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FIRE: A DETERMINISTIC MODEL FOR ESTIMATING SURVIVABILITY THROUGH AREA SURFACE TO AIR MISSILE DEFENSES.

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Recent advances in sensor and guidance system technology coupled with projected improvements in cluster munitions appear to offer the possibility of delivering effective nonnuclear payloads to within a few meters of targets that are located hundreds of kilometers from the initial launch point. Using unmanned delivery systems in high attrition environments is particularly attractive since effective munitions delivery against high value, preprogrammed targets can be accomplished without exposing expensive aircraft to severe enemy air defenses. Because of the attractiveness of unmanned, deep strike missions, many standoff missile (SOM) and remotely piloted vehicle (RPV) concepts have been proposed by various DOD organizations and defense contractors. The Strike Options Comparison (SOC) Study was initiated by HQ AFSC/XR to provide insights into the development planning needs associated with long range munitions delivery. The SOC Study was structured with the intent of providing consistent and realistic cost/effective comparisons of various SOM and RPV concepts for accurately delivering munitions on targets as far as 650 kilometers beyond the forward-edge-of-the-battle-area (FEBA). As a benchmark, the capabilities of the F-111D in performing the deep strike mission were subjected to the same comparison analysis as the SOM and RPV conceptual systems.

The diverse characteristics of the strike options considered in the study presented a broad spectrum of survivability problems. One of the key analytical tasks in the SOC Study was to obtain consistent survivability estimates for the various deep strike delivery systems penetrating areas defended by surface-to-air missiles (SAM), airborne interceptors, and terminal defenses. In this report, a simplified methodology for estimating survivability of deep strike raids penetrating through SAM area defenses is described. A listing of a digital computer model which was developed to implement the methodology is provided in an appendix to the report. The material presented herein was carefully selected to avoid security classification and thus allow the methodology and model description to be distributed without undue hindrance. Classified data relating to survivability of SAM area defenses, as well as airborne interceptors, and terminal defenses are contained in DAS-TR-77-8, Strike Options Comparison (SOC) Study - Final Report, SECRET, publication pending.

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One of the recurrent problems associated with the analysis of competing airborne system concepts in a wartime environment is the determination of comparable estimates of attrition from surface-to-air-missiles (SAMs). The FIRE attrition model is a partial solution to this need. It provides attrition estimates of single vehicles or groups of vehicles flying straight and level through a corridor containing up to 10 types of SAMs. The geometric and temporal aspects of SAM/penetrator interactions are modeled in substantial detail. This requires

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a fairly detailed SAM model. The penetrator on the other hand is characterized simply by speed, altitude, and a single salvo P_k relative to each SAM type. The model allows heuristic modelling of the effects of decoys, chaff, and electronic countermeasures (ECM) as penetrator aids.

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INTRODUCTION

The probability of an airborne vehicle surviving a penetration of territory defended by hostile ground based weapons is dependent upon many factors. These factors may generally be thought of as influencing either the number of defenses encountered or the outcome of an encounter when it takes place. The analyst has the choice of modeling these factors either deterministically or stochastically. In the stochastic approach, the problem is usually modeled in elaborate detail, with the end result being the average of many trials (replications) based on "MONTE CARLO" random draws. A stochastic model is generally justified only if the nature of the statistical distributions describing the modeled random processes can be estimated and are believed to be important to the final answer. A deterministic (expected value) model, on the other hand, is based only on the statistical means of the distributions describing the random model processes. As a rule, expected value models require fewer and less detailed inputs than a stochastic model, and they produce many more results than a stochastic model per unit analyst time and per unit computer time. For these reasons, the deterministic approach is by far the superior of the two for situations involving inadequately defined systems or processes. Such situations are overwhelmingly pervasive in the authors' experience.

The FIRE survivability model, developed for use in the Strike Options Comparison (SOC) Study by the Directorate of Aerospace Studies, is a deterministic model. Its approach is straightforward: (1) determine, for the given conditions, the average probability of a penetrator in a raid surviving an encounter with a single site of each type of SAM (the average being taken with respect to penetrator offset relative to the site), then (2) determine the subsequent expected survivability of a member of the raid as a function of penetration distance (sites potentially encountered).

The model contains provisions for handling in varying detail the following aspects of the survivability problem relative to ground based defenses:

Penetration Scenario

- Corridor dimensions (the area containing the defenses)
- Penetration distance
- Distribution of defenses (up to 10 types of SAMs)

Raids of Penetrators

- Number of penetrators
- Two-dimensional distribution of penetrators
- Penetration altitude
- Penetration speed

Penetration Aid Effectiveness (heuristic)

- Decoys
- Chaff
- Electronic Countermeasures (ECM)

Defense Availability

- Terrain degradation of firing opportunities
- Reduction of number of defenders from previous suppression efforts
- Defense readiness (to exclude travel time, downtime, etc.)

Surface-to-Air Missile (SAM) Characteristics

- Launchers per site
- Missiles per launcher
- Launcher reload time
- Radar self-screening angle
- Maximum effective flyout range
- Average missile flyout speed
- Probability of kill
- Sensor height above ground
- Maximum sensor range
- Geometric missile launch restrictions
- Time from raid detection to first salvo
- Time interval between salvos
- Salvo reliability

The manner in which the previously mentioned factors are considered in the model will be discussed in section 2 with references to the associated input variables. The input technique and the input variables are discussed in section 3. The calculation of the penetrator survival probability is treated in section 4, while the calculation of the number of salvos fired at the raid for a given offset is explained in section 5. Two appendices conclude the report. Appendix A discusses the difficulties of modeling the effects of terrain masking relative to low altitude penetrators. Appendix B provides a well-commented FORTRAN listing of the model.

SECTION 2

MODEL DESCRIPTION

A. PENETRATION SCENARIO

The FIRE model uses the concept of a rectangular penetration corridor (CORDWTH, NDIST)[1] in which all SAM/penetrator interactions take place. Nominally the model corridor is associated with some real geographic area. The number, distribution, and capabilities of SAM defenses within the model corridor are based on an estimate of what is expected to be in the geographic area in the time frame of the study. In conjunction with the corridor concept a partitioned, discrete distribution of defenses is assumed. The area of the corridor behind the FEBA is divided into adjacent intervals each n kilometers deep (DEL), and the number of each type of SAM is specified for each interval (NSAML, NSAMH). Within a given interval locations are not specified but the SAMs are assumed to be randomly positioned in a direction parallel to the FEBA.

Two distinct sets of up to 10 SAM types may be defined in the model at any one time. Usually one set is defined as the "low altitude" defense; the other as the "high altitude" defense in the corridor. This aspect of the program is merely a convenience, for each set is identically treated in the program logic. Both sets could as well represent low or high altitude defenses (ILOW).

B. PENETRATOR RAIDS

Penetrators may fly singly or in groups (raids) of two or more (NPENT). The FIRE model allows only a single penetrator type to be considered in a given case. The survivability of a penetrator is very much dependent upon the size of the

1. Throughout this section, references to input identifiers are given to direct the reader to the appropriate input cards defining the aspect of the model under discussion. These identifiers and associated inputs are discussed in the following section. Not all identifiers are discussed in this section. The reader's attention is specifically directed to the "bookkeeping" identifiers TITLE, IPINT, ENDCASE, and ENDJOB as well as NPHI, TERIND, and XLAMBDA which are discussed in section 4 or 5.

group of which it is a part because of the dilution of the defenses. For example, a single penetrator receives all the fire from a SAM site; a penetrator in a group of 10 receives on the average about 1/10 of the fire. A raid may be started on the enemy side of the FEBA to simulate a raid of standoff weapons launched behind the FEBA (PSTART).

A raid composed of multiple penetrators must have dimension. Ideally, it should be structured in three dimensions. The FIRE model allows only for raid width (SP) perpendicular to the direction of flight and raid depth (TR) parallel to the direction of flight. The raid is assumed to be rectangular and to be contained in a plane parallel to the ground. The raid width affects the probability of encountering a SAM site; the depth affects the length of time the raid is exposed to fire from a site. Within the model, the dimensions of the rectangle are determined by the number of penetrators and the number of equally spaced columns and rows into which they are placed (PENC). The situation is depicted in figure 1. The penetrator speed (VP) affects the length of time a raid is exposed

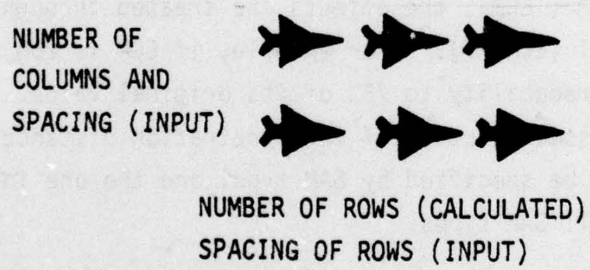

Figure 1. Raid Structure

to fire. This in turn affects the number of salvos which may be fired; hence, the probability of penetrator survival. Penetrator altitude (HM) also affects the time a raid is exposed to fire from a site. Reducing penetrator altitude has the effect of postponing the point of detection (see section 5); hence, reducing the exposure time of the penetrator to the defenses. The effect is more pronounced the lower the penetrator.

C. PENETRATION AIDS

Penetration aids can reduce the number of salvos fired and/or the effectiveness of salvos which are fired (PKH, PKL).

The accurate determination of the effectiveness of penetration aids is nearly an impossible task. Furthermore, in most comparative or parametric evaluations of survivability, the fundamental question concerns what may be gained from a penetration aid of some preselected effectiveness. The approach taken in FIRE is simply to allow the specification of effectiveness of the penetration aid over some selectable portion of the penetration. For example, it is possible to specify that chaff is used (ICHAFF) over some interval of the penetration (CHAFFS, CHAFFE), and that it is 25% effective in that interval (CHEFF) in that it reduces the number of effective SAM encounters to 75% of what they would be without chaff. Chaff effectiveness can be specified by SAM type, but the one interval which may be specified applies to all SAM types.

In the case of ECM (IECM), the effects are treated through a reduction of the SAM probability of kill (ECMEFF).[2] For example, if ECM is 25% effective, it reduces the single shot kill probability to 75% of its original value. As with chaff, ECM may be specified over some fraction of the penetration distance (ECMS, ECME). ECM effectiveness also can be specified by SAM type, and the one interval which may be specified applies to all SAM types.

The final penetration aid which is modeled is the decoy (IDECOY). Decoys are assumed to be perfect in the sense that the defense is as likely to fire at a decoy as at a lethal penetrator. Thus, their effect is to dilute the defenses as would additional penetrators. Decoys may be specified over some fraction of the penetration (DSTR, DEND). They do not enter into the calculation of the raid dimensions in the model. If it is desired to treat the decoys as expanding the

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2. Deceptive ECM will lower the P_k of a missile. Noise ECM will behave in a manner similar to chaff by reducing the number of effective SAM encounters or shortening the encounter by delaying burnthrough, thus reducing the number of salvos fired. This latter effect may be simulated by reducing the radar range or effective SAM range as deemed appropriate.

raid dimensions, the spacing given for the lethal penetrators may be increased appropriately. Only one type of decoy may be considered, although it may be used to decoy multiple SAM types as specified (PENCDEC, DECPPEN). Penetrators carrying decoys are attrited in proportion to their number.

D. SAM CHARACTERISTICS

The number of missile salvos which a SAM site can fire at a raid is determined primarily by the time the penetrators are exposed, the number of salvos available for firing, and the rapidity with which they can be launched. FIRE permits specifying many parameters affecting these areas.

The number of missiles per launcher (NML) and the number of launchers per site (ISET, ISETL) are specified as well as the number of missiles constituting a salvo (SALSZ). Additionally, the time from penetrator detection to firing the initial salvo, the subsequent time between salvos (ISET, ISETL),[3] and the launcher reload time (SRLD) are specified. Clearly the flyout time of the missile salvo is also important. Missile flyout time is calculated in FIRE on the basis that the missile always flies to the intercept point in a straight line at constant speed (ISET, ISETL). Although this is an unsophisticated model, it is generally adequate. Suppose, for example, a high altitude intercept takes place at 20 km from the site and that the actual flyout time is 40 sec (true average straight line speed of 500 m/sec). If the average estimated speed used in the model were 600 m/sec, the model flyout time would be about 33 seconds -- a 7 second error. Such an error is relatively unimportant when considered with uncertainties in firing doctrine, time between salvos, terrain masking, site availability, etc.

The SAM sensor as modeled in FIRE is specified by three parameters -- sensor height above ground, maximum sensor range (ISET, ISETL), and sensor self-screening angle (ALPHA). The self-screening angle describes how close to the terrain the

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3. The time between salvos is the time from "intercept" by one salvo to the launching of the next. When multiple missile salvos are fired, there is an interval between the individual missile launches. FIRE does not explicitly model this interval, but it may be allowed for by adjusting the time between salvos.

radar may look. It may also be used to impose a constant masking angle about the sensor. For low altitude penetrators, this angle usually determines the radar detection range; hence, the exposure duration of a penetrator to the SAM. The geometry of the situation is discussed and illustrated in section 5. The effect of sensor height is also treated in section 5.

Initially terrain was brought into the problem through a probability that terrain masking does not prevent a SAM from firing (what might be called the "probability of favorable terrain") (ISET, ISETL). The probabilities were taken from work done for the SOC Study by Dr. Charles C. Carson of Sandia Laboratories.[4] Later consideration of the terrain problem resulted in an improved method for treating terrain with the FIRE model.

The new methodology uses a weighted average masking angle and sets to unity P_t, the probability of favorable terrain.[5] This implies the availability of a probability distribution of masking angles, but calculation of meaningful P_t's has the same implication. The calculation of a weighted average masking angle may be made in several ways. The most straightforward method simply uses the probabilities of occurrence of various masking angles as the weights. Another way involves the computation of the expected number of shots per site as a function of constant masking angle and the subsequent determination of the masking angle corresponding to the weighted average of expected number of shots.

Each SAM type in FIRE is modeled as being able to fire at penetrators within a cylinder (ISET, ISETL) whose axis passes through the site perpendicular to the earth. A smaller coaxial cylinder defines a "dead zone" (ISET, ISETL) within which penetrators are safe from intercept. The dead zone arises primarily from launcher elevation limitations and warhead fuzing delays.

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4. Taken from a classified report.

5. During the course of the SOC Study, the only masking angle used was the sensor self-masking angle.

The model allows the first salvo to be fired a specified time after the penetrator enters site sensor coverage (ISET, ISETL). Sensor coverage for radar guided SAMs is modeled as a hemisphere. It can be modeled differently for IR SAMs to account for the fact that much of the IR signal may be masked as a penetrator approaches the site. This has been handled by allowing detection to occur only when the azimuth angle of the site as seen from the penetration reaches some predetermined value between 0 and 90 degrees (ASPECT). The situation is depicted in figure 2.

Radar guided SAMs are restricted in the model from launching at the penetrator after the penetrator has passed the site. The IR SAMs are not subject to this restriction. (The differentiation between radar guidance and IR guidance was made after the SOC Study.)

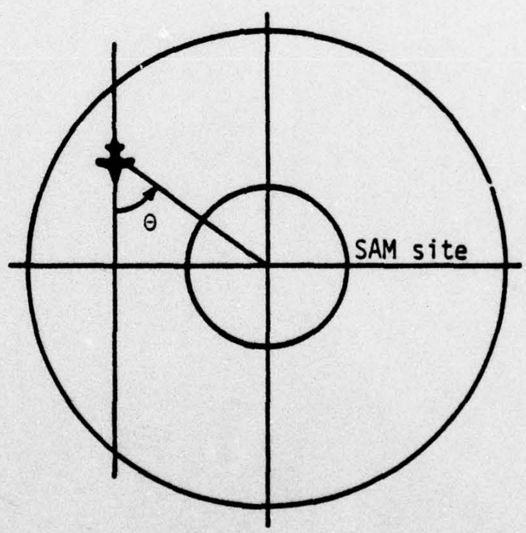

Figure 2. The Definition of the Input Parameter ASPECT

E. AVAILABILITY OF DEFENSES

Defenses in the field are available only a percentage of the time. They are subject to downtime for mechanical and electronic problems, they may be in transit, or their crews may not be capable of responding in time for various reasons. The FIRE model allows for a "readiness factor" which is the probability a defense site is available (ISET, ISETL).[6] It is also possible to specify the probability that a launcher at a site is ready (PLCHRDY) and the reliability of a salvo (ROS). Salvo reliability is a multiplier of missile salvo P_k.

In addition to the readiness factors, FIRE allows the availability of each SAM type to be decreased by an arbitrary factor (DF). This allows the analyst, for example, to simulate some level of defense suppression for the various SAMs without having to explicitly respecify their distribution.

It is important to note that the model has no altitude or speed restrictions by which SAM types are judged ineligible to fire at a raid. SAM types which cannot fire at a raid for either of these reasons should not be input.

6. The readiness factors used in the SOC Study were adopted from a classified reference.

SECTION 3

INPUT

The input routine for FIRE is based on a concept first adopted by the authors in 1965. This concept, which identifies individual input variables and groups of variables by an alphanumeric identifier, provides the user with (1) a printed record of all inputs, (2) no requirement for ordering inputs (except when two or more cards are associated with an identifier), (3) variation of the initial data set by inputing only the changes (simplifies stacking cases), and (4) a check of all identifiers against a dictionary of allowed identifiers, thus helping to minimize input errors.

An identifier card always contains the identifier left justified in column 1. Any remaining fields on the card may contain data. The field structure can vary with the program; FIRE using the format A7, 3X, E20.8.[8] The identifier is checked for validity, and if valid, it is used as a signal to the program describing what information is on the card and/or what associated cards should follow. All cards read are displayed in the output. Invalid identifiers, should any be found, are indicated and the program is halted after checking the rest of the input for that case.

There follows a list of identifiers used in FIRE. Their functions are described through a discussion of the input parameters associated with them. Parameter default values are given when appropriate.

ALPHA Indicates that the i-th field of the following card contains the radar self-screening angle for SAM type i which specifies how close to the terrain the radar can operate (default 0.5 degrees). This angle can also be used to simulate a constant masking angle. Following card has a 10F8.0 format.

8. A useful format in many instances is A10, 2I5, 6F10.0. The integer fields may be used for integer input or for indices of arrays.

ASPECT	Defines the forward hemisphere angular tracking capability of SAM sensors (see figure 2, section 2). The default is zero which corresponds to the standard situation for radar.
CHAFFE	Indicates the penetrator distance in kilometers from the FEBA at which the chaff effectiveness modeling ends.
CHAFFS	Indicates the penetration distance in kilometers from the FEBA at which the chaff effectiveness modeling begins.
CHEFF	Indicates that the i-th field of the following card contains the chaff effectiveness for SAM type i. A value of zero indicates that the chaff is completely effective. A value of one indicates no effectiveness. This parameter is a multiplier of the probability of encountering a site. Format of following card is 10F8.0.
CORWDTH	Indicates that the first field of the next card specifies the corridor width for the "low altitude" SAMs, the second field for the "high altitude" SAMs (format 2F8.0).
DECPPEN	Indicates that the i-th field of the following card contains the number of perfect decoys, N, relative to SAM type i carried per decoy-carrying penetrator. Entries should be either zero or N as only one type decoy is permitted. Following card has a 10F8.0 format.
DEL	The depth in kilometers of the intervals specifying the positions of the defenses (default 10).
DEND	Indicates the penetration distance in kilometers from the FEBA at which the decoy effectiveness modeling ends.
DF	Indicates that the i-th field of the next card contains a multiplier of the availability of SAM type i. The multiplier represents the probability a SAM site has been suppressed. The format of the following card is 10F8.0. (Default 1.0.)

DSTR Indicates the penetration distance in kilometers from the FEBA at which the decoy effectiveness modeling begins.

ECME Indicates the penetration distance in kilometers from the FEBA at which the ECM effectiveness modeling ends.

ECMEFF Indicates that the i-th field of the following card contains the ECM effectiveness for SAM type i. A value of zero indicates that the ECM is completely effective. A value of one indicates no effectiveness. This parameter is a multiplier of the single shot P_k (not the salvo P_k which is input). Format of following card is 10F8.0.

ECMS Indicates the penetration distance in kilometers from the FEBA at which the ECM effectiveness modeling begins.

ENDCASE Signifies the end of input for the case in question.

ENDJOB Signifies the end of a run. The ENDJOB card does not perform the function of ENDCASE card.

HM The altitude of the penetrator above the ground measured in kilometers.

ICHAFF A value of unity indicates that chaff effectiveness will be modeled for the present case. A value of zero indicates otherwise (default zero).

IDECOY A value of unity indicates that decoy effectiveness will be modeled for the present case. A value of zero indicates otherwise (default zero).

IECM A value of unity indicates that ECM effectiveness will be modeled for the present case. A value of zero indicates otherwise (default zero).

ILOW For a value of unity, SAM parameters representing SAM characteristics against "low altitude" penetrators are chosen. For a value of zero SAM characteristics against "high altitude" penetrators are selected (default zero).

IPINT A variable controlling output. The survivability output is given for every IPINT times DEL kilometers where DEL is the depth of the corridor intervals (default five).

ISET Indicates that the following card will specify for which high altitude SAMs data are to be read, and that the cards following that will contain the SAM data. The format for the card following the ISET card is 10I1. A "0" in column i indicates no data for SAM type i are to be read, a "1" indicates that data are to be read. The cards following this card (one card for each "1" and ordered by SAM type i) specify by field

(1) SAM type i
(2) Number of launchers per site
(3) Probability that type i SAM site is ready to fire if called upon
(4) Probability of "favorable terrain"
(5) Time from first possible detection of raid to firing first salvo (seconds)
(6) Time between salvos (seconds)
(7) Maximum useful missile flyout range (km)
(8) Average missile flyout velocity (km/sec)
(9) Radius of dead zone (km)
(10) Maximum sensor range (km)
(11) Height of sensor above ground (km)

The format is I2, I3, 3X, 8F8.2, F8.3.

ISETL This identifier and its attendant cards are similar to ISET and its associated cards. They describe SAM characteristics against low altitude penetrators.

NDIST The number of points spaced DEL kilometers apart (where DEL is the depth of the corridor intervals) at which survival probability is to be calculated. NDIST may be regarded as specifying corridor depth or alternately maximum penetration distance (default 65).

NML Indicates that the i-th field of the following card contains the number of missiles per launcher for SAM type i. The following card has a 10F8.0 format.

NPENT The number of penetrator raid sizes to be considered (1-10). The following card (format 10I5) gives the respective raid sizes.

NPHI The number of penetrator offsets considered in calculating the probability of survival of a penetrator encountering a SAM site. Default is 19.

NSAMH Defines the high altitude SAM type for which the following cards contain the number of SAMs per specified n kilometer interval (see DEL). The first card following gives the number of intervals (N) which are to be specified (format I5). The remaining N cards give the number of the interval (1 = 0-n km, 2 = n-2n km, etc.) and the corresponding number of SAMs, one interval per card (format 2I5).

NSAML This identifier and its attendant cards are similar to NSAMH and its associated cards. They describe the distribution of SAMs effective against low altitude penetrators.

PENC The number of penetrator columns to be formed from the penetrators. A column extends parallel to the direction of flight.

PENCDEC The number of penetrators carrying decoys. Penetrators carrying decoys do not penetrate further after releasing their decoys.

PKH — Indicates that the i-th field of the following card gives the salvo P_k's for SAM type i against the "high altitude" penetrator type under consideration. The following card has the format 10F8.0.

PKL — Similar to PKH except that it gives the salvo P_k's for "low altitude" penetrators.

PLCHRDY — Indicates that the i-th field of the following card contains the probability of a launcher of a type i SAM being ready at the time the raid passes (default 1). Format of following card is 10F8.0.

PSTART — Allows the starting of a raid at any of several distances past the FEBA. The value should correspond to an integral multiple of the interval depth DEL (default zero).

ROS — Indicates that the i-th field of the following card contains the reliability of a salvo of an i-th type SAM (default 1.0). Format of following card is 10F8.0.

SALSZ — Indicates that the i-th field of the following card gives the number of missiles in a salvo of SAM type i (default two). The following card has the format 10F8.0.

SP — The spacing between columns of penetrators measured in kilometers.

SRLD — Indicates that the i-th field of the next card specifies the launcher reload time for SAM type i (in seconds). Format of following card is 10F8.0.

TERIND — Indicates that the i-th field of the following card specifies for SAM type i whether all launchers at a site are affected independently by terrain effects (= 1.0) or whether they are affected as a group (=0) (see section 4). Following card has a 10F8.0 format.

TITLE	Indicates that the case title is given on the following card. The format of the following card is 10A8.
TR	The spacing between rows of penetrators measured in seconds. A row extends perpendicular to the direction of flight.
VP	The velocity of the penetrators measured in kilometers/sec.

SECTION 4

CALCULATION OF PENETRATOR PROBABILITY OF SURVIVAL

There are many possible models for determining the survival probability of a given penetrator of a raid which is attacked by a SAM site. The differences are reducible to the assumptions on which the models are based. The FIRE model contains the following assumptions:

1. A SAM site consists of one or more launchers, all of whose missiles are pooled for the purpose of determining the number of salvos available to the site.

2. The SAM site uses a shoot-look-shoot firing doctrine against a raid of penetrators until all salvos have been fired or the raid leaves SAM coverage.

3. The salvos of a site are uniformly distributed over the members of the raid.

4. Launchers are in close proximity, allowing the site to be treated as a point when determining the lethal envelope.

5. The terrain effects (as manifested by the "probability of favorable terrain") may apply independently to each launcher or apply to the site as a whole. These two cases will be called "terrain independent" and "terrain dependent," respectively. Formulations for both cases will be derived.

The initial formulation will develop the technique for calculating the expected probability of survival of a penetrator which encounters an available SAM site. This average will be calculated with respect to the offset from the site at which the raid passes the site.[9] Penetrators are assumed to fly straight

9. The center of the raid is used to determine the value of the offset. Although not demonstrated here, the raid width can be shown to be of little importance in the final result.

and level at constant speed throughout the encounter. The expected value is approximated by considering a number of evenly spaced discrete offsets beginning with site overflight (zero offset) and progressing to the extreme of the nominal SAM effective radius, R_e. These offsets will be designated O_0, O_1, ..., O_K, respectively. There are actually two offsets designated by O_1, O_2, ..., O_K; one on either side of the site. Thus the average survival probability is calculated relative to 2K + 1 offsets, each of which represents the survival probability of the raid penetrating in an interval of offset centered on some O_i and $\frac{2R_e}{2K+1}$ km wide. The probability of the raid being in the interval represented by offset O_i is

$$\frac{1}{2K+1} \qquad \text{for} \qquad i = 0$$

$$\frac{2}{2K+1} \qquad \text{for} \qquad i = 1, \ldots, K \quad .$$

For SAM type i, let

N ≡ number of penetrators in the original raid

P_j ≡ probability a given penetrator in the raid has survived to encounter the site, i.e., has survived through the previous (j - 1) intervals

SR_i ≡ salvo reliability

PK_i ≡ SAM salvo P_K

PLR_i ≡ probability that a given launcher at the site is ready

PT_i ≡ probability of favorable terrain for terrain dependent case

$\overline{PT}_i$ ≡ probability of favorable terrain for terrain independent case

NL_i ≡ number of launchers at the site

$S_{i,n,k}$ ≡ the number of salvos that a site with exactly n launchers available (ready) can fire at a raid with offset O_k

The probability of having exactly n of NL launchers at a site available is given by the binominal theorem as

$$P(n) = \binom{NL_i}{n} PLR_i^n (1 - PLR_i)^{NL_i - n}$$

$$= \frac{(NL_i)!}{n!(NL_i - n)!} PLR_i^n (1 - PLR_i)^{NL_i - n} \quad (1)$$

The probability of survival of a given penetrator of a raid with offset O_k may then be written

$$PS\{O_k\} = \sum_{n=0}^{NL_i} P(n)(1 - PK_i)^{(S_{i,n,k}SR_i)/NP_j} \quad (2)$$

for $(S_{i,n,k}SR_i)/NP_j \geq 1$, or

$$PS\{O_k\} = \sum_{n=0}^{NL_i} P(n)(1 - PK_i S_{i,n,k}SR_i/NP_j) \quad (3)$$

for $(S_{i,n,k}SR_i)/NP_j < 1$. Here NP_j is the number of penetrators surviving and is taken as the maximum of NP_j and 1 (it does not make sense to consider less than one penetrator). The determination of $S_{i,n,k}$ is discussed in section 5. It is calculated for each offset, for each possible number of available launchers n, n = 0, ..., NL_i. Since $S_{i,0,k} \equiv 0$, equations 2 and 3 may be rewritten as

$$PS\{O_k\} = P(0) + \sum_{n=1}^{NL_i} P(n)(1 - PK_i)^{(S_{i,n,k}SR_i)/NP_j} \quad (4)$$

and

$$PS\{0_k\} = P(0) + \sum_{n=1}^{NL_i} P(n)(1 - PK_i S_{i,n,k} SR_i / NP_j) \quad , \qquad (5)$$

respectively.

The probability of a given penetrator surviving an encounter over all possible offsets is then simply

$$PS\{E_i,A_i,T_i\} = \frac{1}{2K+1} PS\{0_0\} + \frac{2}{2K+1} \sum_{k=1}^{K} PS\{0_k\} \qquad (6)$$

where the notation $\{E_i,A_i,T_i\}$ simply is intended as a reminder that site encounter and availability have been assumed for a type i SAM site, as has favorable terrain.

The assumption of favorable terrain is removed in one of two ways, depending upon whether the terrain dependent or terrain independent case applies. Probability of survival for the terrain dependent case becomes

$$PS\{E_i, A_i\} = 1 - PT_i(1 - PS\{E_i, A_i, T_i\}) \qquad (7)$$

For the independent case, equation (6) still applies if PLR_i in equation 1 is replaced by $(PLR_i * \overline{PT}_i)$, i.e.,

$$PS\{E_i,A_i\} = \frac{1}{2K+1} PS\{0_0\} + \frac{2}{2K+1} \sum_{k=1}^{K} PS\{0_k\} \qquad (8)$$

Introducing the probability of the site being available, PSA_i, i.e., determining the conditional probability that a penetrator survives a site given encounter, $PS\{E_i\}$, gives

$$PS\{E_i\} = (1 - PSA_i) + PSA_i \times PS\{E_i, A_i\} \quad (9)$$

Removing the final condition to produce the probability of survival relative to a site of SAM type i, PS_i, gives

$$PS_i = (1 - PE_i) + PE_i \times PS\{E_i\} \quad (10)$$

where PE_i is the probability of encountering the site.

In the FIRE model PE_i is taken as

$$2(R_s + R_w)/C_w$$

where C_w = corridor width

R_w = raid width

R_s = SAM effective radius as determined by calculation ($R_s \leq R_e$, the nominal effective radius of the SAM when not subjected to sensor masking, etc.)

For NS_{ij} sites of SAM type i in the j-th interval

$$PS_i(NS_{ij}) = [(1 - PE_i) + PE_i \times PSS_{ij}\{E_i\}]^{NS_{ij}} \quad (11)$$

The product of the $PS_i(NS_{ij})$ over all SAM types and over all traversed intervals gives the overall probability of survival.

$$PS = \prod_j \prod_i PS_i(NS_{ij})$$

When decoys are present the number of penetrators becomes $NP_j + N_d P_{dj}$, where N_d is the number of decoys released and P_{dj} is their subsequent probability of survival through the (j - 1)st interval. Since decoys may be released after the penetrators carrying the decoys have been subjected to attrition, N_d is given by

$$N_c P_j D_p$$

where N_c is the number of penetrators carrying decoys and D_p represents the number of decoys carried per decoy-carrying penetrator.

SECTION 5

EXPECTED NUMBER OF SALVOS PER SAM ENCOUNTER

A. INTRODUCTION

Integral to the calculation of the survivability of a penetrator in a raid as discussed in section 4 is the determination of the number of salvos that may be fired at a raid for a SAM encounter at a given offset. This section addresses itself to that problem. Even considering the several simplifying assumptions used here, the discussion is somewhat complicated as it involves both spacial and temporal relationships. It has been divided into five distinct parts: (1) statement of the problem, (2) the effect of masking angle on initial detection of the penetrator, (3) determination of the point of first possible intercept, (4) determination of the point of last possible intercept, and (5) weighting and averaging the results.

B. STATEMENT OF THE PROBLEM

Given a SAM site as described in section 2 and subject to a constant masking angle, approximate the number of salvos such a site could fire at a penetrating raid for a given offset from the site.

C. THE EFFECT OF MASKING ANGLE ON INITIAL PENETRATOR DETECTION

Consider the case of a direct overflight of a SAM by a penetrator at altitude h. The situation is depicted in figure 3 for identical front and rear masking angles.[10] The angles η and ϕ represent the radar self-masking angle and terrain masking angle, respectively. The penetrator will be detected at a ground range of α in front of the site and disappear at a ground range of α behind the site. The SAM must track and fire while the penetrator is visible.[11]

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10. Assumption of constant masking angle is part of the statement of the problem.

11. For the radar guided SAMs, the intercept must take place before the penetrator leaves sensor coverage. For IR SAMs, only launch must take place before the penetrator leaves coverage as the IR missile is autonomous after launch.

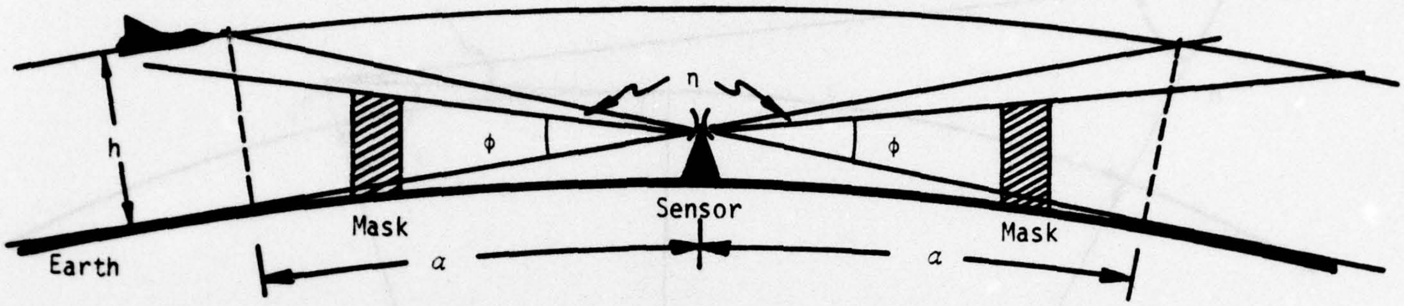

Figure 3. Masking Angle and Detection Range. The geometry of the masking scenario of the FIRE model is shown in a plane containing the center of the Earth, the SAM sensor, and the penetrator. The penetrator is unmasked at an uprange distance a from the site and disappears at a downrange. Clearly, relocating the positions of the masks or changing the sensor height will affect the value of a.

The distance a can be determined from the situation depicted in figure 4. As in figure 3, h is the altitude of the penetrator. α represents the total masking angle (self-masking plus terrain) and h_r is the height of the sensor. In order to allow for refraction of the radar signals by the Earth's atmosphere, the radius of the Earth is taken to be that of an earth 4/3 the size of the actual Earth. This decreases the curvature of the Earth.[12]

It is necessary to find the range, r, at which the penetrator emerges from the mask. We have

$$\sin \beta = \frac{R_e}{R_e + h_r} \quad \text{and} \quad \beta = \arcsin\left(\frac{R_e}{R_e + h_r}\right)$$

whence from the sine formula γ can be determined

$$\frac{\sin(\alpha + \beta)}{R_e + h} = \frac{\sin\gamma}{R_e + h_r}$$

12. This approximation is really of no consequence to the FIRE model's results because relatively short ranges are involved at low altitude between the sensor and penetrator.

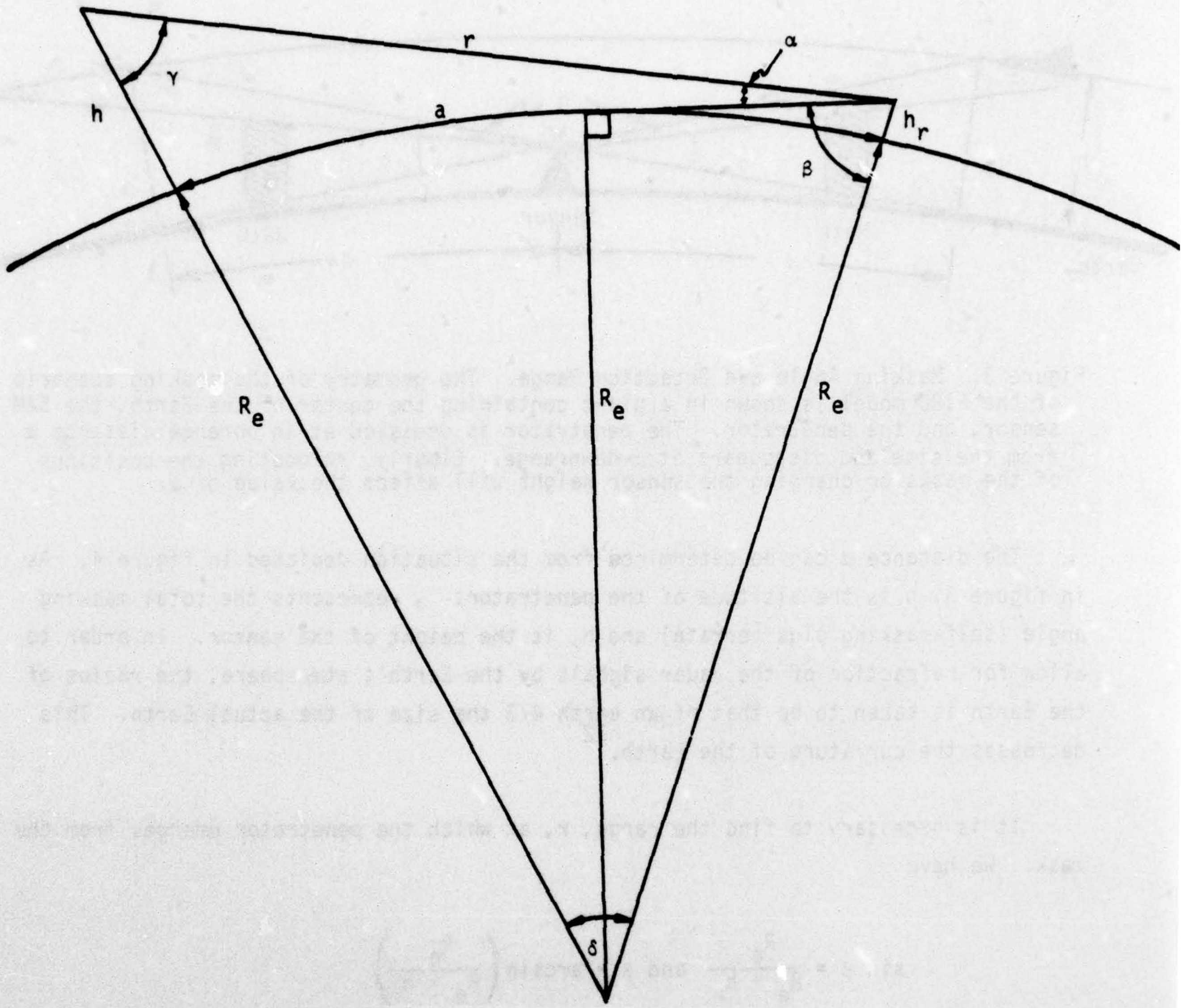

Figure 4. Geometry for Computing Detection Range. The geometry for determining the detection range r of a penetrator (height h) at the apex of angle γ by a sensor at the apex of angle β (h_r above ground) is shown. The masking angle α is the sum of self-masking and terrain masking. R_e is the radius of the Earth. For practical cases, a and r are very nearly equal.

Again, using the sine formula

$$\frac{\sin(\alpha + \beta)}{R_e + h} = \frac{\sin(\pi - \gamma - \alpha - \beta)}{r} = \frac{\sin\delta}{r}$$

or

$$r = \frac{(R_e + h)\sin\delta}{\sin(\alpha + \beta)} \qquad \text{(detection slant range)}$$

And finally,

$$a \simeq r \cos\alpha \qquad \text{(detection ground range)}$$

This result is also valid for flight paths with nonzero offsets. Thus, for a constant masking angle, the initial detection will always take place on the circumference of a circle, the radius of that circle being determined by the masking angle or the radar range if masking is not a factor.

The assumption of a constant mask angle is a substantial approximation. The general problem of terrain masking is discussed in appendix A.

D. THE DETERMINATION OF THE POINT OF FIRST POSSIBLE INTERCEPT

Let the SAM site be located at the origin of a right-handed x, y, z coordinate system whose x- and y-axes are perpendicular to a radius vector from the center of the Earth to the site. Then the z-axis is coincident with the radius vector. The lethal envelope of the SAM site is modeled as a cylinder of radius r_e whose axis coincides with the + z-axis. Coaxial with the lethal envelope is a smaller cylinder of radius r_d in which intercepts may not take place. This volume is referred to as the dead zone. The sensor coverage is modeled as spherical with an effective radius r_r which is determined by the range of the penetrator at the first detectable signal. This point is determined either by emergence from masking or by the initial point of radar burnthrough when the signal to noise ratio first permits detection.[13] A penetrator, flying straight and level, enters the radar and SAM coverage at altitude h as illustrated in figure 5.

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13. Designated in FIRE by the sensor range (see descriptor ISET). This discussion describes explicitly the situation for the radar, but is applicable with obvious modification to the IR sensor case.

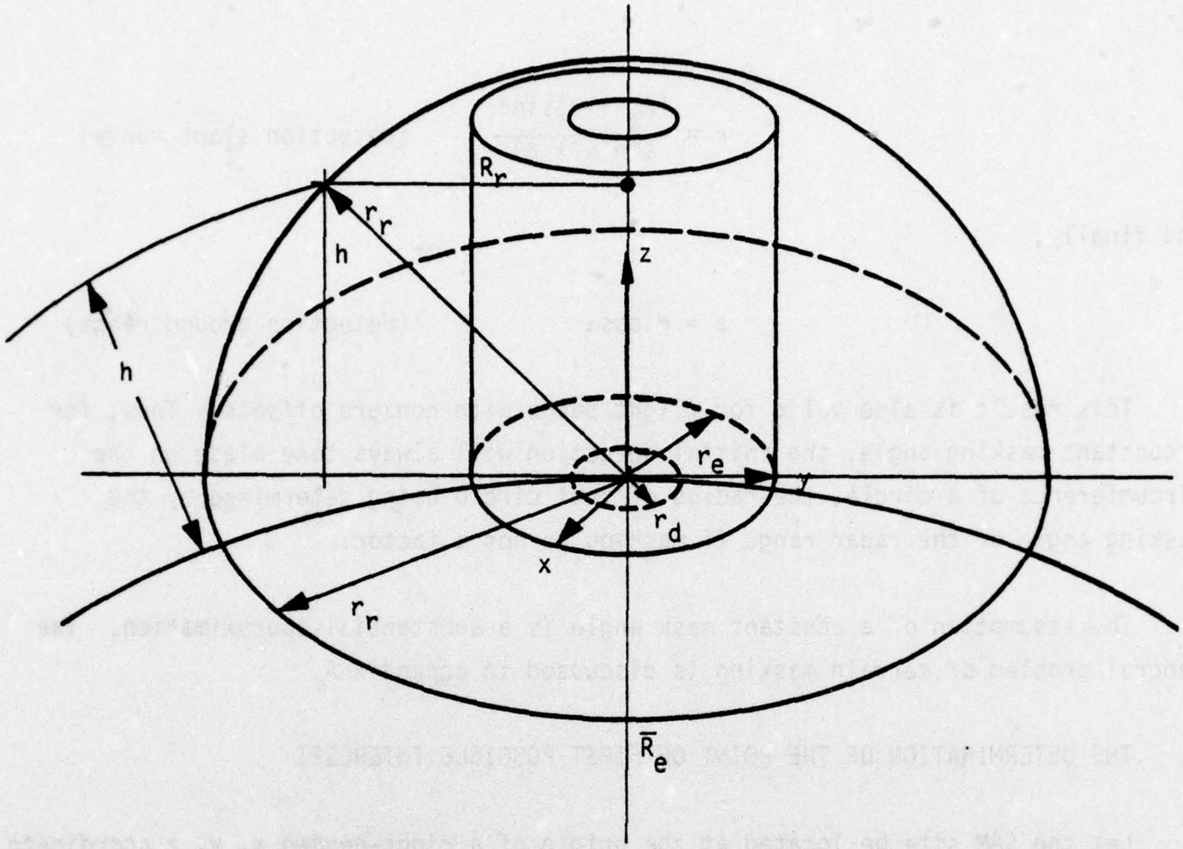

Figure 5. SAM Lethal Cylinder and Spherical Radar Coverage

Since the model is constrained to considering penetrators flying straight and level, the boundaries displayed by a cross section of the cylinder (representing the SAM lethal envelope) and the hemisphere (representing radar range) at the penetrator altitude, h, are of primary interest. Figure 6 represents these boundaries as seen looking down at the + z-axis at a cross section taken perpendicular to the z-axis at altitude h. The radar range relative to the SAM lethal cylinder in this projection is given by $R_r = (r_r^2 - h^2)^{\frac{1}{2}}$.

The situation normally expected is the one presented in figure 6(a) in which the horizontal component of the radar coverage at altitude h exceeds the lethal range of the SAM. However, the situation shown by figure 6(b) in which r_e exceeds R_r could result from radar jamming, small penetrator cross section, or masking of the penetrator.

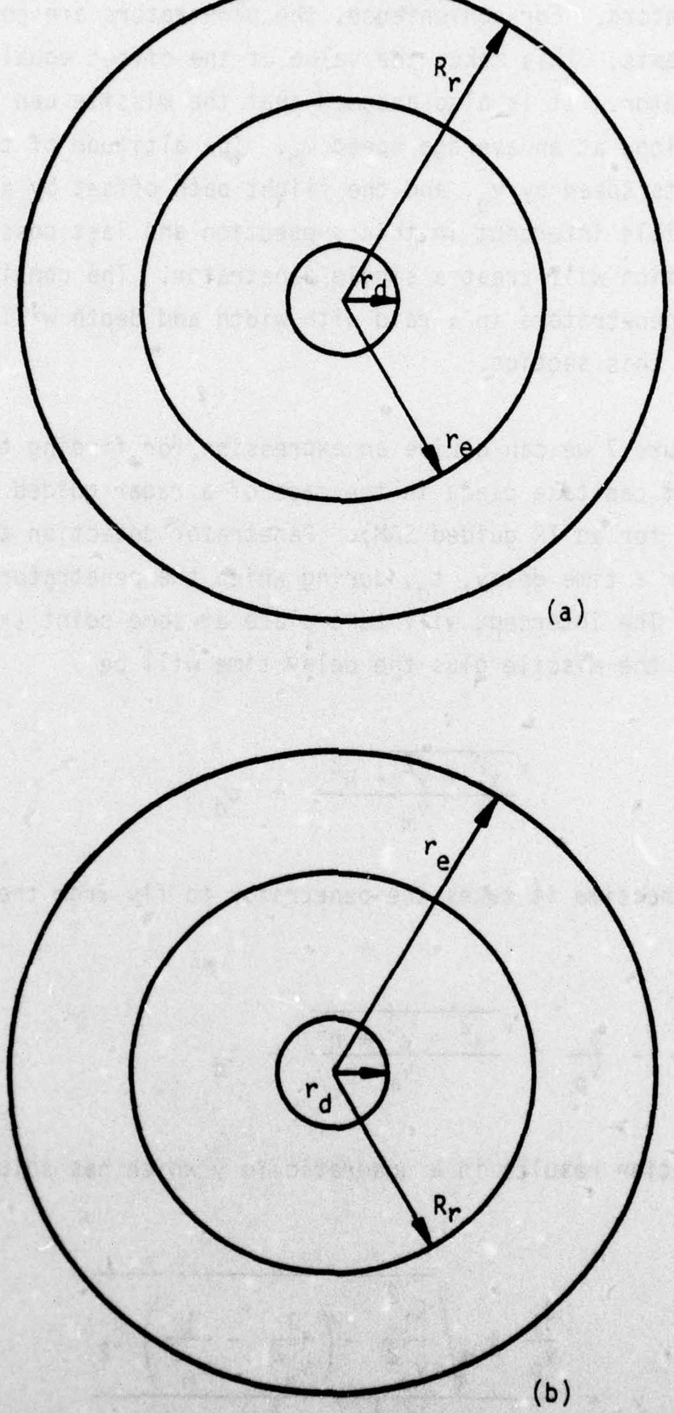

Figure 6. Cross Section of Radar Coverage and SAM Lethal Envelope at Altitude h.

The relationship of time and geometry will determine the interaction of the SAM and the penetrators. For convenience, the penetrators are considered to fly parallel to the y-axis. This makes the value of the offset equal to the x coordinate of the penetrator. It is also assumed that the missile can reach any point in the lethal envelope at an average speed v_m. The altitude of the penetrator is designated by h, its speed by v_p, and the flight path offset by x. The derivation of first possible intercept in this subsection and last possible intercept in the next subsection will treat a single penetrator. The considerations introduced by multiple penetrators in a raid with width and depth will be discussed in subsection E of this section.

Examining figure 7 we can derive an expression for finding the point at which the first intercept can take place in the case of a radar guided SAM (the technique is identical for an IR guided SAM). Penetrator detection takes place at distance R_r. After a time delay, t_d, during which the penetrator flies $t_d v_p$, the missile is fired. The intercept will take place at some point (x, y, z) so that the flight time of the missile plus the delay time will be

$$\frac{\sqrt{x^2 + y^2 + h^2}}{v_m} + t_d$$

which must equal the time it takes the penetrator to fly from the detection point to (x, y) or

$$\frac{\sqrt{R_r^2 - x^2}}{v_p} - \frac{y}{v_p} = \frac{\sqrt{x^2 + y^2 + h^2}}{v_m} + t_d \qquad (1)$$

Squaring this equation results in a quadratic in y which has solutions

$$y = \frac{\frac{C_1}{v_p} \pm \sqrt{\frac{C_1^2}{v_p^2} - \left(\frac{1}{v_p^2} - \frac{1}{v_m^2}\right) C_2}}{\left(\frac{1}{v_p^2} \quad \frac{1}{v_m^2}\right)}$$

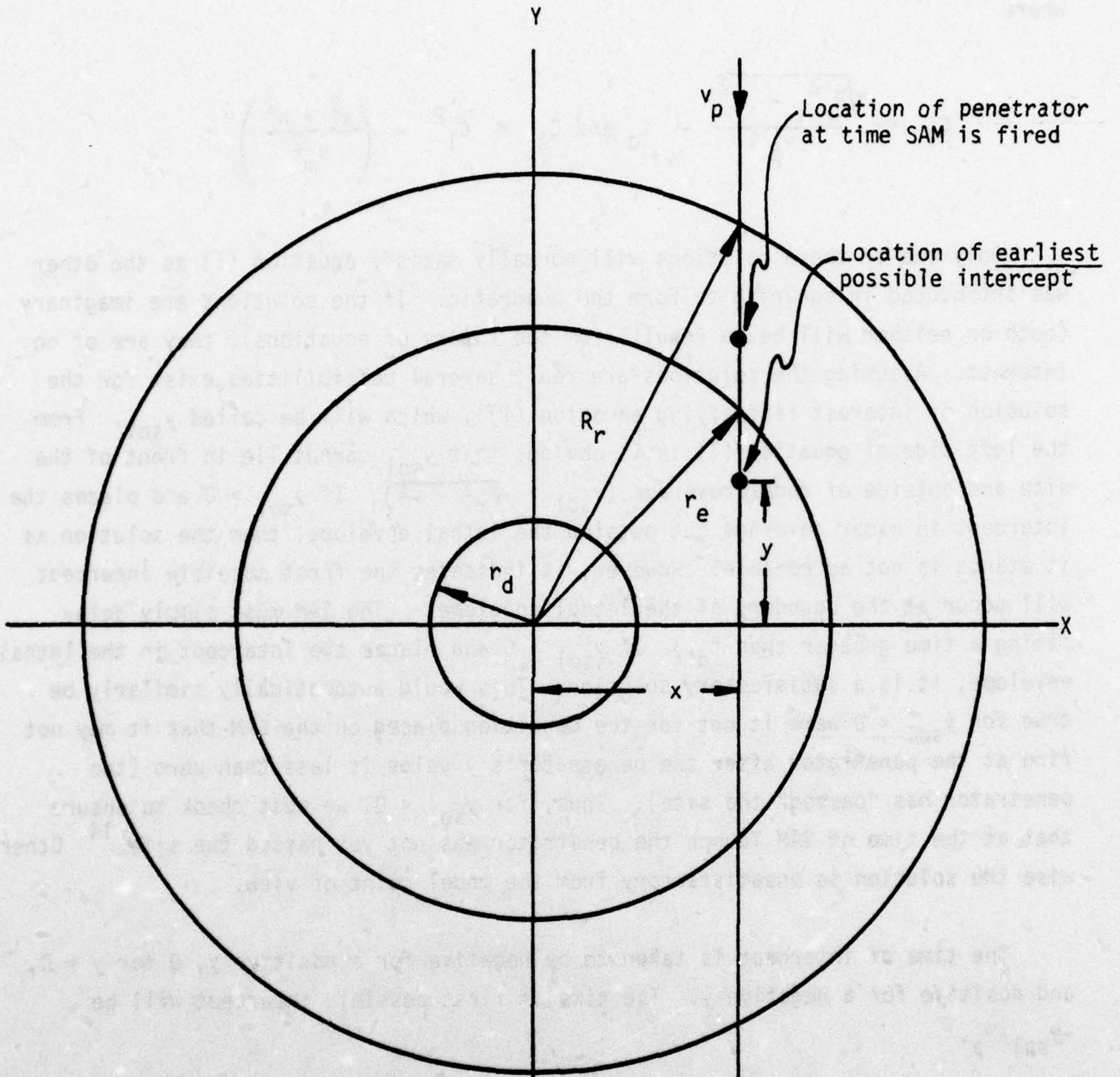

Figure 7. The Geometry For Determining The Position of Earliest Possible Intercept. The SAM which is located at the origin of the coordinate system is being approached by a penetrator with velocity v_p and offset x. The circles represent the SAM dead zone (r_d), SAM effective radius (r_e), and sensor range (R_r).

where

$$C_1 = \frac{\sqrt{R_r^2 - x^2}}{v_p} - t_d \text{ and } C_2 = C_1^2 - \left(\frac{x^2 + h^2}{v_m^2}\right)$$

Only one of these solutions will normally satisfy equation (1) as the other was introduced in squaring to form the quadratic. If the solutions are imaginary (both or neither will be, a result from the theory of equations), they are of no interest. Assuming the solutions are real, several possibilities exist for the solution of interest (satisfying equation (1)), which will be called y_{sol}. From the left side of equation (1) is it obvious that y_{sol} cannot lie in front of the site and outside of radar coverage ($y_{sol} > \sqrt{R_r^2 - x^2}$). If $y_{sol} > 0$ and places the intercept in radar coverage but outside the lethal envelope, then the solution as it stands is not acceptable. However, it indicates the first possible intercept will occur at the boundary of the lethal envelope. (The SAM must simply delay firing a time greater than t_d.) If $y_{sol} \geq 0$ and places the intercept in the lethal envelope, it is a satisfactory solution. This would automatically similarly be true for $y_{sol} < 0$ were it not for the condition placed on the SAM that it may not fire at the penetrator after the penetrator's y value is less than zero (the penetrator has "passed" the site). Thus, for $y_{sol} < 0$, we must check to ensure that at the time of SAM launch the penetrator has not yet passed the site.[14] Otherwise the solution is unsatisfactory from the model point of view.

The time of intercept is taken to be negative for a positive y, 0 for y = 0, and positive for a negative y. The time of first possible intercept will be $-y_{sol}/v_p$.

E. THE DETERMINATION OF THE POSITION AND TIME OF LAST POSSIBLE INTERCEPT

Consider the schematic representation of a SAM site's coverage and a penetrator flight path as shown in figure 8. The point P_f represents the position of

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14. This restriction is not imposed on IR SAMs which may fire until the raid leaves sensor coverage.

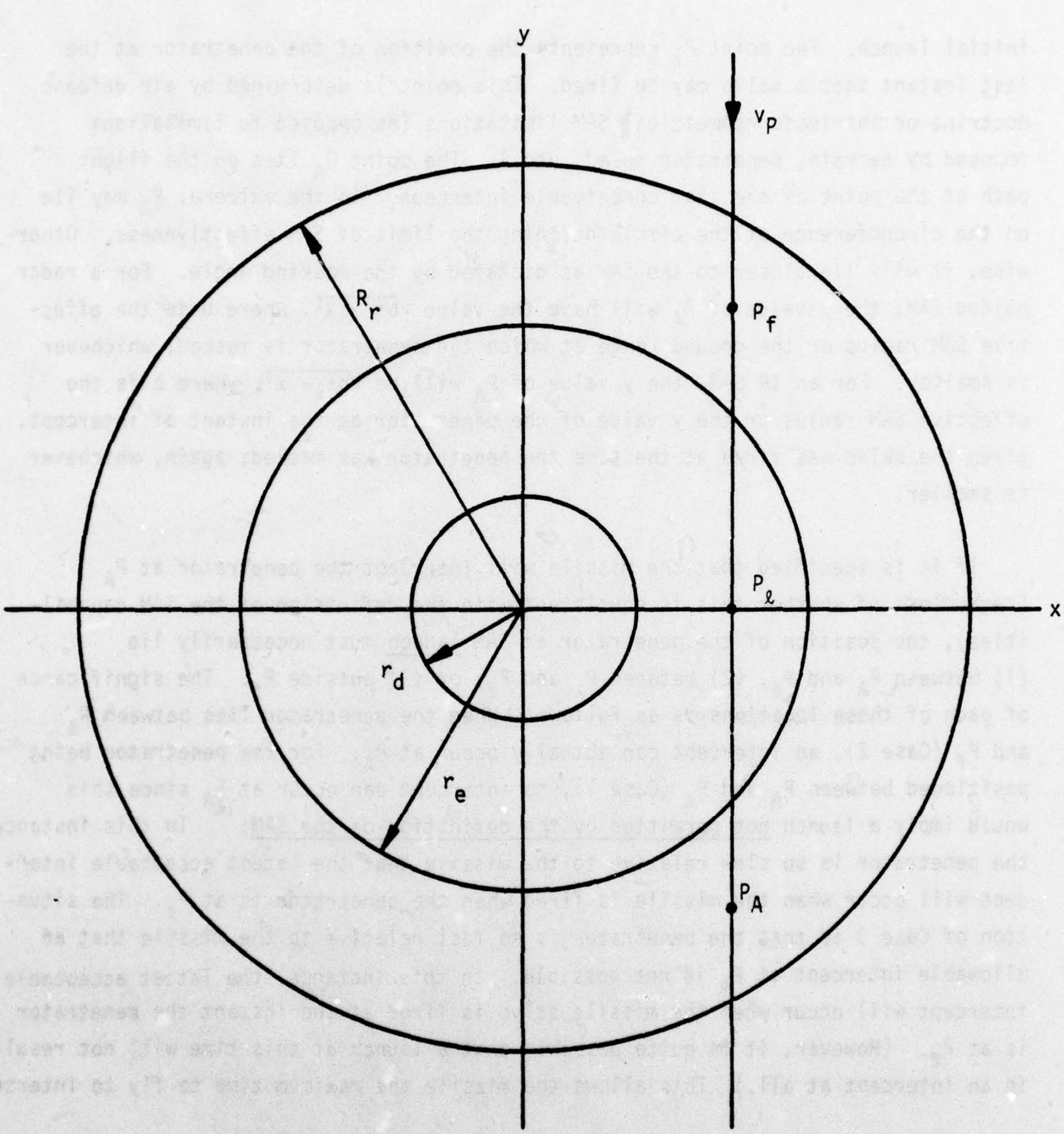

Figure 8. The Geometry for Determining the Position of the Last Possible Intercept. The situation displayed is for a radar guided SAM as P_ℓ is located at the point the penetrator passes the site. The arguments in the text in no way depend upon this choice.

the penetrator at the instant the first salvo may be fired. This point is determined by penetrator detection range and the required time delay from detection to initial launch. The point P_ℓ represents the position of the penetrator at the last instant that a salvo may be fired. This point is determined by air defense doctrine or intrinsic geometrical SAM limitations (as opposed to limitations imposed by terrain, penetrator speed, etc.). The point P_A lies on the flight path at the point of the last conceivable intercept. In the extreme, P_A may lie on the circumference of the circle defining the limit of SAM effectiveness. Otherwise, it will lie closer to the SAM as dictated by the masking angle. For a radar guided SAM, the y value of P_A will have the value $-\sqrt{b^2 - x^2}$, where b is the effective SAM radius or the ground range at which the penetrator is masked, whichever is smaller. For an IR SAM, the y value of P_A will be $-\sqrt{b^2 - x^2}$, where b is the effective SAM radius or the y value of the penetrator at the instant of intercept, given the salvo was fired at the time the penetrator was masked; again, whichever is smaller.

If it is specified that the missile will intercept the penetrator at P_A (regardless of whether this is consistent with the definition of the SAM capabilities), the position of the penetrator at SAM launch must necessarily lie (1) between P_A and P_ℓ, (2) between P_ℓ and P_f, or (3) outside P_f. The significance of each of these locations is as follows: When the penetrator lies between P_ℓ and P_f (Case 2), an intercept can actually occur at P_A. For the penetrator being positioned between P_A and P_ℓ (Case 1), no intercept can occur at P_A since this would imply a launch not permitted by the definition of the SAM.[15] In this instance, the penetrator is so slow relative to the missile that the latest acceptable intercept will occur when the missile is fired when the penetrator is at P_ℓ. The situation of Case 3 is that the penetrator is so fast relative to the missile that an allowable intercept at P_A is not possible. In this instance, the latest acceptable intercept will occur when the missile salvo is fired at the instant the penetrator is at P_f. (However, it is quite possible that a launch at this time will not result in an intercept at all.) This allows the missile the maximum time to fly to intercept.

In summary, the above discussion indicates how to determine the position of the penetrator at SAM launch which results in the latest possible intercept. This makes it straightforward to calculate also the position of that intercept and its time of occurrence.

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15. See, again, the definition of P_ℓ.

For Case 1 (missile launch at P_ℓ), the penetrator will fly a distance[16] $y_{p_\ell} - y_{int}$ at speed v_p in time $(y_{p_\ell} - y_{int})/v_p$. At the same time, the missile will fly

$$\frac{\sqrt{x^2 + h^2 + y_{int}^2}}{v_m}$$

Hence,

$$\frac{\sqrt{x^2 + h^2 + y_{int}^2}}{v_m} = \frac{y_{p_\ell}}{v_p} - \frac{y_{int}}{v_p} \qquad (2)$$

which yields solutions

$$y_{int} = \frac{\frac{C_1}{v_p} \pm \sqrt{\frac{C_1^2}{v_p^2} - \left(\frac{1}{v_p^2} - \frac{1}{v_m^2}\right) C_2}}{\frac{1}{v_p^2} - \frac{1}{v_m^2}}$$

where

$$C_1 = \frac{y_{p_\ell}}{v_p} \quad \text{and} \quad C_2 = C_1^2 - \frac{x^2 + h^2}{v_m^2}$$

16. In the following discussion the y subscripts have the following meanings: y_{int} = y coordinate of the penetrator at intercept; y_{p_f}, y_{p_ℓ}, y_A are the y values of the points P_f, P_ℓ, and A.

As these solutions were obtained by squaring (2) and solving the resulting quadratic, only one satisfies equation (2). The appropriate y will lie between P_A and P_ℓ. The time of intercept is $-y_{int}/v_p$.

For Case 2 (intercept at P_A), the time of intercept is simply

$$\frac{\sqrt{r_e^2 + h^2}}{v_m}$$

where r_e is the effective radius of the SAM or that determined by the masking angle.

Finally, for Case 3, the time of flight of the penetrator is

$$\frac{y_{p_f} - y_{int}}{v_p}$$

which equals the time of flight of the missile

$$\frac{\sqrt{x^2 + h^2 + y_{int}^2}}{v_m}$$

The solutions are

$$y_{int} = \frac{\dfrac{C_1}{v_p} \pm \sqrt{\dfrac{C_1^2}{v_p^2} - \left(\dfrac{1}{v_p^2} - \dfrac{1}{v_m^2}\right) C_2}}{\left(\dfrac{1}{v_p^2} - \dfrac{1}{v_m^2}\right)} \qquad (3)$$

where

$$C_1 = \frac{y_{p_f}}{v_p} \text{ and } C_2 = C_1^{\,2} - \frac{x^2 + h^2}{v_m^{\,2}}$$

Again, only one solution satisfies the original equation, equation (3). The appropriate y_{int} will lie between P_A and 0, if a y_{int} exists. The corresponding time of intercept is $-y_{int}/v_p$.

F. THE EFFECT OF MULTI-PENETRATOR RAIDS AND THE AVERAGE NUMBER[17] OF SHOTS PER RAID

Penetrator raids as modeled in FIRE possess width and depth. To a high degree of approximation, the number of shots fired at a raid by a site is independent of the raid width. However, raid depth can be very important in determining the number of salvos because the deeper a raid, the longer it is exposed to fire.

As a raid passes a SAM site, its members may be fired upon at various distances from the site. This should be considered in computing the total number of shots. First, flyout time is a linear function (in FIRE) of the site to penetrator distance at intercept. Second, where the raid will be fired upon is open to question and can probably at best be treated as a random phenomenon. The basis of the method for handling this is shown in figure 9. A SAM site and penetrator flight path are depicted. At any point, F, on the flight path where an intercept may be performed, the raid will take a time to pass of

$$\frac{\text{raid depth}}{\text{penetrator velocity}}$$

If it is assumed that the front of the raid is intercepted at F, then depending upon raid depth, time between salvos, and flyout time for the missile, the raid

17. The method of averaging described here is obviously only one of many which might have been used. The choice of this one merely reflects the choice of the analyst.

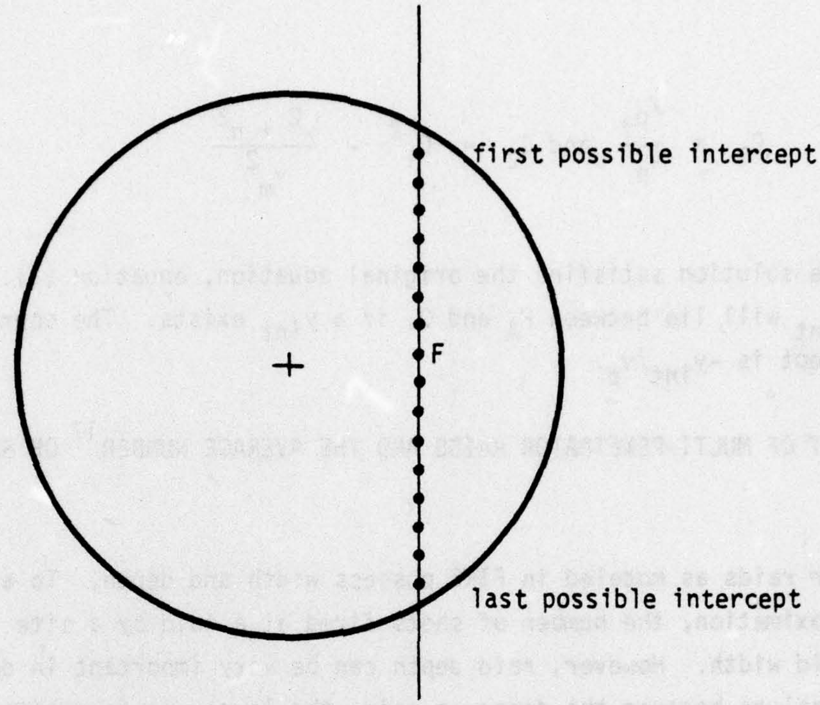

Figure 9. Method of Determining the Number of Salvos Fired for a Given Offset Fired

may be additionally intercepted at F, 0, 1, 2, ..., or more times before it passes F (only integers are permitted). This number varies purely as a function of flyout time, as raid depth and time between salvos remain constant as the location of F varies.

FIRE makes this calculation for a number of points, F, evenly spaced between, and including, the points of first and last possible intercept. A weighted average flyout time is calculated where the weighting factors are the total salvos which can be fired as the raid passes a given point. This average gives definition to the notion that the raid will be attacked more at short distances from the site than at longer distances. The number of shots for the given offset is then taken simply as

$$\frac{\text{time of last intercept - time of first intercept - time in dead zone}}{\text{average flyout time + time delay between salvos}}$$

where, if necessary, the exhaustion of missiles on launchers and subsequent reloading time are taken into account to reduce this number appropriately. The calculation is performed for each of the K offsets discussed in section 4 for each of the possible number of available salvos.

APPENDIX A

THE TERRAIN MODELING PROBLEM

There is no aspect of the survivability problem for low altitude penetrations as important and as difficult to treat accurately as that of the interaction of the terrain with SAMs and penetrators. This appendix has been included specifically to discuss this interaction, the reasons for its importance, and those factors which must be considered in any detailed model.

For penetrators whose altitudes are substantially below 300 meters, terrain effects may drive survivability results. This is illustrated in figure A-1 by results obtained from the FIRE model. Four curves giving the survival probability

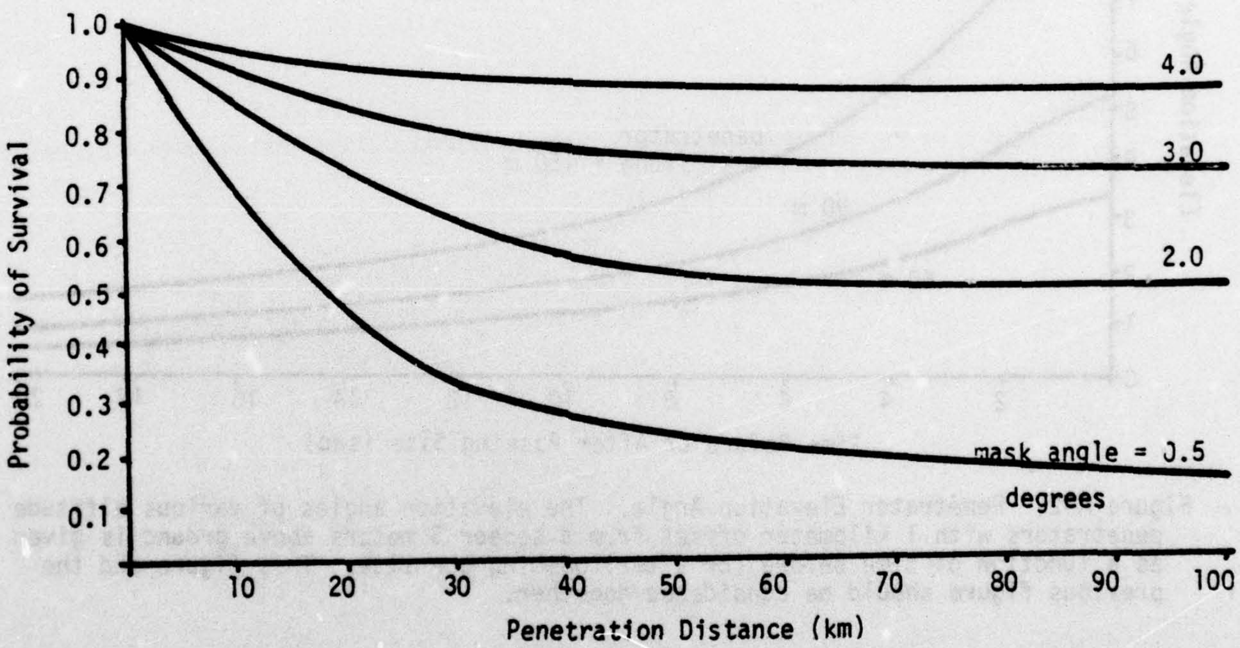

Figure A-1. The Effect of Masking Angle on Survivability. The effect of masking angle on the survivability of a single penetrator at 90 m altitude is depicted. For each curve, the constant masking angle indicated was given to all defenses.

of a single penetrator as a function of penetration distance are plotted for a 90 m altitude penetration.[18] Each curve represents a different constant masking angle about all SAM sites. The effect of increasing masking angle is dramatic. Unfortunately for the analyst, the ideal situation of constant masking angle is not representative of the real world. The reason for the pronounced dependence on masking angle can be seen in figure A-2 which shows penetrator elevation angles for a particular flight path offset and several altitudes as a function of the time in seconds from passing the site.

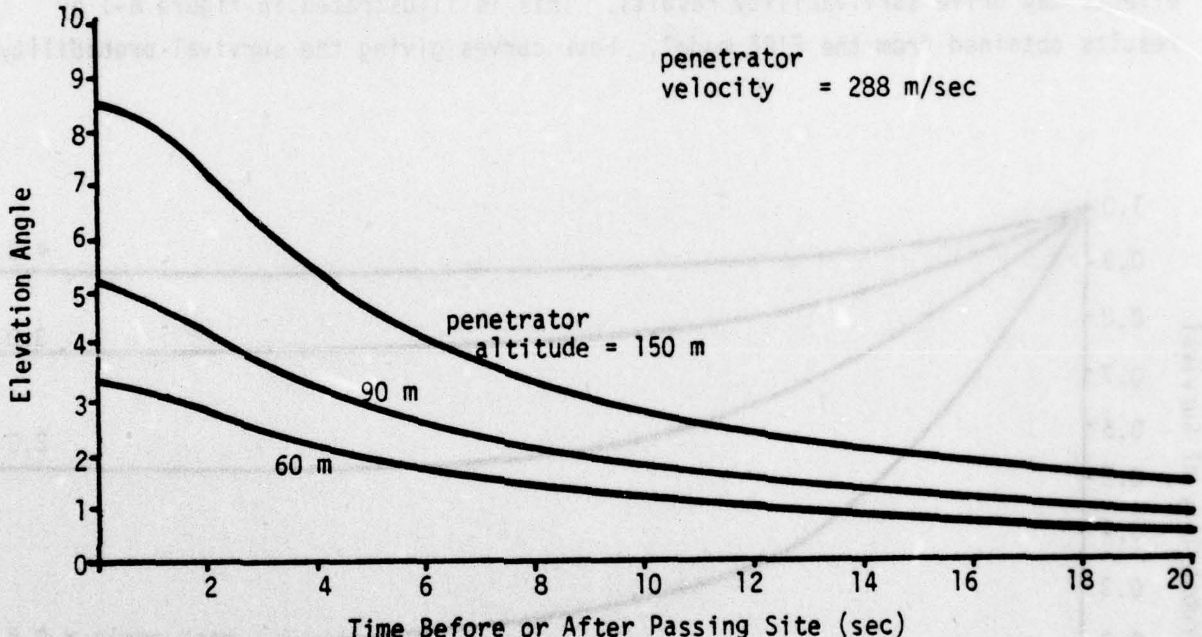

Figure A-2. Penetrator Elevation Angle. The elevation angles of various altitude penetrators with 1 kilometer offset from a sensor 3 meters above ground is given as a function of time before (or after) passing the site. This figure and the previous figure should be considered together.

18. These cases are typical of a heavy defense environment. As they are merely illustrative, no additional details of the scenario are given.

The first requirement in constructing a detailed terrain model is an understanding of the issues involved. First, it must be recognized that the determination of the terrain masking around a SAM is partly a function of chance and partly a function of choice. For example, a mobile SAM escorting a convoy is more or less relegated to accepting the masking angles imposed by the terrain and vegetation surrounding the road. Such masking angles are likely to have a distribution worse than that of sites chosen at random.[19] On the other hand, premeditated site selection could[20] result in a much more favorable distribution of masking angles than for sites selected at random. Ideally then, a good terrain model must include the option of selecting different terrain scenarios for each type of SAM, and possibly for subsets of each type of SAM.

For an expected value model such as FIRE, the foregoing discussion implies that a means must be devised of statistically describing the mask angles about a site. A simple example shows, unfortunately, that this distribution should ideally also include information about distances to the masking features. For example, a distant mask will hide a close penetrator seen with the mask as background if the clutter rejection capabilities of the SAM sensor are not adequate. Such a statistical distribution must also take vegetation and man-made structures into account. This can be seen from table A-1 which gives, as a function of observer to mask distance, the increment in distance above the observer necessary to produce the specified masking angle. It can be seen from the table that a 12 meter tree will constitute approximately a 5 degree mask at 100 meters distance for a 3 meter high observer.

19. Roads tend to systematically exclude sites such as hilltops and include valleys.

20. Sites selected to provide good coverage for the SAM must necessarily increase the visibility of the SAM to any penetrator. There appears to be no lack of supporters of the position that this tradeoff is uppermost in the minds of site commanders.

Table A-1
EXCESS ABOVE OBSERVER HEIGHT (m) NEEDED TO
CREATE SPECIFIED MASKING ANGLE

OBSERVER TO MASK DISTANCE (m)	MASKING ANGLE 1°	2°	3°	4°	5°
10	.17	.35	.52	.70	.87
20	.34	.70	1.05	1.40	1.75
30	.52	1.05	1.57	2.10	2.62
40	.69	1.40	2.10	2.80	3.50
50	.87	1.75	2.62	3.50	4.37
75	1.31	2.62	3.93	5.24	6.56
100	1.75	3.49	5.24	6.99	8.75
200	3.49	6.98	10.48	13.99	17.50
500	8.73	17.46	26.20	34.96	43.74
1000	17.46	34.92	52.41	69.93	87.49

Another major aspect of the problem concerns the degradation of the SAM capabilities because of intermittent tracking of the penetrator caused by masking. How do breaks in track affect shot opportunities? How do breaks in track affect kill probability? What is the probability that track will be broken at the time of intercept? These are all potentially important questions which are dependent on the design of the SAM.

The FIRE model has not adequately addressed any of these issues. As a result, the low altitude survival probabilities may differ somewhat from those which would be obtained from a more detailed treatment of the terrain.

APPENDIX B

PROGRAM LISTING

```
      PROGRAM FIRE(INPUT,OUTPUT,DEBUG=OUTPUT)
C
C        PROGRAM FIRE IA A DETERMINISTIC AIRBORNE PENETRATOR SURVIVABIL-
C        ITY MODEL WHICH CONSIDERS RAIDS OF PENETRATORS AGAINST UP TO TEN
C        DISTINCT SAM TYPES LOCATED WITHIN A CORRIDOR AS A FUNCTION OF
C        DISTANCE FROM THE FEBA. THE MODEL IS DESCRIBED IN DAS-TR-76-9.
C        FIRE A DETERMINISTC MODEL FOR ESTIMATING SURVIVABILITY THROUGH
C        AREA SURFACE TO AIR MISSILE DEFENSES. OCTOBER 1976.
C
C
C        ALL DISTANCES IN PROGRAM FIRE ARE EXPRESSED    KILOMETERS.
C        PENETRATION DISTANCE IS CONSIDERED PLUS BEHIN  THE FEBA, MINUS
C        IN FRONT OF THE FEBA.
C
      COMMON /A/ NPHI,ITYPE,DT,RS,VM,HM,VP,RDEP,NP,DTF
      COMMON /B/ DZONE,RMAX
      COMMON /C/ ILOW,ALPHA(10),HR,ISET(10),ISETL(10),ASPECT(10)
      COMMON /D/ DETORA,PI
      COMMON /E/ PKX,PTX,NLCH,XPPX,PSSEAIJ,DEPTH,AVSHT
      COMMON /F/ NDIST
      COMMON /G/ TD(10),SR(10),SV(10),NS(10),DZ(10),HRS(10),RR(10),PO(10
     1),PT(10),PKSS(10),TOF(10)
      COMMON /J/ ENVL1(10),PEN(10),XSITES(10)
      COMMON /K/ NML(10),POL(10),PTL(10),TDL(10),SRL(10),SVL(10),DZL(10)
     1,RRL(10),HRSL(10),PKSL(10),ITITLE(11),TDLF(10),NLCHRL(10),TERIND(1
     20)
      COMMON /P2/ NPENT,NPT(10),SALSZ(10),NLCHR(10),PLCHRDY(10),RCS(10)
      COMMON /P3/ PENC,TR,SP,CORWDTH(2),DEL
      COMMON /P4/ PSTART,ICHAFF,CHAFFS,CHAFFE,IECM,ECMS,ECME,IDECOY,DSTR
     1,DEND,CHEFF(10),ECMEFF(10)
      COMMON /P44/ IPINT,DF(10),DECPPEN(10),PENCDEC
      COMMON /NHLN/ NSAM(66,10,2)
C
      DIMENSION EN(10), ITP(10), PS(10)
      DIMENSION SPPX(10), DECSTRT(10)
      DIMENSION XSITS(10)
C
C        CALCULATE DEGREES TO RADIANS CONVERSION FACTOR
      PI=4.*ATAN(1.)
      DETORA=PI/180.
```

```
C
C         BEGIN LOOP ON CASES
C
    2 CONTINUE
      CALL INPUT1
C         SELECT HIGH OR LOW DEFENSES
      IALT=2-ILOW
C         PRINT CASE TITLE
      PRINT 15, (ITITLE(I),I=1,8)
C
C         BEGIN LOOP ON PENETRATION RAID SIZE
C
      DO 14 M=1,NPENT
C         SET THE TOTAL NUMBER OF PENETRATORS IN THE RAID
      NP=NPT(M)
C         CALCULATE THE NUMBER OF ROWS OF PENETRATORS
      NROW=NP/PENC+0.99999
C         CALCULATE THE DEPTH AND WIDTH OF THE RAID IN KM
      DEPTH=(NROW-1)*TR*VP
      WIDTH=(PENC-1.)*SP
C         PRINT RAID INFORMATION
      PRINT 17, NP,WIDTH,DEPTH
C         INITIALIZE RUNNING PENETRATOR AND DECOY SURVIVAL PROBABILITIES
C         FOR CURRENT INTERVAL AND ALL INTERVALS TO DATE
      SURVP=1.0
      SURVPT=1.0
      SURVD=1.0
      SURVDT=1.0
C         INITIALIZE THE NUMBER OF DECOYS SURVIVING TO RELEASE (ZERO VALUE
C         USED AS TEST)
      DO 3 I=1,10
      DECSTRT(I)=0
    3 CONTINUE
C         INITIALIZATION
      DO 4 I=1,10
      XSITS(I)=0.
      PS(I)=1.0
    4 CONTINUE
      PDIST=PSTART
      INN1=0
C
C         BEGIN LOOP ON PENETATION DISTANCE INTERVAL
C
      DO 13 J=1,NDIST
C         CALCULATE PRESENT PENETRATION DISTANCE
      PDIST=PDIST+DEL
C         CALCULATE PRESENT PENETRATION INTERVAL
      IDIST=PDIST/DEL
C         INITIALIZE IX TO INDEX SAM RESULTS
      IX=0
```

```
C
C         BEGIN LOOP ON SAMS TO DETERMINE PROBABILITY OF SURVIVAL VALUES
C
      DO 12 I=1,10
C        DETERMINE IF SAM TYPE I IS TO BE CONSIDERED FOR THIS CASE
      IF (DF(I).EQ.0.OR.(ILOW.EQ.0.AND.ISET(I).EQ.0).OR.(ILOW.EQ.1.AND.I
     1SETL(I).EQ.0)) GO TO 12
C        SAM TYPE I IS TO BE CONSIDERED
      IX=IX+1
C           CALCULATE THE NUMBER OF SITES OF SAM TYPE I   THE J-TH BAND
      XSITES(IX)=NSAM(IDIST+1,I,IALT)-NSAM(IDIST,I,I   )
C        STORE SAM TYPE FOR LATER PRINTING
      ITP(IX)=I
C        SELECT IF HIGH OR LOW ALTITUDE SAM PARAMETERS ARE TO BE USED
      IF (ILOW.EQ.1) GO TO 5
C        CALCULATE SAM AVAILABILITY AND SET TERRAIN DEGRADATION AND PK
C        FOR HIGH ALTITUDE SAM SALVOS
      PDX=PD(I)*DF(I)
      PTX=PT(I)
      NLCH=NLCHR(I)
      PKX=PKSS(I)
      GO TO 6
C        CALCULATE SAM AVAILABILITY AND SET TERRAIN DEGRADATION AND PK
C        FOR LOW ALTITUDE SAM SALVOS
    5 CONTINUE
      PDX=PDL(I)*DF(I)
      PTX=PTL(I)
      NLCH=NLCHRL(I)
      PKX=PKSL(I)
    6 CONTINUE
C        CHECK FOR PRESENCE OF CHAFF IN THIS INTERVAL
      IF (ICHAFF.NE.1.OR.PDIST.GT.CHAFFE.OR.PDIST-DEL.LT.CHAFFS) GO TO 7
C        CHAFF IS PRESENT IN INTERVAL, SET CHAFF DEGRADATION
      XM=CHEFF(I)
      GO TO 8
C        CHAFF IS NOT PRESENT IN INTERVAL
    7 CONTINUE
      XM=1.0
C        CHECK FOR PRESENCE OF ECM IN THIS INTERVAL
    8 CONTINUE
      IF (IECM.NE.1.OR.PDIST.GT.ECME.OR.PDIST-DEL.LT.ECMS) GO TO 9
C        ECM PRESENT IN INTERVAL, REVISE SAM SALVO PK
      PKSS1=ECMEFF(I)*(1.0-(1.0-PKX)**(1.0/SALSZ(I)))
      PKX=1.-(1.-PKSS1)**SALSZ(I)
    9 CONTINUE
C        CHECK FOR PRESENCE OF DECOYS IN THIS INTERVAL
      IF (IDECOY.NE.1.OR.PDIST.GT.DEND.OR.PDIST-DEL.LT.DSTR) GO TO 10
C        DECOYS ARE PRESENT IN INTERVAL
C        CALCULATE INITIAL NUMBER OF DECOYS IF FIRST INTERVAL WITH DECOYS
      IF (DECSTRT(I).EQ.0) DECSTRT(I)=DECPPEN(I)*SURVPT*PENCDEC
```

```
C        CALCULATE NUMBER OF PENETRATORS
      XPPX=SURVPT*(NP-PENCDEC)+SURVDT*DECSTRT(I)
      IF (XPPX.LT.1.0) XPPX=1.0
      IF (PENSUR.LT.1.0) PENSUR=1.0
      GO TO 11
C        DECOYS ARE NOT PRESENT IN INTERVAL, CALCULATE NUMBER OF
C        PENETRATORS
   10 CONTINUE
      XPPX=SURVPT*NP
      IF (IDECOY.EQ.1.AND.PDIST.GT.DEND) XPPX=SURVPT*   ?-PENCDEC)
      IF (XPPX.LT.1.0) XPPX=1.0
   11 CONTINUE
C        SAVE TOTAL PENETRATORS SEEN BY SAM TYPE I (INCLUDING DECOYS)
      SPPX(IX)=XPPX
      IF (J.EQ.1.OR.XSITES(IX).NE.0) CALL NSHOTS (I)
      IF (J.EQ.1) EN(IX)=AVSHT
C        CALCULATE PROBABILITY A PENETRATOR SURVIVES A SINGLE SITE OF
C        TYPE I IN THE JTH BAND, GIVEN SITE ENCOUNTER
      PSSEIJ=1.0-PDX+PDX*PSSEAIJ
C        CALCULATE PROBABILITY OF ENCOUNTER WITH TYPE I DEFENSES IN THE
C        JTH BAND
      PEN(IX)=AMIN1(2.0*(ENVL1(I)+WIDTH)/CORWDTH(IALT),1.0)*XM
C          CALCULATE THE PROBABILITY OF SURVIVING ONE SITE
      PS1IJ=1.0-PEN(IX)+PEN(IX)*PSSEIJ
C          CALCULATE THE PROBABILITY OF SURVIVING ALL SITES OF SAM TYPE I
C          IN THE INTERVAL
      PSNIJ=PS1IJ**XSITES(IX)
C        CALCULATE SURVIVAL PROBABILITY OF PENETRATOR RELATIVE TO I-TH
C        TYPE SAM
      PS(IX)=PS(IX)*PSNIJ
C        CALCULATE PENETRATOR SURVIVAL PROBABILITY TO PRESENT
      SURVP=SURVP*PSNIJ
C        CALCULATE DECOY SURVIVAL PROBABILITY TO PRESENT IF APPLICABLE
      IF (IDECOY.EQ.1.AND.PDIST.LE.DEND.AND.PDIST-DEL.GT.DSTR.AND.DECSTR
     1T(I).NE.0) SURVD=SURVD*PSNIJ
      XSITS(IX)=XSITS(IX)+XSITES(IX)
   12 CONTINUE
      SURVPT=SURVP
      SURVDT=SURVD
C        CALCULATE THE NUMBER OF PENETRATORS SURVIVING
      PENSUR=SURVPT*NP
      IF (IDECOY.EQ.1.AND.PDIST-DEL.GE.DSTR) PENSUR=SURVPT*(NP-PENCDEC)
C        INCREMENT PRINT INTERVAL COUNTER
      INN1=INN1+1
C        DETERMINE IF OUTPUT DUE THIS INTERVAL
      IF (INN1.NE.IPINT) GO TO 13
C        RESET PRINT INTERVAL COUNTER
      INN1=0
C        OUTPUT SURVIVAL PROBABILITIES
      PRINT 16, PDIST,PENSUR,SURVP,(ITP(I),EN(I),PEN(I),XSITS(I),SPPX(I)
```

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```
     1,PS(I),I=1,IX)
  13 CONTINUE
  14 CONTINUE
C       CHECK FOR ADDITIONAL CASES
     GO TO 2
C
C
C
  15 FORMAT (1H1///10X,8A10)
  16 FORMAT (//19H PENETRATION DEPTH=,F5.1,5X,32HNUM[illegible] OF PENETRATORS
    1SURVIVING=,F5.1,5X,42HPROBABILITY OF GIVEN PEN[illegible]ATOR SURVIVING=,F
    24.2/1X,4HTYPE,6X,7HSALVOS/,7X,5H PROB,10X,6HTO[illegible]/,5X,11HPENETRATO
    3RS,5X,8HSURVIVAL/1X,4HSITE,7X,4HSITE,9X,9HENCOUNTER,7X,5HSITES,8X,
    44HSEEN,7X,11HPROBABILITY/(I3,2F14.2,F12.1,2F14.2))
  17 FORMAT (//23H NUMBER OF PENETRATORS=,I5/,12H RAID WIDTH=,F6.2/12H
    1RAID DEPTH=,F6.2//)
     END
```

```
      SUBROUTINE NSHOTS (I)
C
C
C
C        SUBROUTINE NSHOTS IS CALLED FROM PROGRAM FIRE AND IN TURN CALLS
C        SUBROUTINE SHOTS. THE PURPOSE OF NSHOTS IS TO 1) ESTABLISH THE
C        VALUES OF PARAMETERS USED IN SUBROUTINE SHOTS (WHETHER FOR THE
C        HIGH OR LOW ALTITUDE SAM SCENARIO) AND 2) TO A ~RAGE THE RESULTS
C        RETURNED FROM SHOTS. SHOTS IS CALLED FOR A SERI S OF SINGLE
C        COLUMN FLIGHT PATH OFFSETS (RAID DEPTH ONLY I~ CONSIDERED) AND
C        FOR EACH OFFSET RETURNS THE NUMBER OF SAM SAI  S WHICH MAY BE
C        FIRED AT THE RAID. THESE NUMBERS ARE AVERAGEL  O DETERMINE THE
C        EXPECTED NUMBER OF SHOTS PER RAID ENCOUNTER WITH THE SITE. THE
C        EFFECTIVE RADIUS OF THE SITE IS ALSO A PRODUCT OF THE RESULTS
C        OBTAINED FROM SHOTS.
C
      COMMON /A/ NPHI,ITYPE,DT,RS,VM,HM,VP,RDEP,NP,DTF
      COMMON /B/ DZONE,RMAX
      COMMON /C/ ILOW,ALPHA(10),HR,ISET(10),ISETL(10),ASPECT(10)
      COMMON /C1/ SRLD(10)
      COMMON /C2/ TRLD
      COMMON /D/ DETORA,PI
      COMMON /E/ PKX,PTX,NLCH,XPPX,PSSEAIJ,DEPTH,AVSHT
      COMMON /G/ TD(10),SR(10),SV(10),NS(10),DZ(10),HRS(10),RR(10),PD(10
     1),PT(10),PKSS(10),TDF(10)
      COMMON /I/ NX
      COMMON /J/ ENVL1(10),PEN(10),XSITES(10)
      COMMON /K/ NML(10),POL(10),PTL(10),TDL(10),SRL(10),SVL(10),DZL(10)
     1,RRL(10),HRSL(10),PKSL(10),ITITLE(11),TDLF(10),NLCHRL(10),TERIND(1
     20)
      COMMON /P2/ NPENT,NPT(10),SALSZ(10),NLCHR(10),PLCHRDY(10),ROS(10)
C
      DIMENSION PSOK(25), PMLRS(25), NXS(25)
C
C        INITIALIZE COUNTER OF SALVOS FIRED FOR ALL OFFSETS, SAM TYPE,
C        RAID DEPTH, AND SAM RELOAD TIME
      XSHOT=0.
      ITYPE=1
      RDEP=DEPTH
      TRLD=SRLD(I)
      PLR=PLCHRDY(I)
      IF (TERIND(I).EQ.1) PLR=PLR*PTX
C        SELECT SAM PARAMETERS FOR HIGH OR LOW ALTITUDE SCENARIO
      IF (ILOW.NE.1) GO TO 1
C        PARAMETERS ARE FOR LOW ALTITUDE SCENARIO. DEFINITIONS FOR
C        VARIABLES ON RIGHT SIDE OF REPLACEMENT STATEMENT MAY BE INFERRED
C        FROM SUBROUTINE INPUT1 AND DAS-TR-76-9
      RS=SRL(I)
      VM=SVL(I)
      DZONE=DZL(I)
```

```
      HR=HRSL(I)
      DT=TDL(I)
      DTF=TDLF(I)
      RTEMP=RRL(I)
      GO TO 2
C        PARAMETERS ARE FOR HIGH ALTITUDE SCENARIO. DEFINITIONS FOR
C        VARIABLES ON RIGHT SIDE OF REPLACEMENT STATEMENT MAY BE INFERRED
C        FROM SUBROUTINE INPUTI AND DAS-TR-76-9
    1 CONTINUE
      RS=SR(I)
      VM=SV(I)
      DZONE=DZ(I)
      HR=HRS(I)
      DT=TD(I)
      DTF=TDF(I)
      RTEMP=RR(I)
    2 CONTINUE
C          CALCULATE PROBABILITY OF EXACTLY M LAUNCHERS READY.INCLUDE
C          TERRAIN IF INDEPENDENT FROM LAUNCHER TO LAUNCHER
      NLCHP=NLCH+1
      TFAC1=NLCHP
      DO 3 N=1,NLCHP
      M=N-1
      TFAC2=M+1
      TFAC3=TFAC1-M
      PMLRS(N)=(IFACT(NLCH)/(IFACT(M)*IFACT(NLCH-M)))*(PLR+1.0E-100)**M*
     1(1.0-PLR+1.0E-100)**(NLCH-M)
C          CALCULATE NUMBER OF AVAILABLE SALVOS
      NXS(N)=M*NML(I)/SALSZ(I)
    3 CONTINUE
C        INITIALIZE OFFSET AND COUNTER OF OFFSETS RESULTING IN INTERCEPTS
      Z=0.
      MPOINT=0
C          INITIALIZE OFFSET SURVIVAL PROBABILITIES
      DO 4 K=1,25
      PSOK(K)=0
    4 CONTINUE
C       DETERMINE SEPARATION OF ADJACENT FLIGHT PATH OFFSETS
      DELTA=RS/(NPHI-1)
C
C       BEGIN LOOP ON PENETRATOR OFFSET
C
      ZTEST=0
      DO 6 J=1,NPHI
C          CALCULATE OFFSET TO BE CONSIDERED
      Z=(J-1)*DELTA
C          BEGIN LOOP FOR EXACTLY N SITES
      XSHOTR=0
      NLCHP=NLCH+1
      DO 5 N=1,NLCHP
```

```
      PMLR=PMLRS(N)
      NX=NXS(N)
      CALL SHOTS (XSHOT1,Z,J,RTEMP)
      XSHOTR=XSHOTR+XSHOT1*PMLR
      TEST=XSHOT1*ROS(I)/XPPX
      IF (TEST.GE.1.0) PSOK(J)=PMLR*(1.0-PKX)**TEST+PSOK(J)
      IF (TEST.LT.1.0) PSOK(J)=PMLR*(1.0-PKX*TEST)+PSOK(J)
    5 CONTINUE
      IF (Z.EQ.0.AND.XSHOTR.GT.0) ZTEST=1.0
      IF (XSHOTR.GT.0) MPOINT=MPOINT+1
      XSHOT=XSHOT+XSHOTR
    6 CONTINUE
C       ALL FLIGHT PATH OFFSETS WHICH COULD PERMIT INTERCEPT HAVE BEEN
C       EXAMINED
C         CALCULATE THE INTEGRATED SURVIVAL PROBABILITY
      PSSEAIJ=(1.0/(2.0*NPHI+1))*PSOK(1)
      DO 7 J=2,NPHI
      PSSEAIJ=(2.0/(2.0*NPHI+1.0))*PSOK(J)+PSSEAIJ
    7 CONTINUE
      IF (TERIND(I).EQ.0) PSSEAIJ=1.0-(1.0-PSSEAIJ)*PTX
C       CALCULATE HALF-WIDTH OF LETHAL ENVELOPE
      ENVLI(I)=0
      IF (MPOINT.NE.0.AND.ZTEST.EQ.0) ENVLI(I)=MPOINT*DELTA
      IF (MPOINT.NE.0.AND.ZTEST.EQ.1.0) ENVLI(I)=(MPOINT-1.0+0.5)*DELTA
C       RESET NOMINAL SAM RANGE IF MODIFIED IN SHOTS
C       CALCULATE AVERAGE NUMBER OF SALVOS FIRED GIVEN AN ENCOUNTER
      IF (MPOINT.EQ.0) AVSHT=0
      IF (MPOINT.NE.0.AND.ZTEST.EQ.1) AVSHT=XSHOT/(MPOINT-1.0+0.5)
      IF (MPOINT.NE.0.AND.ZTEST.EQ.0) AVSHT=XSHOT/MPOINT
      RETURN
C
C
      END
```

```
      SUBROUTINE SHOTS (XSHOTX,X,K,RSAVE)
C
C        SUBROUTINE SHOTS IS CALLED BY SUBROUTINE NSHOTS. IT CALCULATES
C        FOR A SINGLE COLUMN FLIGHT PATH OFFSET (RAID DEPTH ONLY IS
C        CONSIDERED) THE NUMBER OF SALVOS WHICH THE SAM TYPE UNDER
C        CONSIDERATION CAN FIRE AT THE RAID. IN THE PROCESS IT IS
C        NECESSARY TO DETERMINE THE LOCATION OF THE FIRST AND LAST
C        POSSIBLE INTERCEPTS. IN COMPUTING THE NUMBER O. SALVOS, AN
C        AVERAGE IS TAKEN OVER ALL POSSIBLE INTERCEPT PC NTS WITH SHORT
C        FLYOUT TIMES WEIGHTED MORE HEAVILY THAN LONGE  ONES. LAUNCHER
C        RELOAD TIME IS CONSIDERED.
C
C        THE Y VALUE OF THE PENETRATOR IS POSITIVE BEFORE PASSING THE SAM
C        AND NEGATIVE AFTER. THE ALGEBRAIC SIGN OF TIME IS OPPOSITE THAT
C        OF THE Y PENETRATOR COORDINATE. ASPECT(I).NE.0 INDICATES AN IR
C        GUIDED SAM.
C
      COMMON /A/ NPHI,ITYPE,DT,RS,VM,HM,VP,RDEP,NP,DTF
      COMMON /B/ DZONE,RMAX
      COMMON /C/ ILOW,ALPHA(10),HR,ISET(10),ISETL(10),ASPECT(10)
      COMMON /C2/ TRLD
      COMMON /D/ DETORA,PI
      COMMON /I/ NX
C
      DIMENSION Y(2), YFST(50), TFST(50), YLST(50), TLST(50)
C
      DATA (ASPECT(I),I=1,9)/8*0.0,0.7854/
C
C        TEST FOR ZERO OFFSET
      IF (X.NE.0) GO TO 2
C        FOLLOWING INITIALIZATION DONE ONLY FOR ZERO OFFSET
      RDZ=DZONE
      TD=DT
      TDF=DTF
      H=HM
      RD=RDEP
      RE=RS
      RR=RSAVE
C        CALCULATE MAXIMUM LINE-OF-SIGHT RANGE OF SENSOR FOR PENETRATOR
C        WHEN MASKING CONSIDERED. USE 4/3 EARTH FOR RADAR GUIDED SAMS
      REARTH=8495.0
      IF (ASPECT(ITYPE).NE.0) REARTH=6371.0
      BETA=ASIN(REARTH/(REARTH+HR))+ALPHA(ITYPE)*DETORA
      GAMMA=ASIN(SIN(BETA)*(REARTH+HR)/(REARTH+H))
      THETA=PI-(BETA+GAMMA)
      RMAX=SIN(THETA)*(REARTH+H)/SIN(BETA)
C        DOES RADAR MASKING REDUCE SENSOR RANGE
      IF (RMAX.LT.RR) RR=RMAX
C        INITIALIZE POSITIONS AND TIMES OF INTERCEPT POINTS OF INTEREST
C        -10E6 IS A FLAG
```

```
      DO 1 J=1,21
      YFST(J)=-10E6
      TFST(J)=-10E6
      YLST(J)=-10E6
      TLST(J)=-10E6
    1 CONTINUE
C        TEMPORARILY REDUCE NOMINAL EFFECTIVE RANGE OF SAM IF NECESSARY
      IF (RE.GT.RR) RE=RR
    2 CONTINUE
      XSHOTX=0
C        IF OFFSET GREATER THAN EFFECTIVE RADIUS, RETI
      IF (X.GT.RE) RETURN
C        IS FLIGHT PATH THROUGH DEAD ZONE
      IDZ=0
      IF (X.LT.RDZ) IDZ=1
C        DEFINE POSITION OF PENETRATOR AT TIME OF LATEST ALLOWED MISSILE
C        LAUNCH
      YTLST=0
      IF (ASPECT(ITYPE).NE.0) YTLST=-SQRT(RE**2-X**2)
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C        SOLVE FOR Y VALUE OF FIRST INTERCEPT
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      YRR=RR
      IF (ASPECT(ITYPE).NE.0) YRR=X/SIN(ASPECT(ITYPE))
      IF (YRR.GT.RR) YRR=RR
      TEMP=YRR**2-X**2
C        CAN RAID BE DETECTED
      IF (TEMP.LT.0) GO TO 12
C        RAID CAN BE DETECTED
      C1=SQRT(TEMP)/VP-TDF
      A=(1.0/VP**2-1.0/VM**2)
      B=-2.0*C1/VP
      C=C1**2-(X**2+H**2)/VM**2
C        CHECK FOR REAL SOLUTIONS
      TEMP=B**2-4.0*A*C
      IF (TEMP.LT.0) GO TO 12
C        SOLUTIONS ARE REAL
      Y(1)=(-B+SQRT(TEMP))/(2.0*A)
      Y(2)=(-B-SQRT(TEMP))/(2.0*A)
C        TEST ROOTS FOR ACCEPTABILITY
C        IS ONE OF THE ROOTS OF INTEREST
      DO 4 J=1,2
C        DOES ROOT SATISFY ORIGINAL EQUATION
      YT=SQRT(YRR**2-X**2)/VP-Y(J)/VP-SQRT(X**2+Y(J)**2+H**2)/VM-TDF
      IF (ABS(YT).GT.0.001) GO TO 4
C        DOES ROOT LIE WITHIN RADAR COVERAGE AND HAVE POSITIVE FORESET
```

```
      IF (Y(J).GT.SQRT(YRR**2-X**2).AND.Y(J).GE.0) GO TO 4
C        ROOT LIES WITHIN RADAR COVERAGE OR IS NEGATIVE
      IF (Y(J).LT.SQRT(RE**2-X**2).OR.Y(J).LE.0) GO TO 3
C       FIRST INTERCEPT AT BOUNDARY OF LETHAL ENVELOPE
      YFST(K)=SQRT(RE**2-X**2)
      TFST(K)=-YFST(K)/VP
      TFLYM=SQRT(X**2+YFST(K)**2+H**2)/VM
      YPENL=YFST(K)+TFLYM*VP
      GO TO 5
    3 CONTINUE
C       DOES ROOT LIE IN LETHAL ENVELOPE
      IF (ABS(Y(J)).GT.SQRT(RE**2-X**2)) GO TO 4
C       ROOT LIES IN LETHAL ENVELOPE
C       CHECK TO SEE THAT SHOT FIRED BEFORE PENETRATOR PASSED YTLST
      TFLYM=SQRT(X**2+Y(J)**2+H**2)/VM
      YPENL=Y(J)+TFLYM*VP
      IF (YPENL.LT.YTLST) GO TO 4
C       MISSILE FIRED BEFORE PENETRATOR PASSED YTLST. SOLUTION OK
      YFST(K)=Y(J)
      TFST(K)=-YFST(K)/VP
      GO TO 5
    4 CONTINUE
C       THERE IS NO FIRST INTERCEPT
      GO TO 12
C       SET Y-VALUE OF PENETRATOR AT TIME MISSILE LAUNCHED FOR FIRST
C       INTERCEPT
    5 CONTINUE
      YTFST=YPENL
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C       FIND POSITION AND TIME OF LAST INTERCEPT
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C       CALCULATE POSITION OF PENETRATOR AT INSTANT MISSILE IS FIRED
C       PRODUCING AN INTERCEPT AS PENETRATOR LEAVES COVERAGE
      TTEST=SQRT(RE**2+H**2)/VM
      YTEST=-SQRT(RE**2-X**2)+TTEST*VP
      IF (YTEST.LT.YTLST) GO TO 8
      IF (YTEST.LE.YTFST) GO TO 11
C       PENETRATOR IS TOO FAST FOR LEGITIMATE INTERCEPT AT COVERAGE
C       LIMIT. LATEST INTERCEPT OCCURS FOR MISSILE LAUNCH WITH PENETRATO
C       AT YTFST
      C1=YTFST/VP
      A=(1.0/VP**2-1.0/VM**2)
      B=-2.0*C1/VP
      C=C1**2-(X**2+H**2)/VM**2
      TEMP=B**2-4.0*A*C
      Y(1)=(-B+SQRT(TEMP))/(2.0*A)
```

```
      Y(2)=(-B-SQRT(TEMP))/(2.0*A)
      DO 6 J=1,2
      L=J
      YT=SQRT(X**2+Y(J)**2+H**2)/VM-YTFST/VP+Y(J)/VP
      IF (ABS(YT).LT.0.001) GO TO 7
    6 CONTINUE
      STOP 5
    7 CONTINUE
      YLST(K)=Y(L)
      TLST(K)=-YLST(K)/VP
      GO TO 12
    8 CONTINUE
C        PENETRATOR IS TOO SLOW FOR LEGITIMATE INTERCEPT AT COVERAGE
C        LIMIT. LATEST INTERCEPT OCCURS FOR MISSILE LAUNCH WITH PENETRATO
C        AT YTLST
      C1=YTLST/VP
      A=(1.0/VP**2-1.0/VM**2)
      B=-2.0*C1/VP
      C=C1**2-(X**2+H**2)/VM**2
      TEMP=B**2-4.0*A*C
      Y(1)=(-B+SQRT(TEMP))/(2.0*A)
      Y(2)=(-B-SQRT(TEMP))/(2.0*A)
      DO 9 J=1,2
      L=J
      YT=SQRT(X**2+Y(J)**2+H**2)/VM+Y(J)/VP-YTLST/VP
      IF (ABS(YT).LT.0.001) GO TO 10
    9 CONTINUE
      STOP 10
   10 CONTINUE
      YLST(K)=Y(L)
      TLST(K)=-YLST(K)/VP
      GO TO 12
   11 CONTINUE
C        LAST INTERCEPT TAKES PLACE AT COVERAGE LIMIT
      YLST(K)=-SQRT(RE**2-X**2)
      TLST(K)=-YLST(K)/VP
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C        FIND WEIGHTING FACTORS FOR SPECIFIC VALUES OF T, TFST(K).LE.T.LE
C     .TLST(K)
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
   12 CONTINUE
C        TEST FOR VALID INTERCEPTS
      IF (TFST(K).NE.-10E6) GO TO 13
C        NO INTERCEPTS POSSIBLE
      XSHOTX=0
      RETURN
```

```
   13 CONTINUE
      TRAID=RD/VP
      TLENGTH=-2.0
      NPOINT=0
      NSHOT=0
      TFLYS=0
      TCHK=TFST(K)-2.0
      YCHK=YFST(K)+2.0*VP
C        CALCULATE FLYOUT TIME FOR INTERCEPT AT (X,YCHK) ST TIME TCHK
C        AND WEIGHT FLYOUT TIME ACCORDING TO NUMBER OF  OSSIBLE SALVOS
C        FIRED AT RAID AT THAT POINT (DISREGARDING POS  BLE EXHAUSTION OF
C        MISSILES ON LAUNCHERS).
      DO 15 I=1,1000
      TCHK=TCHK+2.0
      IF (TCHK.GT.TLST(K)) GO TO 16
      YCHK=YCHK-2.0*VP
C        SKIP DEAD ZONE TESTS IF FLIGHT PATH NOT THROUGH DEAD ZONE
      IF (IDZ.EQ.0) GO TO 14
      IF (SQRT(YCHK**2+X**2).LT.RDZ) GO TO 15
   14 CONTINUE
      TLENGTH=TLENGTH+2.0
      NPOINT=NPOINT+1
      TFLYM=SQRT(X**2+YCHK**2+H**2)/VM
      TSHOT=INT(TRAID/(TFLYM+TD))+1.0
      NSHOT=NSHOT+TSHOT
      TFLYS=TFLYS+TFLYM*TSHOT
C
   15 CONTINUE
   16 CONTINUE
      IF (NSHOT.NE.0) GO TO 17
      XSHOTX=0
      RETURN
   17 CONTINUE
C        CALCULATE AVERAGE FLYOUT TIME
      TFLYA=TFLYS/NSHOT
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     DETERMINE MAXIMUM NUMBER OF SHOTS WHICH MAY BE FIRED AT RAID
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C        CALCULATE NUMBER OF SHOTS WITHOUT REGARD TO LAUNCHER RELOADING
      NS=(TLENGTH+TRAID)/(TFLYA+TD)+1.0
C        CHECK TO SEE IF MISSILES WILL BE EXHAUSTED
      IF (NS.GT.NX) GO TO 18
C        RELOADING NOT REQUIRED
      XSHOTX=NS
      RETURN
   18 CONTINUE
```

```
C         MISSILES WILL BE EXHAUSTED. IS THERE ENOUGH TIME TO RELOAD
      IF (NX*(TFLYA+TD)+TRLD.LE.(TLST(K)-TFST(K))) GO TO 19
C         RAID WILL PASS BEFORE LAUNCHERS CAN BE RELOADED
      XSHOTX=NX
      RETURN
   19 CONTINUE
C         CALCULATE NUMBER OF FIRE-RELOAD CYCLES PERMITTED BY AVAILABLE
C         TIME AND SUBSEQUENT NUMBER OF SALVOS WHICH CAN BE FIRED
      NCYCLE=XCYCLE=(TLST(K)-TFST(K))/(NX*(TFLYA+TD)+TR D)
      FCYCLE=XCYCLE-NCYCLE
      IF (FCYCLE*(NX*(TFLYA+TD)+TRLD).GT.NX*(TFLYA+T[     GO TO 20
      XSHOTX=NCYCLE*NX+FCYCLE*((NX*(TFLYA+TD)+TRLD)/(  .*TFLYA+TD))*NX
      RETURN
   20 CONTINUE
      XSHOTX=(NCYCLE+1)*NX
      RETURN
C
      END
```

```
      FUNCTION IFACT (I)
C
C       FUNCTION IFACT CALCULATES I FACTORIAL
C
      IFACT=1
      IF (I.EQ.0) RETURN
      DO 1 J=1,I
      IFACT=IFACT*J
    1 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INPUT1
C
C        SUBROUTINE INPUT1 HANDLES ALL INPUT FOR PROGRAM FIRE. INPUT1 IS
C        CALLED WHENEVER FIRE REQUIRES NEW DATA FOR ADDITIONAL CASES. THE
C        BASIS FOR INPUT IS THE ALPHANUMERIC IDENTIFIER (SEE ICOM ARRAY)
C        WHICH IDENTIFIES THE INPUT VALUE FOLLOWING IT ON THE CARD AND/OR
C        INDICATES THE DISPOSITION OF THE INPUTS ON SUCCESSIVE CARDS. IN
C        GOING FROM CASE TO CASE ONLY INPUTS WHICH CHAN  T MUST BE GIVEN
C        (UNCHANGED INPUTS ON THE SAME CARDS MUST BE REF ATED). THE
C        ORDER OF INPUTS IS IMMATERIAL EXCEPT WITHIN S   S OF CARDS
C        ASSOCIATED WITH AN IDENTIFIER. UNRECOGNIZED     NTIFIERS PREVENT
C        RETURN TO FIRE FROM INPUT1. INPUTS DISCUSSED   DAS-TR-76-9
C
      COMMON /A/ NPHI,ITYPE,DT,RS,VM,HM,VP,RDEP,NP,DTF
      COMMON /B/ DZONE,RMAX
      COMMON /C/ ILOW,ALPHA(10),HR,ISET(10),ISETL(10),ASPECT(10)
      COMMON /C1/ SRLD(10)
      COMMON /D/ DETORA,PI
      COMMON /F/ NDIST
      COMMON /G/ TD(10),SR(10),SV(10),NS(10),DZ(10),HRS(10),RR(10),PD(10
     1),PT(10),PKSS(10),TDF(10)
      COMMON /K/ NML(10),PDL(10),PTL(10),TDL(10),SRL(10),SVL(10),DZL(10)
     1,RRL(10),HRSL(10),PKSL(10),ITITLE(11),TDLF(10),NLCHRL(10),TERIND(1
     20)
      COMMON /P2/ NPENT,NPT(10),SALSZ(10),NLCHR(10),PLCHRDY(10),ROS(10)
      COMMON /P3/ PENC,TR,SP,CORWDTH(2),DEL
      COMMON /P4/ PSTART,ICHAFF,CHAFFS,CHAFFE,IECM,ECMS,ECME,IDECOY,DSTR
     1,DEND,CHEFF(10),ECMEFF(10)
      COMMON /P44/ IPINT,DF(10),DECPPEN(10),PENCDEC
      COMMON /NHLN/ NSAM(66,10,2)
C
      DIMENSION ICOM(70)
C
      DATA ((ICOM(I),I=1,54)=4HNPHI,5HNPENT,4HPENC,2HTR,2HSP,2H  ,2HHM,2
     1HVP,3HROS,3HNML,7HENDCASE,6HENDJOB,6H      ,5HSALSZ,7HPLCHRDY,4H
     2   ,3HDEL,4HILOW,5HALPHA,2H  ,5H     ,2H  ,5HNDIST,6H      ,2H  ,4H
     3ISET,7H       ,5HISETL,6HASPECT,3HPKH,3HPKL,5HTITLE,6HPSTART,6HICH
     4AFF,6HCHAFFS,6HCHAFFE,5HCHEFF,4HIECM,4HECMS,4HECME,6HECMEFF,6HIDEC
     5OY,4HDSTR,4HDEND,6HTERIND,4HSRLD,6H      ,7HDECPPEN,7HPENCDEC,5HIP
     6INT,2HDF,7HCORWDTH,5HNSAML,5HNSAMH)
C
C         INITIALIZE ILLEGITIMATE IDENTIFIER FLAG
       IX=0
C         EJECT PAGE
       PRINT 33
C         READ IDENTIFIER CARD
     1 READ 34, NAME,X
       PRINT 35, NAME,X
C
C         BEGIN CHECKING FOR IDENTIFIER MATCH
```

```
C
      IF (NAME.EQ.ICOM(1)) NPHI=X
      IF (NAME.NE.ICOM(2)) GO TO 2
      NPENT=X
      READ 36, (NPT(I),I=1,NPENT)
      PRINT 37, (NPT(I),I=1,NPENT)
    2 CONTINUE
      IF (NAME.EQ.ICOM(3)) PENC=X
      IF (NAME.EQ.ICOM(4)) TR=X
      IF (NAME.EQ.ICOM(5)) SP=X
      IF (NAME.EQ.ICOM(7)) HM=X
      IF (NAME.EQ.ICOM(8)) VP=X
      IF (NAME.NE.ICOM(9)) GO TO 3
      READ 39, (ROS(I),I=1,10)
      PRINT 38, (ROS(I),I=1,10)
    3 CONTINUE
      IF (NAME.NE.ICOM(10)) GO TO 4
      READ 36, (NML(I),I=1,10)
      PRINT 37, (NML(I),I=1,10)
    4 CONTINUE
      IF (NAME.EQ.ICOM(11)) GO TO 31
      IF (NAME.EQ.ICOM(12)) CALL EXIT
      IF (NAME.NE.ICOM(14)) GO TO 5
      READ 39, (SALSZ(I),I=1,10)
      PRINT 38, (SALSZ(I),I=1,10)
    5 CONTINUE
      IF (NAME.NE.ICOM(15)) GO TO 6
      READ 39, (PLCHRDY(I),I=1,10)
      PRINT 38, (PLCHRDY(I),I=1,10)
    6 CONTINUE
      IF (NAME.EQ.ICOM(17)) DEL=X
      IF (NAME.EQ.ICOM(18)) ILOW=X
      IF (NAME.NE.ICOM(19)) GO TO 7
      READ 39, (ALPHA(I),I=1,10)
      PRINT 38, (ALPHA(I),I=1,10)
    7 CONTINUE
      IF (NAME.EQ.ICOM(23)) NDIST=X
      IF (NAME.NE.ICOM(26)) GO TO 9
C        READ HIGH ALTITUDE SCENARIO SAM DATA
      READ 40, (ISET(I),I=1,10)
      PRINT 41, (ISET(I),I=1,10)
      PRINT 42
      DO 8 J=1,10
      IF (ISET(J).NE.1) GO TO 8
      I=J
      READ 43, I,NLCHR(I),PD(I),PT(I),TOF(I),TD(I),SR(I),SV(I),DZ(I),RR(
     1I),HRS(I)
      PRINT 43, I,NLCHR(I),PD(I),PT(I),TOF(I),TD(I),SR(I),SV(I),DZ(I),RR
     1(I),HRS(I)
    8 CONTINUE
```

```
    9 CONTINUE
      IF (NAME.NE.ICOM(28)) GO TO 11
C       READ LOW ALTITUDE SCENARIO SAM DATA
      READ 40, (ISETL(I),I=1,10)
      PRINT 41, (ISETL(I),I=1,10)
      PRINT 42
      DO 10 J=1,10
      IF (ISETL(J).NE.1) GO TO 10
      I=J
      READ 43, I,NLCHRL(I),PDL(I),PTL(I),TDLF(I),TDL(  ,SRL(I),SVL(I),DZ
     1L(I),RRL(I),HRSL(I)
      PRINT 43, I,NLCHRL(I),PDL(I),PTL(I),TDLF(I),TDL   ),SRL(I),SVL(I),D
     1ZL(I),RRL(I),HRSL(I)
   10 CONTINUE
   11 CONTINUE
      IF (NAME.NE.ICOM(29)) GO TO 13
      READ 39, (ASPECT(I),I=1,10)
      PRINT 38, (ASPECT(I),I=1,10)
      DO 12 I=1,10
      ASPECT(I)=ASPECT(I)*6.2831853/360.0
   12 CONTINUE
   13 CONTINUE
      IF (NAME.NE.ICOM(30)) GO TO 14
      READ 39, (PKSS(I),I=1,10)
      PRINT 44, (PKSS(I),I=1,10)
   14 CONTINUE
      IF (NAME.NE.ICOM(31)) GO TO 15
      READ 39, (PKSL(I),I=1,10)
      PRINT 38, (PKSL(I),I=1,10)
   15 CONTINUE
      IF (NAME.NE.ICOM(32)) GO TO 16
      READ 45, (ITITLE(I),I=1,8)
      PRINT 46, (ITITLE(I),I=1,8)
   16 CONTINUE
      IF (NAME.EQ.ICOM(33)) PSTART=X
      IF (NAME.EQ.ICOM(34)) ICHAFF=X
      IF (NAME.EQ.ICOM(35)) CHAFFS=X
      IF (NAME.EQ.ICOM(36)) CHAFFE=X
      IF (NAME.NE.ICOM(37)) GO TO 17
      READ 39, (CHEFF(I),I=1,10)
      PRINT 38, (CHEFF(I),I=1,10)
   17 CONTINUE
      IF (NAME.EQ.ICOM(38)) IECM=X
      IF (NAME.EQ.ICOM(39)) ECMS=X
      IF (NAME.EQ.ICOM(40)) ECME=X
      IF (NAME.NE.ICOM(41)) GO TO 18
      READ 39, (ECMEFF(I),I=1,10)
      PRINT 38, (ECMEFF(I),I=1,10)
   18 CONTINUE
      IF (NAME.EQ.ICOM(42)) IDECOY=X
```

```
      IF (NAME.EQ.ICOM(43)) DSTR=X
      IF (NAME.EQ.ICOM(44)) DEND=X
      IF (NAME.NE.ICOM(45)) GO TO 19
      READ 39, (TERIND(I),I=1,10)
      PRINT 38, (TERIND(I),I=1,10)
   19 CONTINUE
      IF (NAME.NE.ICOM(46)) GO TO 20
      READ 39, (SRLD(I),I=1,10)
      PRINT 38, (SRLD(I),I=1,10)
   20 CONTINUE
      IF (NAME.NE.ICOM(48)) GO TO 21
      READ 39, (DECPPEN(I),I=1,10)
      PRINT 38, (DECPPEN(I),I=1,10)
   21 CONTINUE
      IF (NAME.EQ.ICOM(49)) PENCDEC=X
      IF (NAME.EQ.ICOM(50)) IPINT=X
      IF (NAME.NE.ICOM(51)) GO TO 24
      IF (X.LE.0.) GO TO 23
      DO 22 I=1,10
   22 DF(I)=X
      GO TO 24
   23 CONTINUE
      READ 39, (DF(I),I=1,10)
      PRINT 38, (DF(I),I=1,10)
   24 CONTINUE
      IF (NAME.NE.ICOM(52)) GO TO 25
      READ 39, CORWDTH(1),CORWDTH(2)
      PRINT 38, CORWDTH(1),CORWDTH(2)
   25 CONTINUE
      IF (NAME.NE.ICOM(53).A.NAME.NE.ICOM(54)) GO TO 29
C        READ DEFENSE SCENARIO (250)
      K=1
      IF (NAME.EQ.ICOM(54)) K=2
      READ 36, NNL
      PRINT 36, NNL
      PRINT 32
      NNN=X
      DO 26 I=1,66
   26 NSAM(I,NNN,K)=0
      DO 27 I=1,NNL
      READ 36, NZON,NSAM(NZON+1,NNN,K)
   27 PRINT 36, NZON,NSAM(NZON+1,NNN,K)
      DO 28 I=2,66
   28 NSAM(I,NNN,K)=NSAM(I,NNN,K)+NSAM(I-1,NNN,K)
   29 CONTINUE
C        DETERMINE IF IDENTIFIER IS LEGITIMATE
      DO 30 I=1,54
      IF (ICOM(I).EQ.NAME) GO TO 1
   30 CONTINUE
C        IDENTIFIER IS NOT LEGITIMATE
```

```
      IX=1
      PRINT 47, NAME
      GO TO 1
C        EXIT IF AT LEAST ONE ILLEGITIMATE IDENTIFIER
   31 IF (IX.EQ.1) CALL EXIT
      RETURN
C
C
C
   32 FORMAT (13H ZONE  NUMBER)
   33 FORMAT (1H1)
   34 FORMAT (A7,3X,E20.8)
   35 FORMAT (10X,A7,3X,F10.3)
   36 FORMAT (10I5)
   37 FORMAT (10X,10I5)
   38 FORMAT (10X,10F10.2)
   39 FORMAT (10F8.0)
   40 FORMAT (10I1)
   41 FORMAT (10X,10I1)
   42 FORMAT (7H T NL/S,6X,2HPD,5X,2HPT,5X,3HTDF,5X,2HTD,6X,2HSR,8X,2HSV
     1,5X,2HDZ,4X,2HRR,8X,3HHRS)
   43 FORMAT (I2,I3,3X,8F8.2,F8.3)
   44 FORMAT (10X,10F10.2)
   45 FORMAT (8A10)
   46 FORMAT (10X,8A10)
   47 FORMAT (2X,A7,21H IS NOT IN DICTIONARY)
      END
```