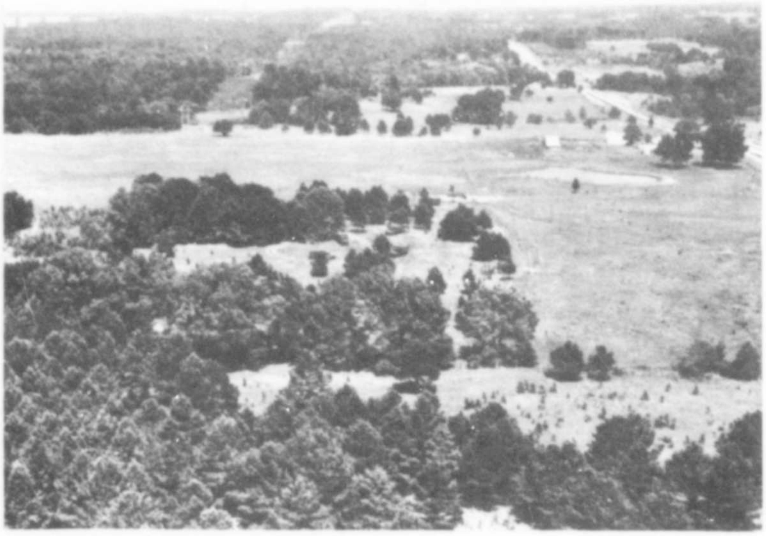

FIGURE A-3. Vehicle Park With Low "Contrastiness" Rating.

FIGURE A-4. Revetted Tanks With High Pattern Rating.

FIGURE A-5. Antitank Missile Launchers With Medium Pattern Rating.

FIGURE A-6. Signal Company With Low Pattern Rating.

The signal company (Figure A-6) is arranged more or less randomly within a larger set of random elements (trees), and not closely associated with prominent clearings, roadways, or other man-made patterns. It should be noted that the trees also provide considerable masking, but the mask effects are discussed below under Range Estimation.

Sources of Target/Background Information. The discussion in the preceding paragraphs has been based largely upon characteristics which are visible in the photographic examples. However, in an operational setting similar low-altitude oblique photos may not be available. In such a case, the "Contrastiness" and "Associated Pattern" must be estimated from other sources. The quality of the estimates will be heavily dependent upon the nature of the available briefing information.

If current high-altitude vertical photographic coverage of the target area is available, "Contrastiness" and "Associated Pattern" can be estimated from them, much as it is with oblique photographs. Some transformation of the scene must be made in order to visualize the appearance from an oblique approach, but contrast and distinctiveness of pattern are distorted less than some other characteristics by a large change in viewing angle.

If no photographic coverage is available, estimates will have to be made from whatever maps and verbal descriptions are available. The accuracy of such estimates will undoubtedly depend heavily upon the experience of the estimator, especially within the appropriate theater of operations. For example, in a moist area with good vegetation ground cover, any fresh revetment or trenching will be characterized by a contrasty area from which the top layers of grass and soil have been scraped (see Figures A-2 and A-4.)

Conversion to Probability Numbers. The preceding paragraphs have shown how to evaluate the "Contrastiness" and "Associated Pattern" characteristics as high, medium, or low. The expected acquisition probability can be computed from these estimates by reference to Table A-1. Thus, for example, a target rated "high" in both factors would almost certainly be acquired on one pass (P_{MAX} = 1.00). Figure A-7, an ordered array of vehicles in an open field, represents such a target. Figure A-2 represents a target rated "medium" on both factors, resulting in a predicted P_{MAX} = 0.56, from Table A-1. Figure A-3 represents a target rated "low" on both factors, with a predicted P_{MAX} = 0.25.

Estimation of Available Range

Available range, R_A, is estimated separately from probability because it has been found to be sensitive to quite different parameters, and it is not highly correlated with P_{ACQ}.

TABLE A-1. Maximum Probability of Target Acquisition.

Estimate of pattern	Estimate of "contrastiness"		
	High	Medium	Low
High	1.00	0.75	0.50
Medium	0.75	0.56	0.37
Low	0.50	0.37	0.25

FIGURE A-7. Vehicles in Open Field.

Two factors commonly encountered in target search from the air tend to place a rather sharp upper limit on R_A. They are *masking* and *haze*. If a target is hidden by a ridge or a tree line, it cannot be seen beyond the unmask range no matter how contrasty and obvious it is. Almost as definite is the range at which objects emerge from the haze. At the range where apparent contrast between target elements is reduced to 1% or so, none of its features can be seen. Meteorological range is, in fact, defined as the range at which a large, high-contrast target cannot be seen.

Target size also limits available range (if no mask intervenes and the air is very clear), but not quite as sharply as the other two factors. The field data examined showed that visual observers rarely acquire targets whose major dimensions are less than about 4 minutes of arc, or roughly 1.25 mrad. Hence, target size could be used to compute a third "limit" (although a less abrupt one) on R_A. *Target size is not used in the algorithm at present.*

Two factors have been presented which will be used in the algorithm to set a limit on R_A, unmask range, and meteorological range (or visibility). The actual range at which the target can be considered to be *available* for acquisition will be the smaller of the two. Methods of estimating these quantities will be discussed below.

Acquisition Range

The actual range at which acquisition will take place cannot be greater than the smallest of the limiting ranges, but it can be smaller, and usually is. In fact, the field data show that, on the average, target acquisition is achieved at about half the maximum available range. Thus, $\bar{R}_{ACQ}$ (the predicted median range) is obtained by dividing the available range by 2.

Distribution of Acquisition Ranges. Not all observers will acquire a target at the same range, due to variations in search patterns and many other factors. In fact, examination of the data shows that the middle 60% of acquisition ranges tends to fall in a rather narrow band about the median value. The remainder may be widely scattered, and are much more difficult to predict. However, an estimate of the range at which most acquisitions will occur would seem to be more useful than an estimate of the extremes (short or long) achieved by a few observers. Certainly the best estimate for the next observer is that his performance will fall near the median.

Because of the difficulty of estimating extreme acquisition performance, and the relatively limited utility of extreme estimates for prediction, the SIMTAC model is designed to predict the performance of those falling nearest the median value.

The examination of field data showed that the middle 60% of acquisition ranges seemed to fall in a nearly linear region between the 20th percentile and the 80th percentile. Furthermore, the slope of the linear portion typically ran from about 1.25 $\bar{R}_{ACQ}$ to 0.75 $\bar{R}_{ACQ}$.

It must be kept in mind that these values are for 20, 50, and 80% of *those who succeed*. Those who do not acquire were estimated in the preceding section ($1 - P_{ACQ}$).

Presentation of Results

Probably the most useful way of presenting the estimates of P_{ACQ} and R_{ACQ} is graphically. Although the algorithm uses the computed values in further calculations and does not print them out, an example will be instructive in understanding the calculation process.

Assume, for the example, a target that has been judged by the algorithm user to have a high pattern associated with it and to have medium contrastiness. Assume further that the unmask range of the target is 16 km and that the visibility in the target area is 20 km. The workwheet that follows can be used to make the required computations. The plot of the results is shown in Figure A-8.

WORKSHEET

SIMPLIFIED TARGET ACQUISITION MODEL (SIMTAC)

I. IDENTIFICATION

Target *Assume a target of high pattern and medium contrastiness.*

II. PROBABILITY OF ACQUISITION

Estimate of "Contrastiness" →		High	Medium	Low
Estimate of "Pattern"	High	*1.00*	*0.75*	*0.50*
	Medium	*0.75*	*0.56*	*0.37*
	Low	*0.50*	*0.37*	*0.25*

Estimate degree of "contrastiness" and "pattern" related to the target from photographs or best available data.
Circle the number in the table above where the two estimates intersect.

Probability of Acquisition (from Table) P_{ACQ} = *0.75*

For later use, also calculate 0.2 P_{ACQ} *0.15*, 0.5 P_{ACQ} *0.375*, and 0.8 P_{ACQ} *0.60*.

III. RANGE AT ACQUISITION

A. Masking

The probability of a clear-line-of-sight is computed in the algorithm from actual survey data. For this example, however, let us simply assume that the target is unmasked at a range of 16 km.

Unmask range, R_{A_1} = *16 km*

WORKSHEET (continued)

III. RANGE AT ACQUISITION (continued)

B. Meteorological Range . . . . R_{A_2} = *20 km* (mi or km)

C. Predicted Median Range at Acquisition

$$\bar{R}_{ACQ} = \left(\frac{\text{Smallest of } R_{A_1} \text{ or } R_{A_2} = \underline{\textit{16 km}} \text{ (mi or km)}}{2} \right)$$

$\bar{R}_{ACQ}$ = *8 km* (mi or km)

D. 20th Percentile Range

Range by which 20% of observers can be expected to acquire target:

$$R_{20} = \left(1.25\ \bar{R}_{ACQ}\right) = \underline{\textit{10 km}} \text{ (mi or km)}$$

E. 80th Percentile Range

Range by which 80% of observers can be expected to acquire target:

$$R_{80} = \left(0.75\ \bar{R}_{ACQ}\right) = \underline{\textit{6 km}} \text{ (mi or km)}$$

WORKSHEET (continued)

F. The values taken from the worksheet are plotted as shown in the table below (see Figure A-8).

Values To Be Plotted

P_{ACQ}	at	R_{ACQ}
0.75		0
0.60		6
0.50		8
0.38		10

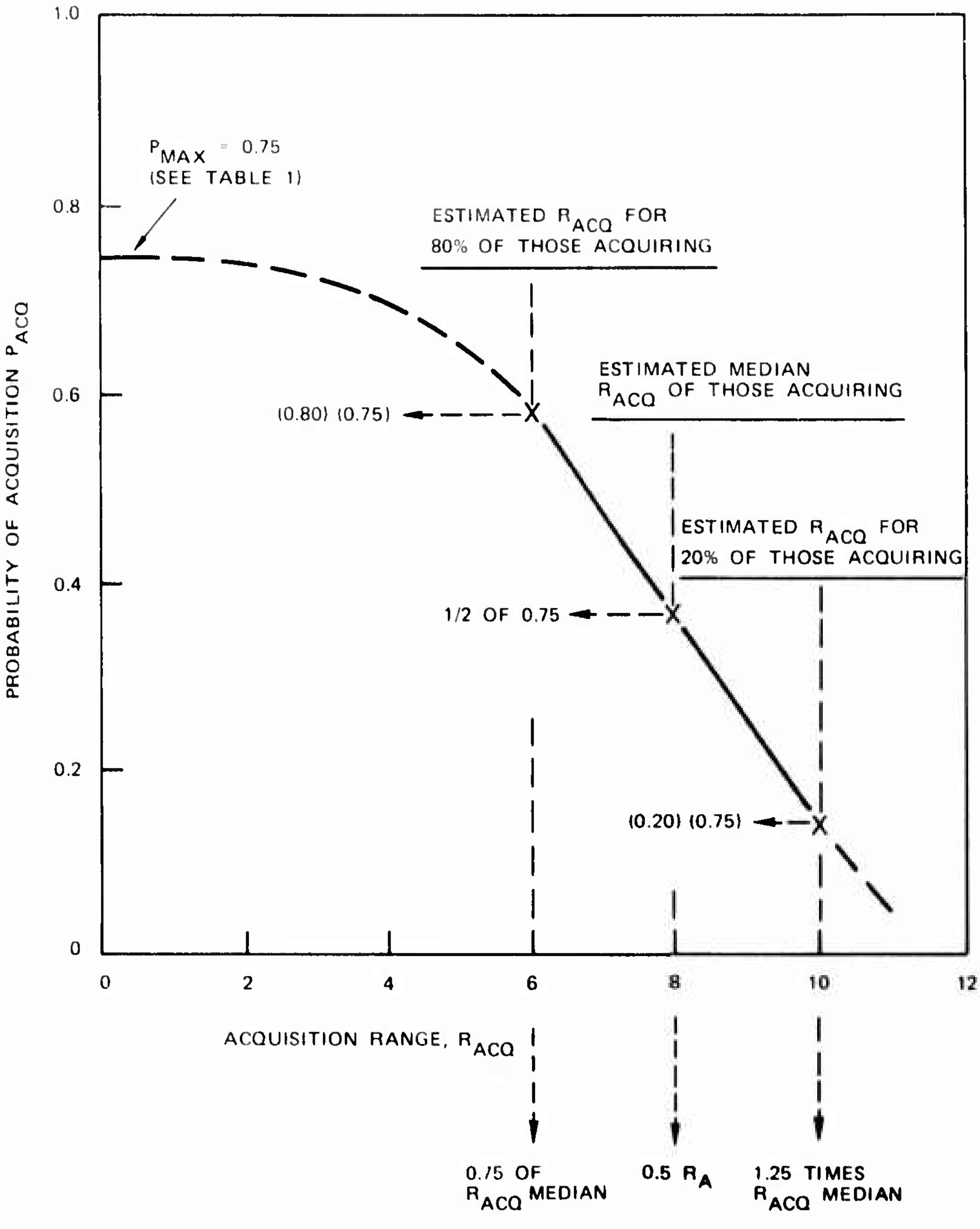

FIGURE A-8. Example Computation for an Assumed High-Pattern, Medium-Contrastiness Target With an Unmask Range of 16 km (R_A = 16 km). Note that 0.5 R_A = R_{ACQ}.

Appendix B
COMPUTER PROGRAM

GENERAL DESCRIPTION

Main Program

The attack is considered to start from some range, REPT. At intervals between REPT and the target, computations are made of the probability of acquisition by the equation

$$PACQ = PMAX\ e^{-\left(\frac{RRQ}{R - 0.75\ RRQ}\right)^2}$$

The values for R are the range values at the specified intervals. PMAX is the maximum probability of acquisition discussed on p. 16.

The equation derivation and definition of the variables for RRQ, range required, were given on pp. 7-9. RRQ is independent of the range of the attacker. It is a function of various weapon, pilot, and aircraft variables, including α, the angle the target is off the flight path, and TOP, the operating time of the weapon. The user has the option of using distributions instead of single values, for α and TOP. When distributions are used, an RRQ is computed for every combination of α and TOP. NA and NOP are the number of αs and TOPs in their distribution.

	TOP_1	TOP_2	. . .	TOP_{NOP}
α_1	RRQ_{11}	. . .		$RRQ_{1,NOP}$
α_2	.			
.	.			
.	.			
.				
α_{NA}	$RRQ_{NA,1}$			$RRQ_{NA,NOP}$

At each range interval, a PACQ is computed for each of these RRQs, using the above equation.

$$
\begin{array}{ccc|ccc}
 & R_1 & & & R_2 & \\
\hline
RRQ_{1,1} & \cdots & RRQ_{NA,NOP} & RRQ_{1,1} & \cdots & RRQ_{NA,NOP} \\
\downarrow & & \downarrow & \downarrow & & \downarrow \\
PACQ_{1,1,1} & \cdots & PACQ_{1,NA,NOP} & PACQ_{2,1,1} & \cdots & PACQ_{2,NA,NOP}
\end{array}
$$

$$
\begin{array}{c}
R_3 \quad \ldots \text{ etc.} \\
\hline
\ldots
\end{array}
$$

The PACQs are multiplied by the probability of the TOPs and αs occurring (PTOP and PALPH). The products are summed to produce a single PACQ at each range interval.

$$
\begin{array}{c}
R_1 \\
\hline
PALPH_1 \sum_{k=1}^{NOP} PACQ_{1,1,k} \cdot PTOP_k \\
+ \\
\vdots \\
+ \\
PALPH_{NA} \sum_{k=1}^{NOP} PACQ_{1,NA,k} \cdot PTOP_k \\
\downarrow \\
PACQ_1
\end{array}
$$

etc., for all the range intervals

Along the range line, each PACQ is multiplied by the probability of the unmask range being R, (PMSK) and the products are summed from REPT to R = 0, to give the probability of launch with masking as the limiting factor. Each original PACQ is also multiplied by the probability of the visibility range being R (PVIS); those products are summed to give the probability of launch with visibility as the limiting factor.

$$\underbrace{PACQ_1 \cdot PMSK_1}_{R_1} + \underbrace{PACQ_2 \cdot PMSK_2}_{R_2} + \ldots = \text{PLAUNCH with masking as limiting factor}$$

$$PACQ_1 \cdot PVIS_1 + PACQ_2 \cdot PVIS_2 + \ldots = \text{PLAUNCH with visibility as limiting factor}$$

The two launch probabilities are compared and the lower one is taken as the probability of successfully launching the weapon at the time and place specified. A listing of the programs and subroutines begins on page 51.

Subroutines

FREQ. Subroutine FREQ is used to convert a cumulative probability curve into a discrete probability distribution. The user provides up to 10 data points from a cumulative curve and the number of classes he wishes to have in the distribution. As used by this program, the curve is a visibility curve and the number of classes is the same as the number of range intervals.

MASK. Subroutine MASK retrieves raw terrain masking data from the MASKDATA file and computes a discrete probability distribution from it for the desired altitude and range intervals. The user provides the code for the type of terrain, which must correspond to one of the eight types described in NWC TP 5908.[10] For quick reference, an abbreviated description of terrain types is presented in Table B-1. The user may use masking data that is not in the NWC MASKDATA file. The data should be in the form of mask angles, in degrees, and range to mask object, in meters. The READ and FORMAT statements (#5 and #600) in the MASK subroutine can easily be changed to suit the format of other data. The data cards should be inserted in the Data Card Deck in place of the

[7
8ADD MASKDATA.] terrain type card and should end with an end-of-file.

The input data for the program is listed in Table B-2. The format and order of data cards are given in Table B-3, and the program itself is listed in Table B-4.

TABLE B-1. Description of Terrains.*

Code	Description	
	Terrain	Vegetation
FLTOPN	Farmland, fairly flat	Thick forests in distance
FRSMTH	Desert, fairly smooth	Scattered bushes
RLGCLS	Farmland, rolling	Thick forests, close
MODRUF	Desert, moderately rough Hills, rolling	Scattered bushes
FLTCLS	Farmland, flat	Thick forests, close
MODRLG	Hills, gently rolling	Scattered trees
ROUGH	Desert, rough	Scattered bushes
SHRLG	Hills, sharply rolling	Thickly scattered trees

* Terrain types are arranged in order of increasing severity of masking.

TABLE B-2. Input Data Description for Algorithm Program.

Definitions		Units of measure	Limits
Code	Description		
LOC	Geographical location of the run		
TME	Season or month of the year		
REPT	Range from the target at which the attack is to begin	ft	
NSTP	Number of intervals at which computations are to be made		20
NP	Number of pairs to be read from visibility curve		10
X,Y	Points on a cumulative visibility curve. Should be consistent with LOC and TME		
V	Aircraft velocity	knots	
NG	Maximum number of *g*'s that will be acceptable to the aircraft and pilot		
TD	Time to decide that object on ground is a target	sec	
TRI	Time to roll aircraft into a turn	sec	
TRO	Time to roll aircraft out of a turn	sec	
NPMX	Number of maximum probabilities of acquisition to be read		10
PMAX	Maximum probability of acquisition		1.0
NALT	Number of aircraft altitudes to be read		[illegible]
ALT	Aircraft altitude	ft	
PALT	Probability of ALT being under ceiling (Should be consistent with LOC and TME.)		1.0
RMIN	Minimum range at which the weapon may be safely delivered	ft	
NALPHD	Number of distributions of α (angle target is off flight path) to be read		10
NA	Number of α's in the distribution		10
ALPHA	Angle target is off flight path, α	deg	
PALPH	Probability that target is α off flight path		Must sum to 1.0 for each dist
NOPD	Number of operating time distributions to be read		10
NOP	Number of operating times in the distribution		10
TOP	Operating time of the weapon	sec	
POP	Probability of weapon operating time being TOP		Must sum to 1.0 for each dist
Terrain	One of the eight terrain types listed in Table A-1		

TABLE B-3. Format and Order of Data Cards for Algorithm Program.

	LOC	TME					
Column:	1-24	25-48					
	(4A6, 4A6)						
	REPT	NSTP					
Column:	1-6	7-12					
	(F6.0, I6)						
	NP						
Column:	1-6						
	(I6)						
	X_1	Y_1		X_{NP} Y_{NP}			
Column:	1-6	7-12	. . .	up to 72			
	(12 F6.0)						
	V	NG	TD	TRI	TRO		
Column:	1-6	7-12	13-18	19-24	25-30		
	(10F6.0)						
	NPMX	$PMAX_1$	$PMAX_2$		. . .	$PMAX_{NPMX}$	
Column:	1-6	7-12	13-18		. . .	up to 72	
	(I6, 11F6.0)						
	NALT						
Column:	1-6						
	(I6)						
	ALT_1	$PALT_1$	ALT_2	$PALT_2$	. . .	ALT_{NALT}	$PALT_{NALT}$
Column:	1-6	7-12	13-18	19-20	. . .	up to 72	
	(12 F6.0)						
	$RMIN_1$	$RMIN_2$	$RMIN_3$		. . .	$RMIN_{NALT}$	
Column:	1-6	7-12	13-18		. . .	up to 32	
	(12F 6.0)						
	NALPHD						
Column:	1-6						
	(I6)						
Repeat NALPHD times	NA						
	1-6						
	(I6)						
	$ALPHA_1$	$PALPH_1$	$ALPHA_2$	$PALPH_2$	. . .	$ALPHA_{NA}$	$PALPH_{NA}$
	1-6	7-12	13-18	19-24	. .	up to 72	
	(12F 6.0)						

TABLE B-3. (Contd.)

	NOPD					
Column:	1-6					
	(I6)					
Repeat NOPD times	NOP					
	1-6					
	(I6)					
	TOP_1	POP_1	TOP_2	POP_2		TOP_{NOP} POP_{NOP}
	1-6	7-12	13-18	19-24	. . .	up to 72
	(12F 6.0)					
	7/8ADD	MASKDATA.	TERRAIN			
Column:	1-4	6-14	15-20			
	7/8FIN					
Column:	1-4					

TABLE B-4. Algorithm Program Listing.

```
C WEAPON UTILITY PROGRAM
C COMPUTES PROBABILITIES OF MISSILE LAUNCH AS A FUNCTION OF RANGE REQUIRED
C TARGET, SEASON AND LOCATION.  COMPUTES RRO ARRAY AS FUNCTION OF TD, DECISION
C TIME, TRI, ROLL IN TIME, TRO, ROLL OUT TIME, TOP, WEAPON OPERATING TIME, V, VE
C LOCITY, RMIN, WEAPON MINIMUM RANGE, NG, NUMBER OF TOLERABLE GS
C ANGLE OF TARGET OFF OF FLIGHT PATH
      DIMENSION LOC(4),TME(4)
      DIMENSION LFCTR(2),ALPHA(10,10),TOP(10,10),PALPH(10,10),POP(10,10)
      DIMENSION PMAX(10),NALP(10),NOPT(10),RRQ(10,10),PLRM(10,26)
       DIMENSION ALT(50),PALT(50),RMIN(50)
      DIMENSION LIMR(30),PACQ(26),PLR(26)
      DATA LFCTR/'MASK','VIS'/
      REAL NG
      REAL LIMR
      REAL LRSTP
      INTEGER CTR
      CTR=0
      READ(5,203)(LOC(I),I=1,4),(TME(I),I=1,4)
  203 FORMAT(4A6,4A6)
      READ(5,202)REPT,NSTP
  202 FORMAT(F6.0,I6)
      LRSTP=REPT/NSTP
      NSTP1=NSTP+1
      LIMR(1)=0
      CALL FREQ(NSTP,0.,REPT,PLR)
C RETURN WITH PROBABILITY OF VISIBILITY BEING AT LEAST AS GREAT AS R IN PLR
      READ(5,201)V,NG,TD,TRI,TRO
  201 FORMAT(10F6.0)
      V=V*(1.68781)
      RADMN=(V**2.)/(32.174*(NG**2.-1.)**0.5)
      VP=V/(1.6871)
      READ(5,200)NPMX,(PMAX(I),I=1,NPMX)
  200 FORMAT(I6,11F6.0)
      READ(5,204)NALT
  204 FORMAT(I6)
      READ(5,206)(ALT(I),PALT(I),I=1,NALT)
      READ(5,206)(RMIN(I),I=1,NALT)
  206 FORMAT(12F6.0)
      READ(5,204)NALPHD
      DO5L=1,NALPHD
      READ(5,204)NALP(L)
      NA=NALP(L)
    5 READ(5,206)(ALPHA(L,J),PALPH(L,J),J=1,NA)
      READ(5,204)NOPD
      DO 6LL=1,NOPD
      READ(5,204)NOPT(LL)
      NOP=NOPT(LL)
    6 READ(5,206)(TOP(LL,K),POP(LL,K),K=1,NOP)
      AL=ALT(1)
      CALL MASK(REPT,NSTP,AL,1,PLRM)
      WRITE(6,599)
  599 FORMAT(1H1)
      DO20NL=1,NALT
```

TABLE B-4. (Contd.)

```
      CTR=CTR+1
      IF(CTR.LT.4)GO TO 10
      CTR=0
      WRITE(6,599)
   10 WRITE(6,600)LOC,TME
  600 FORMAT(1H0,///,' WEAPON UTILITY PROGRAM',33X,'LOCATION ',4A6,' TIME
     X ',4A6)
      WRITE(6,604)TD,VP,ALT(NL),PALT(NL)
  604 FORMAT(1H0,'DECISION TIME',F4.1,' SEC',7X,'A/C VELOCITY',F6.0,1X,'
     XKNOTS',4X,'ALTITUDE',F8.0,'FT',9X,'P ALT UNDER CEILING',F6.3)
      WRITE(6,606)TRI,NG,TRO,RMIN(NL)
  606 FORMAT(1H ,'ROLL TIME ',F6.2,' SEC',7X,'NO. OF G,S',F6.1,12X,'ROLL
     X OUT TIME',F6.0,' SEC',4X,'MIN RELEASE R',F7.0,' FT')
      AL=ALT(NL)
      CALL MASK1(AL,PLRM)
      WRITE(6,612)
  612 FORMAT(1H0,'ANGLE-OFF(DEG)',3X,'OPERATING TIME(SEC)',3X,'PMAX',3X,
     X'P LAUNCH',3X,'LIMITING FACTOR',3X,'P LAUNCH',7X,'LIMITING FACTOR'
     X)
      WRITE(6,613)
  613 FORMAT(1H ,'(DISTRIBUTION    (DISTRIBUTICN',45X,'(WITH CEILING)')
      WRITE(6,614)
  614 FORMAT(1H ,' MEAN)',12X,'MEAN)')
      DO 20L=1,NALPHD
      SMAL=0
      NA=NALP(L)
      DO45J=1,NA
   45 SMAL=SMAL+ALPHA(L,J)*PALPH(L,J)
      DO 20LL=1,NOPD
      SMOP=0
      NOP=NOPT(LL)
      DO46K=1,NOP
   46 SMOP=SMOP+TOP(LL,K)*POP(LL,K)
      DO67J=1,NA
      ALPH=ALPHA(L,J)*0.01745
 THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF(ALPH.EQ.0)GO TO 60
      A=V*(TD+TRI)
   55 C=A*COS(ALPH)+RADMN*SIN(ALPH)
      GO TO 65
   60 A=V*TD
      GO TO 55
   65 DO 67K=1,NOP
 THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF(ALPH.EQ.0)GO TO 70
      B=V*(TRO+TOP(LL,K))+RMIN(NL)
   66 RP(J,K)=(C+SQRT(C**2.-A**2.+B**2.))
      GO TO 67
   70 B=V*TOP(LL,K)+RMIN(NL)
      GO TO 66
   67 CONTINUE
   75 DO 20N=1,NPMX
      DO 18I=1,NSTP1
      I1=I+1
```

TABLE B-4. (Contd.)

```
      LIMR(I1)=LIMR(I)+LRSTP
      PACO(I)=0
      DO85J=1,NA
      SPAC=0
      DO80K=1,NOP
      IF(RRQ(J,K).LT.LIMR(I))GO TO 16
      PAC=0
      GO TO 80
   16 EX=-((RRQ(J,K)/(LIMR(I)-0.75*RRQ(J,K)))**2.)
      PAC=PMAX(N)*EXP(EX)
   80 SPAC=SPAC+POP(LL,K)*PAC
   85 PACO(I)=PACO(I)+SPAC*PALPH(L,J)
   18 CONTINUE
      SUMV=0
      DO30I=1,NSTP1
   30 SUMV=SUMV+PACO(I)*PLR(I)
      SUMVC=SUMV*PALT(NL)
C SUMVC=P OF LAUNCH INCLUDING P ALT UNDER CEILING
C SUMV= P OF LAUNCH WITH VISIBILITY AS LIMITING FACTOR
      SMA=0
      DO35I=1,NSTP1
   35 SMA=SMA+PACO(I)*PLRM(1,I)
      SMAC=SMA*PALT(NL)
C SMA=P OF LAUNCH WITH MASK AS LIMITING FACTOR
C SMAC= P OF LAUNCH INCLUDING P ALT UNDER CEILING
      IF(SUMV.LT.SMA)GO TO 37
      NK=1
      GO TO 40
   37 NK=2
      SMA=SUMV
   40 IF(SUMVC.LT.SMAC)GO TO 47
      NKC=1
      GO TO 50
   47 NKC=2
      SMAC=SUMVC
   50 WRITE(6,616)SMAL,SMOP,PMAX(N),SMA,LFCTR(NK),SMAC,LFCTR(NKC)
  616 FORMAT(1H ,3X,F4.0,13X,F4.0,14X,F5.3,3X,F5.3,10X,A6,5X,F8.3,12XA6)
   20 CONTINUE
      END
```

TABLE B-4. (Contd.)

```
00101        SUBROUTINE FREQ(NC,XF1,XFNC1,PLR)
00101  C STRAIGHT LINE FIT BETWEEN POINTS AND FREQUENCY DISTRIBUTION SUBPROGRAM
00101  C  COMPUTES (N-1)VALUES OF M AND C FOR N PAIRS OF POINTS
00101  C POINTS PROVIDED SHOULD BE IN ORDER FROM SMALLEST TO LARGEST VALUES OF X
00101  C COMPUTES FREQUENCY DISTRIBUTION FROM CUMULATIVE PROBABILITY
00103        DIMENSION X(10),Y(26),M(10),C(10)
00104        DIMENSION XF(26),FRQ(26),PLR(26)
00105        NC1=NC+1
00106        REAL M
00107        READ(5,600)NP
00112    600 FORMAT(1I6)
00113        READ(5,601)(X(I),Y(I),I=1,NP)
00122        NP1=NP-1
00123    601 FORMAT(12F6.0)
00124        DO10I=1,NP1
00127        I2=I+1
00130        M(I)=(Y(I2)-Y(I))/(X(I2)-X(I))
00131      8 C(I)=Y(I)-M(I)*X(I)
00132     10 CONTINUE
00134        XF(1)=XF1
00135        XF(NC1)=XFNC1
00135  C TEST IF ENDPOINTS INSIDE DTACRV CURVE
00136        IF(XF(1).LT.X(1)) GO TO 50
00140        CS=(XF(NC1)-XF(1))/NC
00141        N=1
00142        DO7K=1,NC1
00145        IF(XF(K).GE.X(NP))GO TO 9
00147      2 IF(XF(K).GT.X(N+1))GO TO 5
00151        Y(K)=M(N)*XF(K)+C(N)
00152        XF(K+1)=XF(K)+CS
00153        GO TO 7
00154      5 N=N+1
00155        GO TO 2
00156      7 CONTINUE
00160        GO TO 11
00161      9 Y(K)=M(N)*XF(K)+C(N)
00162        NC1=K
00163     11 FRQ(NC1)=0
00164        N=N/2
00165        IF(M(N).GT.0)GO TO 12
00167        IF(Y(NC1).GT.0.)FRQ(NC1)=Y(NC1)
00171        GO TO 14
00172     12 IF(Y(NC1).GT.0.)FRQ(NC1)=1.-Y(NC1)
00174     14 SUMF=FRQ(NC1)
00175        DO 15K=1,NC
00200        FRQ(K)=ABS(Y(K)-Y(K+1))
00201     15 SUMF=SUMF+FRQ(K)
00203        DO40K=1,NC1
00206     40 PLR(K)=FRQ(K)
00210        GO TO 55
00211     50 WRITE(6,700)
00213    700 FORMAT(1H0,'ENDPOINTS OUTSIDE LIMITS')
00214        RETURN
00215     55 END
```

TABLE B-4. (Contd.)

```
      SUBROUTINE MASK(RMAX,NSTP,ALTMAX,NASTP,PLRM)
      DIMENSION EMSK(150,4),RD(150,4),PROB(20,10)
      DIMENSION R(20),HC(20,150),HF(10),PLRM(10,20)
      RMX=RMAX/3.280833
      RINT=RMX/NSTP
      ALTMX=ALTMAX/3.280833
      ALTINT=ALTMX/NASTP
      NR=NSTP+1
      NHF=NASTP +1
      IF(NHF.EQ.2)NHF=1
      K=1
      READ(5,598)TT
  598 FORMAT(A6)
    5 READ(5,600,END=99)(EMSK(K,I),RD(K,I),I=1,4)
  600 FORMAT(9X,4(F8.6,F7.0,1X))
      K=K+1
      GO TO 5
   99 NRAD=K-1
      SALT=0
      SRD=0
      DO10I=1,NRAD
      SRD=SRD+RD(I,4)
      ANG=EMSK(I,4)
   10 SALT=SALT+RD(I,4)*TAN(ANG)
      SRD=SRD*3.280833/NRAD
      SALT=SALT*3.280833/NRAD
      DO30K=1,NR
      R(K)=(K-1)*RINT
      DO16I=1,NRAD
      TST=0
      DO16J=1,4
   THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF(TST.EQ.1.)GO TO 16
   THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF(EMSK(I,J).EQ.0)GO TO 16
      IF(R(K).LE.RD(I,J))GO TO 11
      IF(J.EQ.4)GO TO 13
      GO TO 16
   11 IF(J.GT.1)GO TO 12
      ANG=0
      GO TO 14
   12 JJ=J-1
      ANG=EMSK(I,JJ)
      GO TO 14
   13 ANG=EMSK(I,J)
   14 HC(K,I)=R(K)*TAN(ANG)
      TST=1.0
   16 CONTINUE
      DO30I=1,NHF
      IF(NHF.EQ.1)GO TO 25
      HF(I)=(I-1)*ALTINT
   20 PROB(K,I)=0
      DO18L=1,NRAD
   18 IF(HF(I).GE.HC(K,L))PROB(K,I)=PROB(K,I)+1
      PROB(K,I)=PROB(K,I)/NRAD
      GO TO 30
```

TABLE B-4. (Contd.)

```
 25 HF(1)=ALTINT
    GO TO 20
 30 CONTINUE
    GO TO 50
    ENTRY MASK1(ALTI,PLRM)
    ALTI=ALTI/3.280833
    DO 33K=1,NR
    PROB(K,1)=0
    DO32L=1,NRAD
 32 IF(ALTI.GE.HC(K,L))PROB(K,1)=PROB(K,1)+1
 33 PROB(K,1)=PROB(K,1)/NRAD
    NHF=1
 50 WRITE(6,700)TT,SALT,SRD
700 FORMAT(1H0,'TERRAIN TYPE  ',A6,'  MEAN SKYLINE HEIGHT ABOVE SITE
   X',F7.0,' FT  ', 'MEAN RANGE TO SKYLINE IS ',F10.0,' FT')
```

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