Probabilistic Assessment of Tornado-Borne Missile Speeds

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ERRATA

In Equation 13, delete: i = 1, j = 1; k = 1; \& = 1; N_1; N_L; N_j; N_4.

Immediately following Equation 13, insert sentence: Where the summation extends over those values of i, j, k, and \& that are simultaneously associated with hitting missile speeds greater than $V_{max}^m$. 
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1. INTRODUCTION

Estimates of tornado-borne missile speeds for nuclear power plant design purposes were previously presented by the writers in Ref. 1. One of the assumptions on which these estimates were based was that the missiles start their motion from a point located on the tornado translation axis, at a distance upwind of the tornado center equal to the radius of maximum circumferential wind speeds. In addition, it was assumed in Ref. 1 that the speed with which a missile hits a target is equal to the maximum speed, denoted by $V_{H}^{\text{max}}$, that the same missile would attain if its trajectory were unobstructed by the presence of any obstacle.

Clearly, neither of these assumptions is realistic. The purpose of this report is to attempt an approach to the missile speed problem that takes into account the fact that the initial positions of the missiles with respect to the tornado center are not necessarily those assumed in Ref. 1, and that the speeds with which the missiles hit the targets are not necessarily equal to $V_{H}^{\text{max}}$.

2. APPROACHES TO THE PROBABILISTIC STUDY OF MISSILE SPEEDS

Estimates of tornado-borne missile speeds corresponding to a specified probability of occurrence must take into account a large number of factors, including: rate of occurrence of tornadoes at the geographical location of concern; tornado wind field; number, location, and physical characteristics of potential missiles, including aerodynamic characteristics; nature and magnitude of forces opposing or inducing missile take-off; and location and configuration of potential targets.

One possible approach to a probabilistic study of tornado-borne missile speeds is the use of Monte Carlo techniques in conjunction with probability distributions of the various parameters characterizing the factors listed above. Such an approach would involve a volume of computation that is likely to be enormous indeed. Moreover, many of the pertinent probability distributions are not, or are still only poorly, known. The writers believe that an exhaustive Monte Carlo approach of the type outlined above might be warranted for long-term research purposes, particularly if significant improvements are anticipated in the probabilistic modeling of the various factors involved. However, for the present, it is the writers opinion that much of the probabilistic and physical modeling of tornadoes and tornado-borne missiles that has evolved since the publication of Ref. 1 is not sufficiently well established to be relied upon confidently in the study presented herein.

For these reasons, the objective of this investigation has been limited to attempting a comparison between the speeds estimated in Ref. 1 on the one hand, and hit speeds obtained on the basis of the assumptions listed below, on the other hand:
1. The models used in Ref. 1 are correct with respect to (a) the probabilistic behavior of the tornado wind speeds, (b) the tornado wind field, and (c) the aerodynamic behavior of the tumbling missiles.

2. The number, geometry, and location of the potential targets is specified.

3. A specified number of missiles with specified properties and locations are present at the nuclear power plant site at the time of the tornado strikes, i.e., a "missile set-up" is specified. Alternatively, several possible missile set-ups are specified, each associated with a specified probability of occurrence, the sum of these probabilities being unity.

4. A specified area over or near the nuclear power plant is swept by tornadoes with specified wind speeds, to which there correspond probabilities of occurrence consistent with the estimates of Ref. 2.

5. Each missile starts its motion when the tornado-induced aerodynamic force, $F_a$, acting upon the missile at rest is such that

$$ F_a > F $$

where $F$ = specified force. For convenience, the value of $F$ is specified via a coefficient, $k$, in the relation

$$ F = kmg $$

where $m$ = mass of missile, and $g$ = acceleration of gravity.

3. PROBABILITIES OF OCCURRENCE OF TORNADOES

Consider some point $A$ within a nuclear power plant site. Let the event, $T$, that a tornado will hit point $A$, and the event, $(T, V_{torn})$, that the point $A$ will be hit by a tornado with maximum speeds larger than $V_{torn}$ be denoted by $P_A(T)$ and $P_A(T, V_{torn})$, respectively.

Assume first, for the sake of simplicity, that the direction of the tornado axes of translation is fixed. Point $A$ will be hit by a tornado only if the distance, $L$, from point $A$ to the tornado axis of translation is $L < b/2$, where $b =$ tornado path width (Fig. 1). An additional condition is that the distance, $M$, (along the axis of translation) between point $A$ and the center, $C$, of the tornado path area be $M < d/2$, where $d =$ tornado path length (Fig. 1). The following relation holds:

$$ P_A(T, V_{torn}) = \int_{-d/2}^{d/2} \int_{-b/2}^{b/2} P_A(T, V_{torn}, m, \xi) \, dm \, d\xi \quad (3) $$
where \( P_A(T, V_{\text{torn}}, m, \xi) \) \( dm \, d\xi = \text{probability of occurrence of a tornado such that the center of its path is inside the elemental area } d\xi \, dm. \)

The effect of a tornado upon the trajectory of a given missile that it is going to pick up is clearly dependent upon the distance between that missile and the tornado axis of translation. On the other hand, if Eq. 1 holds, the effect of the distance between the missile and the center }\text{C} is in most cases unimportant. Indeed, this effect is significant only if \( M = -d/2 \). The tornado path length, \( d \), being of the order of 10 km, the probability that \( M = -d/2 \) is relatively small. Therefore, the influence of \( M \) upon the probabilistic estimates of missile hit speeds will generally be small.

Denoting the marginal distribution of \( P_A \) with respect to \( m \) by \( P_A \), Eq. 3 is written as

\[
P_A(T, V_{\text{torn}}) = \int_{-b/2}^{b/2} P_A(T, V_{\text{torn}}, \xi) \, d\xi
\]

where \( P_A(T, V_{\text{torn}}, \xi) \) \( d\xi = \text{probability of occurrence of tornadoes that strike point } A \text{ and have axes of translation crossing the segment } d\xi, \text{ the midpoint of which is at a distance } \xi \text{ from } A \text{ (Fig. 2a). In terms of discrete probabilities, Eq. 4 is written as}

\[
P_A(T, V_{\text{torn}}) = \sum_{i=1}^{N_1} P_A(T, V_{\text{torn}}, L_i)
\]

\[
P_A(T, V_{\text{torn}}, L_i) = \int_{L_i - \Delta L/2}^{L_i + \Delta L/2} P_A(T, V_{\text{torn}}, \xi) \, d\xi
\]

and

\[
N_1 = \frac{b}{\Delta L}
\]

\( P_A(T, V_{\text{torn}}, L_i) \) is the probability of occurrence of tornadoes that strike point \( A \) and have axes of translation crossing the segment \( \Delta L \), the midpoint of which is at a distance \( L_i \) from \( A \) (Fig. 2b). Since it is reasonable to assume that the probability of occurrence of tornadoes across the distance \( b \) is uniform,

\[
P_A(T, V_{\text{torn}}, L_i) = \frac{1}{N_1} P_A(T, V_{\text{torn}})
\]

Let now the probability that point \( A \) will be struck by tornadoes with maximum wind speeds included in the interval \( (V_{\text{torn}} - \Delta V_{\text{torn}}, V_{\text{torn}} + \Delta V_{\text{torn}}) \) be denoted by \( P_A(T, V_{\text{torn}}) \Delta V_{\text{torn}} \). Tails of probability density functions \( P_A(T, V_{\text{torn}}) \) can be estimated from the results of Ref. 2, as shown in Appendix A.
n additional assumption used in this work pertains to the choice of the width b. The estimates of probabilities of occurrence \( P_A(T) \) and \( P_A(T, V_{\text{torn}}) \) given in Ref. 2 are based, for any geographical location, upon the average individual tornado area, a (or, equivalently, upon the product of the average tornado path length, \( d \), by the average individual tornado path width, \( b \). For consistency with the estimates of Ref. 2, it is assumed in this report that if \( V_{\text{torn}} \) is equal to the maximum wind speed of the Design Basis Tornado [2], then to a probability \( P_A(T, V_{\text{torn}}) = 10^{-7} \) /year there corresponds in Fig. 2 a value of the tornado path width \( b = b_0 \).

A final comment pertains to the case where the direction, \( a \), of the tornado axis of translation is a random variable. In that case

\[
P_A(T, V_{\text{torn}}) = \sum_i P_A(T, V_{\text{torn}}, a_i) \tag{9}
\]

where \( P_A(T, V_{\text{torn}}, a_i) = \) probability that point A will be struck by a tornado with maximum wind speed larger than \( V_{\text{torn}} \), and with a translation axis having a direction defined by \( a_i \).

4. PROBABILITIES OF OCCURRENCE OF MISSILE HIT SPEEDS

4.1 SIMPLIFIED ANALYSIS

For the purposes of this report, a simplified analysis is defined as one that is based upon the following assumptions:

1. The number, geometry, and location of the potential targets is specified.

2. A missile set-up (consisting of number and location of missiles, all the missiles having the same aerodynamic coefficient, area, and mass) is specified. The probability of occurrence of this set-up is assumed to be unity.

3. The coefficient \( k \) in Eq. 2 is specified.

4. Tornadoes with a specified maximum wind speed, \( V_{\text{torn}} \), equal to the maximum wind speed of the Design Basis Tornado will occur in such a way that their axes of translation will cross, and be normal to, a specified segment with length \( b \). The segment \( b \) is divided into \( N_1 \) subsegments. The probability of occurrence of a tornado, \( T_i \), whose axis of translation passes through the center of such a subsegment is \( 10^{-7}/N_1 \) per year.

The effect of tornado \( T_i \) is to sweep a number of missiles and cause some of them to hit the targets with various horizontal speeds. Let the highest of these speeds be denoted by \( V_{\text{max}}^m \). The probability of occurrence of at least one hit with speed \( V_{\text{max}}^m \) is then \( 10^{-7}/N_1 \). If, of the \( N_1 \) tornadoes \( T_i \)
(i = 2, 3, ..., N_j), a number q will be associated with hitting missile speeds greater than \( V^\text{max}_m \), the probability of occurrence of hits with speeds equal to or greater than \( V^\text{max}_m \) will be \( 10^{-7} \frac{q}{N^2} \).

4.2 ANALYSIS IN WHICH VARIABILITIES OF ADDITIONAL FACTORS ARE CONSIDERED

The procedure for estimating missile speeds developed in this report can also take into account the variabilities of the following factors:

1. Missile set-ups. As previously indicated, it is possible to specify \( N_2 \) missile set-ups, denoted by \( S_{M_i} \) (i = 1, 2, ..., \( N_2 \)), each set-up being associated with a probability of occurrence \( P(S_{M_i}) \). The sum of these probabilities is unity.

2. Tornado type. Each tornado type is characterized by a maximum tornado wind speed and by the corresponding wind field as defined in Ref. 1. Let each tornado type be identified by the symbol \( T_{V_i} \) (i = 1, 2, ..., \( N_3 \)). Probabilities of occurrence of various tornado types, \( P(T_{V_i}) \), can be estimated as suggested in Appendix A or by using additional information given, e.g., in Ref. 2. Note that

\[
\sum_{i=1}^{N_3} P(T_{V_i}) = 10^{-7}C \tag{10}
\]

In Eq. 10, \( C = 1 \) if the maximum wind speed in the least intense of the i tornado types, \( \min[V_{\text{torn} i}] \), is equal to the maximum wind speed of the Design basis Tornado at the geographical location of concern, \( V^\text{DBT}_{\text{torn}} \). If \( \min[V_{\text{torn} i}] < V^\text{DBT}_{\text{torn}} \), then \( C > 1 \).

3. Direction of Tornado Axis of Translation. Let each translation axis direction be denoted by \( a_i \). To each \( a_i \) (i = 1, 2, ..., \( N_4 \)), there corresponds a probability of occurrence \( P(a_i) \), the sum of these probabilities being unity.

The probabilities of occurrence of missile hit speeds when the variabilities of factors 1 through 3 above are taken into account are calculated in a manner similar to that indicated for the case of the simplified analysis, except that the probability of occurrence of the largest hitting missile speed, \( V^\text{max}_m \), associated with a given missile set-up \( S_{M_j} \), a given tornado type, \( T_{V_k} \), a given direction of the axis of translation, \( a_\| \), and a given portion of the axis of translation, \( L_\perp \), is

\[
P_{ijkm}(V^\text{max}_m) = P(L_\perp)P(S_{M_j})P(T_{V_k})P(a_\|) \tag{11}
\]
where
\[ P(L_1) = \frac{b}{n} \]  
(12a)
\[ = \frac{1}{N_L} \]  
(12b)

The total probability of occurrence of hitting missile speeds equal to or larger than \( V_m^{\text{max}} \) is
\[ P(V_m^{\text{max}}) = \sum_{i=1}^{N_1} \sum_{j=1}^{N_L} \sum_{k=1}^{N_j} \sum_{m=1}^{N_4} P(L_i) P(S_{i,j}) P(T_{v_k}) P(\alpha_m) \]  
(13)

5. NUMERICAL EXAMPLES

Figure 3 shows the plan of a BWR (Boiling Water Reactor) nuclear power plant in which the structures denoted by 1, 2, 4, 8, and 12 (i.e., containment, auxiliary building, control building, Diesel generator building, and standby service water cooling tower and basin, respectively) are considered to be important to safety and, therefore must "be designed to withstand the effects of natural phenomena such as tornadoes without loss of capability to perform their safety functions" [3]. These structures have been redrawn schematically in figure 4 to conform to the computer program input format. In Figure 4 the targets are numbered from 1 through 9, and the areas (or "lots") where the potential missiles are located before the tornado landing are numbered from I through IV. The missiles at rest are assumed to be at ground level (elevation zero). Elevations of the top horizontal plane of the targets are also shown in Figure 4 (for example, for target 1 the elevation of the top plane is +40m). All dimensions of Figure 4 are in meters.

5.1 SIMPLIFIED ANALYSES

A set of basic cases was defined, corresponding to the following assumptions:

1. The target consists of any of the buildings denoted by 1 through 9 in figure 4.

2. The positions of the areas (lots) where the missiles are located before the tornado landing are those shown in figure 4.

3. The number and locations of missiles within these areas are as follows:
   - Lot I: One row of two missiles (distance between missiles in x direction: 15m)
   - Lot II: Two rows of 15 missiles each (distance between rows in y direction: 12m; distance between missiles in x direction: 3m)
   - Lot III: One missile
- Lot IV: Twenty rows of 14 missiles each (distance between rows in y direction: 3m; distance between missiles in x direction: 11m).

4. The tornado axes of translation cross, and are normal to, a segment $0'B = b = 150$ m (see figure 4). The segment $b$ is divided into 15 equal subintervals.

5. The angle $\alpha$ between the tornado translation axis and the y axis (figure 4) is $22^\circ$.

Calculations corresponding to the basic case were carried out for various values of $V_{\text{torn}}$ and of $k$, for five types of missiles:

- I - automobile with properties assumed in Ref. 1
- II - automobile with properties based on data suggested in Ref. 4
- III - wood plank
- IV - 12" pipe with properties assumed in Ref. 1
- V - 12" pipe with properties based on data suggested in Ref. 5.

The drag coefficient, area, and mass of these missiles are given in Table 1.

In addition to calculations based on the assumptions just described and corresponding to the basic case, calculations were carried out with one or two of these assumptions modified, all other assumptions being unchanged. The modified assumptions were the following:

- The angle $\alpha$ is different from $22^\circ$
- The coordinates $x_0''$, $y_0''$ of point $0''$ (defining the position of lot IV) are different from those given in figure 4.
- The number of missiles in lot IV is different from that previously given for the basic case. (The modified number of missiles is denoted by $n$, while the number of missiles given for the basic case is denoted by $n_{\text{typ}}$)
- The target consists of building 9 only, rather than of any of the buildings 1 through 9 of figure 4.

The results of the calculations are given in Table 1 for three probability levels. Note that Table 1 is divided into subsections, each identified by a group of three symbols. The first symbol is a Roman numeral indicating the missile type (I through V); the second symbol is a lower case letter indicating the maximum tornado wind speed (a, for 360 mph; b, for 300 mph; c, for 240 mph; d, for 380 mph; and e, for 200 mph); the third symbol is an arabic numeral (1, for the basic case; 2, for the case in which lot IV is displaced; 3, for the case in which the number of missiles is changed; and 4, for the case where the target consists of building 9 only).

Note also that for certain parameter values, missile speeds corresponding to the probability $10^{-7}$, and/or $0.5 \times 10^{-7}$, and/or $0.06 \times 10^{-7}$ are not entered into Table 1 (see, for example, subsection Ia2 of Table 1 for $k = 0.9$, $x_0'' = 60$ m, $y_0'' = -200$m). This reflects the fact that at least one,
eight, or fourteen respectively of the $N_1 = 15$ tornadoes hitting the site (each with probability $10^{-7}/15$) fail to hurl at least one missile onto the target.

5.2 COMMENTS ON RESULTS OF SIMPLIFIED ANALYSES

Effect of Parameter $k$. Note from subsection Ilal of Table 1 that as $k$ increases, the speeds corresponding to a given probability level increase. Indeed, if $k$ were extremely small, the motion of the object would in general begin at a time when the distance between the object and the tornado center would still be relatively large, so that the object would in effect be swept away from the zone of strong tornado winds. Conversely, if $k$ is relatively large, the object stays in its rest position until the tornado winds are sufficiently strong to hurl it with great force. The trend observed in subsections Ilal is also evident in other subsections.

However, an increased $k$ does not necessarily result in an increased hit speed (at some given probability level): see, for example, subsection IIIIdl of Table 1). One explanation is that to an increased $k$ there may correspond certain missile trajectories that do not result in a hit. Therefore, even though the speed of the missile at some point on its trajectory would increase if $k$ were increased, this is irrelevant from the standpoint of this project as long as the missile with the higher speed would fail to hit a target. Another explanation for occasional decreases of the hit speed (for any given probability) as $k$ increases is that, in certain cases, to a smaller value of $k$ there could correspond more unfavorable initial conditions for some missiles.

Direction of Tornado Axis of Translation. For each type of missile, subsections of Table 1 identified by symbols ending in al and bl include in parentheses and brackets speeds corresponding to the angles $\alpha = 1^\circ$ and $\alpha = 45^\circ$, respectively (as opposed to $\alpha = 22^\circ$, which constitutes the basic case). It can be seen that, for the cases investigated, the tornado effects are generally less severe in this example for $\alpha = 1^\circ$ and $\alpha = 45^\circ$ than for $\alpha = 22^\circ$.

Influence of Location of Lot IV. In this example, lot IV contains the bulk of the missiles present on the nuclear power plant grounds. It is seen that if the lot is at a relatively large distance from the targets ($y_o'' = -500$ m), the hit speeds are, as expected, lower than those corresponding to $y_o'' = 100$ m in most, though not all cases.

Note that changing the position of lot IV from $x_o'' = 60$ m, $y_o'' = -100$ m to $x_o'' = 160$ m, $y_o'' = -200$ m, does not always result in a reduction of the hit speeds corresponding to a given probability. For example, such a reduction (from 43 m/s to 13 m/s) does occur for hit speeds with $10^{-7}$ probability of occurrence in the case of missile I with $k = 0.9$ and $V_{torn} = 360$ mph (subsection Ia2 of Table 1). However, in the case of missile I with $k = 0.9$ and $V_{torn} = 240$ mph, there occurs an increase from 33 m/s if $x_o'' = 60$ m, $y_o'' = -100$ m, to 43 m/s if $x_o'' = 160$ m, $y_o'' = -200$ m.
Influence of Number of Missiles. The number of missiles in lot IV was reduced in the ratios n/n_{typ} = 1/8 and n/n_{typ} = 1/50. This was done by reducing the number of rows of missiles, and of missiles in each row, from 20 to 5, and 14 to 7, respectively, for n/n_{typ} = 1/8, and from 20 to 2, and 14 to 3 respectively, for n/n_{typ} = 1/50. For the case n/n_{typ} = 1/8 the effect of the reduction upon the missile speeds corresponding to a given probability of hit was generally small, although, in many instances, of the N_{I} = 15 tornadoes assumed to hit the plant site (each having a probability of occurrence 10^{-7}/N_{I}) at least one hurled no missile onto the targets when the number of missiles was reduced. For the case n/n_{typ} = 1/50 the effect of the reduction was, as expected more significant in most situations.

When the number of missiles in lot IV was increased by a factor of 4 (this was done in the case of the plank and of the 12" pipe), the resulting missile hit speeds were found not to differ, or not to differ significantly, from those obtained in the basic case.

Influence of Target Area. If the only target considered was building 9, as opposed to any of the buildings 1 through 9, the missile speeds corresponding to a given probability level were generally reduced with respect to those obtained for the basic case, although in a few cases the reductions were small.

5.3 COMPARISON BETWEEN VALUES OF HIT SPEEDS FOR THE BASIC CASE AND VALUES V_{H}^{max} OBTAINED IN REF. 1

It is recalled that the tornado paths assumed in Table 1 are defined by the position of the segment 0'B of figure 4. It may well be that a different set of paths might in certain instances have resulted in more severe hits. It appears therefore reasonable to use for design purposes speeds corresponding in Table 1 to the probability level 0.5 x 10^{-7}, say, rather than exactly 10^{-7}.

Missile I ("NBS" Automobile), V_{torn} = 360 mph: V_{H}^{max} = 59 m/s (Ref. 1). It is seen from Table 1, subsections Ia1 through Ia4, that for k < 0.9, V_m < 47 m/s in all cases investigated. While it may be argued that the restraining force for an automobile would usually be of the order of magnitude of the friction force, i.e., k = 0.3, say, it is conceivable that some automobiles might experience some form of blockage that would raise k to higher values. However, if such blockage occurs, it might be expected that the number of automobiles affected by it would be small. Table Ia3 shows that if n/n_{typ} = 1/50 (i.e., if there are only about five automobiles in lot IV, then V_m corresponding to the probability 0.5 x 10^{-7} decreases both for k = 0.9 and k = 2.0 from 45 m/s and 64 m/s to 39 m/s and 17 m/s respectively.

Therefore, in view of the results of subsections Ia1 through Ia4 of Table 1, and assuming that very few automobiles have restraining forces with k ≥ 1.3, it is reasonable to assume for design purposes that the speed of missile I is:

V_m = 50 m/s for V_{torn} = 360 mph
This is a less severe design criterion than that suggested in Ref. 1.

**Missile I ("NBS" Automobile), \( V_{torn} = 300 \) mph; \( V_{max}^{H} = 52 \) m/s (Ref. 1)**

A comparison between subsections Ia1 and Ibl of Table 1 shows that the values of the hit speeds corresponding to a probability of occurrence 0.5 \( \times 10^{-7} \) are about the same for \( V_{torn} = 300 \) mph as for \( V_{torn} = 360 \) mph, except in the case \( k = 0.3 \), when they are considerably larger for \( V_{torn} = 300 \) mph. This is a surprising result, which could be explained by noting that, for constant \( k \), the missile will begin its motion from a position that is closer to the tornado zone of strongest winds when the oncoming tornado is weaker; such a position may in certain cases result in larger hit speeds.

A comparison between subsections Ibl and Ial suggests that design hit speeds for missile I should be only marginally lower in the case \( V_{torn} = 300 \) mph than in the case \( V_{torn} = 360 \) mph. It is therefore suggested that for design purposes,

\[
V_{m} = 48 \text{ m/s for } V_{torn} = 300 \text{ mph}
\]

This value is somewhat lower than that suggested in Ref. 1.

**Missile I ("NBS" Automobile), \( V_{torn} = 240 \) mph; \( V_{max}^{H} = 41 \) m/s (Ref. 1)**

A comparison between subsections Ia1, Ibl and Icl of Table 1, for both the 0.5 \( \times 10^{-7} \) and the 10\(^{-7} \) probability levels, suggests that for design purposes it is reasonable to assume

\[
V_{m} = 45 \text{ m/s for } V_{torn} = 240 \text{ mph}
\]

This value is somewhat larger than that suggested in Ref. 1.

Subsections Idl and Iel show values of \( V_{m} \) for \( V_{torn} = 380 \) mph and \( V_{torn} = 200 \) mph, respectively. The values for \( V_{m} \) for \( V_{torn} = 380 \) mph differ little from the corresponding values for \( V_{torn} = 360 \) mph. Note also that, for \( k = 0.5 \) and \( k = 0.9 \), values of \( V_{m} \) for the probability level 10\(^{-7} \) are, surprisingly, considerably higher for \( V_{torn} = 200 \) mph than the corresponding values for \( V_{torn} = 240 \) mph.

**Missile II ("EPRI" Automobile), \( V_{torn} = 360 \) mph; \( V_{max}^{H} = 46 \) m/s (Ref. 1)**

From a comparison of subsections IIa1 and Ia1 it is seen that, for the same values of \( k \), speeds \( V_{m} \) are higher for Missile II ("EPRI" automobile) than for Missile I ("NBS" automobile). The explanation offered is similar to that advanced in connection with Missile I, \( V_{torn} = 300 \) mph. In this case Missile II will begin its motion from a position that is closer to the tornado zone of strongest winds than would Missile I (the coefficient \( k \) being the same), with a consequent increase in the value of \( V_{m} \).
Therefore it appears reasonable to suggest for design purposes

\[ V_m = 55 \text{ m/s for } V_{torn} = 360 \text{ mph} \]

This is considerably higher than the value suggested in Ref. 1.

Missile II ("EPRI" Automobile), \( V_{torn} = 300 \text{ mph} \): \( V_{H}^{\text{max}} = 27 \text{ m/s} \) (Ref. 1)

A comparison between subsections IIbl and IIa of Table 1 suggests that, for design purposes, the hit speed should be at least

\[ V_m = 50 \text{ m/s for } V_{torn} = 300 \text{ mph} \]

i.e., a larger value than that suggested in Ref. 1.

From subsections IIcl, IIbl, and IIa, it would follow that, for design purposes,

\[ V_m = 45 \text{ m/s for } V_{torn} = 240 \text{ mph} \]

versus 7 m/s, as suggested in Ref. 1.

Missile III (Plank), \( V_{torn} = 360 \text{ mph} \): \( V_{H}^{\text{max}} = 83 \text{ m/s} \) (Ref. 1)

Subsections IIIal through IIa4 of Table 1 suggest that, for design purposes, missile speeds need not exceed

\[ V_m = 60 \text{ m/s for } V_{torn} = 360 \text{ mph} \]

i.e., about 20 m/s less than the value of Ref. 1. Note that the restraining force for a plank can be many times larger than the plank weight. This is a factor that was considered in selecting the speed suggested above.

Missile III (Plank), \( V_{torn} = 300 \text{ mph} \): \( V_{H}^{\text{max}} = 70 \text{ m/s} \) (Ref. 1)

Subsections IIIbl and IIb2 of Table 1 suggest that, for design purposes, missile speeds need not exceed

\[ V_m = 55 \text{ m/s for } V_{torn} = 300 \text{ mph} \]

i.e., 15 m/s less than suggested in Ref. 1.

Missile III (Plank), \( V_{torn} = 240 \text{ mph} \): \( V_{H}^{\text{max}} = 58 \text{ m/s} \) (Ref. 1)

Subsections IIIcl through IIIc3 of Table 1 suggest that, for design purposes, missile speeds need not exceed

\[ V_m = 50 \text{ m/s for } V_{torn} = 240 \text{ mph} \]

i.e., 8 m/s less than suggested in Ref. 1.
Missile IV ("NBS 12" Pipe), $V_{\text{torn}} = 360$ mph: $V_{\text{max}}^{\text{max}} = 47$ m/s (Ref. 1)

Subsections IVa1 through IVa4 of Table 1 suggest that, for design purposes,

$V_{\text{m}} = 65$ m/s for $V_{\text{torn}} = 360$ mph

i.e., considerably more than suggested in Ref. 1. As in the case of the plank, the writers believe that, in the case of the pipe, the restraining force can be larger than the missile weight.

Missile IV ("NBS" 12" Pipe), $V_{\text{torn}} = 300$ mph: $V_{\text{max}}^{\text{max}} = 28$ m/s (Ref. 1)

Subsections IVb1 and IVb2 suggest that, for design purposes,

$V_{\text{m}} = 60$ m/s for $V_{\text{torn}} = 360$ mph

i.e., more than twice as high as suggested in Ref. 1.

Missile IV ("NBS" 12" Pipe), $V_{\text{torn}} = 240$ mph: $V_{\text{max}}^{\text{max}} = 7$ m/s (Ref. 1)

Subsections IVc1 through IVc3 of Table 1 suggest that for design purposes,

$V_{\text{m}} = 50$ m/s for $V_{\text{torn}} = 240$ m/s

i.e., more than seven times as high as suggeted in Ref. 1.

Missile V ("JFC-AES" 12" Pipe), $V_{\text{torn}} = 360$ mph: $V_{\text{max}}^{\text{max}} = 38$ m/s (Ref. 1)

Subsection Vb1 of Table 1 suggests that, for design purposes,

$V_{\text{m}} = 62$ m/s for $V_{\text{torn}} = 360$ mph

This is close to the value obtained for missile IV

Missile V ("JFC-AES" 12" Pipe), $V_{\text{torn}} = 300$ mph: $V_{\text{max}}^{\text{max}} = 15$ m/s (Ref. 1)

Subsection Vb1 of Table 1 suggests that, for design purposes:

$V_{\text{m}} = 52$ m/s for $V_{\text{torn}} = 300$ mph

This is somewhat less than the value $V_{\text{m}} = 60$ m/s obtained for missile IV.

Missile V ("JFC-AES" 12" Pipe), $V_{\text{torn}} = 240$ mph: $V_{\text{max}}^{\text{max}} = 7$ m/s (Ref. 1)

Subsection Vc1 of Table 1 suggests that for design purposes:

$V_{\text{m}} = 45$ m/s for $V_{\text{torn}} = 240$ mph

i.e., about 10% less than for missile IV.
5.4 ANALYSIS IN WHICH ADDITIONAL VARIABILITIES ARE TAKEN INTO ACCOUNT

Calculations were also carried out for missile II (compact automobile) and k = 0.3, k = 0.5, and k = 0.9, using the assumptions 1 through 5 that define the basic case in the preceding simplified analyses. However, unlike the cases previously dealt with, it was not assumed that the site is swept by tornadoes with equal intensities \( V_{\text{torn}} \). Rather, it was assumed that in Eq. 13 the number of tornado types is \( k = 11 \), and that the probabilities of occurrence at the site of tornado types \( T_{v_k} \) are as follows:

<table>
<thead>
<tr>
<th>( T_{v_k} ) (mph)</th>
<th>200</th>
<th>240</th>
<th>300</th>
<th>310</th>
<th>320</th>
<th>330</th>
<th>340</th>
<th>350</th>
<th>360</th>
<th>370</th>
<th>380</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 10^7 P(T_{v_k}) ) per year</td>
<td>100</td>
<td>20</td>
<td>1.6</td>
<td>1.4</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
<td>0.8</td>
<td>0.50</td>
<td>0.25</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Note that \( P(T_{v_k}) \) for \( k \geq 9 \) (i.e., the probability of occurrence of tornadoes with maximum speeds equal to or larger than 360 mph) is approximately \( 10^{-7} \). The probabilities \( P(T_{v_k}) \) were calculated from Appendix A1 for maximum tornado speeds equal to a larger than 310 mph, as follows:

\[
P(T_{v_k}) = p(T, V_{\text{torn}}) \quad V_{\text{torn}} = \frac{V_{k+1} - V_{k-1}}{2}
\]

For maximum tornado speeds less than 310 mph, the curve representing the percent probability of exceeding the value of any given wind speed, included in Ref. 2, was used as a guide.

The resulting missile speed hits \( V_m \), and their calculated probabilities of occurrence, are given below:

**Missile II ("EPRI" automobile)**

<table>
<thead>
<tr>
<th>( k )</th>
<th>( V_m ) (m/s)</th>
<th>( P ) (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>47</td>
<td>2.47 x 10^{-7}</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>0.73 x 10^{-7}</td>
</tr>
<tr>
<td></td>
<td>49</td>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
<td>58</td>
<td>1.44 x 10^{-7}</td>
</tr>
<tr>
<td></td>
<td>59</td>
<td>0.65 x 10^{-7}</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>0.9</td>
<td>66</td>
<td>1.12 x 10^{-7}</td>
</tr>
<tr>
<td></td>
<td>67</td>
<td>0.68 x 10^{-7}</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>0</td>
</tr>
</tbody>
</table>
It can be seen that the results differ relatively little for those corresponding to the probability level $0.5 \times 10^{-7}$ in subsection IIa1 of Table 1 ($V_{torn} = 360$ mph), i.e., 48 m/s versus 44 m/s ($k = 0.3$), 59 m/s versus 58 m/s ($k = 0.5$), and 67 m/s versus 64 m/s ($k = 0.9$).

6. SUMMARY AND CONCLUSIONS

A procedure was developed for estimating speeds with which postulated missiles hit any given set of targets in a nuclear power plant or similar installation. Hit speeds corresponding to probabilities of occurrence of the order of $10^{-7}$ were calculated for a given nuclear power plant, under various assumptions concerning the magnitude of the force opposing missile take-off, direction of tornado axis of translation, number and initial location of missiles, and size of target area. One feature of the calculations that distinguishes them from those of Ref. 1 is that the missile motion does not start from an initial position postulated a priori. Rather, the initial position of the missile is determined by the condition that the aerodynamic force induced by the tornado wind field exceed a specified restraining force specified via a nondimensional parameter $k$. As explained in some detail in Section 4.2, the results no longer depend on the parameter $C_pA/m$ alone, but on that parameter and on the parameter $k$.

The results of the calculations suggest that it is reasonable to use the following hit speeds, $V_m$, for design purposes, in lieu of the speeds given in Ref. 1:

**Missile I ("NBS" automobile)**

Region I (see Ref. 2): $V_m = 50$ m/s in lieu of 59 m/s  
Region II: $V_m = 48$ m/s in lieu of 52 m/s  
Region III: $V_m = 45$ m/s in lieu of 41 m/s

**Missile II ("EPRI" automobile)**

Region I: $V_m = 55$ m/s in lieu of 59 m/s  
Region II: $V_m = 50$ m/s in lieu of 52 m/s  
Region III: $V_m = 45$ m/s in lieu of 41 m/s

**Missile III (plank)**

Region I: $V_m = 60$ m/s in lieu of 83 m/s  
Region II: $V_m = 55$ m/s in lieu of 70 m/s  
Region III: $V_m = 50$ m/s in lieu of 58 m/s

**Missile IV ("NBS" 12" pipe)**

Region I: $V_m = 65$ m/s in lieu of 47 m/s  
Region II: $V_m = 60$ m/s in lieu of 28 m/s  
Region III: $V_m = 50$ m/s in lieu of 7 m/s
Missile V ("JFC-AES" 12" Pipe)

Region I: \( V_m = 62 \text{ m/s} \) in lieu of 38 m/s  
Region II: \( V_m = 52 \text{ m/s} \) in lieu of 15 m/s  
Region III: \( V_m = 45 \text{ m/s} \) in lieu of 6 m/s

The design values suggested above are tentative and subject to three major qualifications. First, they are based upon climatological, meteorological and aerodynamic models that are uncertain. In the writers' opinion these uncertainties are extremely difficult, if not impossible, to quantify in the present state of the art. Second, the suggested values are based upon a single nuclear power plant basic set-up. Calculations carried out for a different set-up might yield somewhat different results. Third, although calculations were carried out assuming thousands of tornado hits sweeping hundreds of missiles each, these calculations have not been exhaustive even for the single basic plant set-up dealt with herein. This was due to the limited resources (approximately one half man year, including computer program development) available for this project.

In spite of these limitations, the writers believe that useful new insights into the tornado-borne missile speed problems have been obtained, and that an efficient and practical computational tool has been developed, that can be used for the purpose of further investigating individual power plants and of refining the design criteria suggested herein.

7. REFERENCES


Table 1. Values of Horizontal Missile Speeds at Time of Hit, \( V_m \), in Meters Per Second, Corresponding to Various Probabilities of Occurrence

I. Automobile with \( C_D = 2.0, A = 6.3m^2, m = 1810 \) kg

\[
V_{\text{torn}} = 360 \text{ mph} (V_H^{\text{max}} \text{ per NBSIR 76-1050: } 59 \text{ m/s})
\]

Ia. Basic Case

10^7 x Probability

<table>
<thead>
<tr>
<th>( k )</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>20 (20)</td>
<td>22 (23)</td>
<td>24 (24)</td>
</tr>
<tr>
<td>0.5</td>
<td>27</td>
<td>37</td>
<td>43</td>
</tr>
<tr>
<td>0.9</td>
<td>43</td>
<td>45</td>
<td>47</td>
</tr>
<tr>
<td>1.3</td>
<td>53 (45) [39]</td>
<td>54 (54) [55]</td>
<td>55 (56) [56]</td>
</tr>
<tr>
<td>2.0</td>
<td>62</td>
<td>64</td>
<td>65</td>
</tr>
</tbody>
</table>

Numbers between parentheses correspond to tornado direction \( \alpha = 1^\circ \)

Numbers between brackets correspond to tornado direction \( \alpha = 45^\circ \)

Ia2. Influence of Location of Lot IV

10^7 x Probability

<table>
<thead>
<tr>
<th>( k )</th>
<th>( x_0'' ), ( y_0'' )</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>60, - 100</td>
<td>43</td>
<td>45</td>
<td>47</td>
</tr>
<tr>
<td>160, - 200</td>
<td></td>
<td>13</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>60, - 500</td>
<td></td>
<td>39</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>60, - 100</td>
<td></td>
<td>62</td>
<td>64</td>
<td>65</td>
</tr>
<tr>
<td>2.0</td>
<td>60, - 200</td>
<td>40</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>160, - 200</td>
<td></td>
<td>63</td>
<td>64</td>
<td>65</td>
</tr>
</tbody>
</table>

\(^a\)meters
Ia3. Influence of Number of Missiles

<table>
<thead>
<tr>
<th>$k$</th>
<th>$\frac{n}{n_{typ}}$</th>
<th>$x_o^a$, $y_o^a$</th>
<th>$10^7 x$ Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td></td>
<td>60, -100</td>
<td></td>
</tr>
<tr>
<td>1/50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>60, -200</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>160, -200</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>60, -100</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>1/50</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2.0</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>60, -200</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>160, -200</td>
<td>16</td>
<td>62</td>
</tr>
</tbody>
</table>

$a$ meters

Ia4. Influence of Target Area

<table>
<thead>
<tr>
<th>$k$</th>
<th>$10^7 x$ Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>0.5</td>
<td>27 (27) 36 (37) 41 (43)</td>
</tr>
<tr>
<td>0.9</td>
<td>- (43) 41 (45) 45 (47)</td>
</tr>
<tr>
<td>1.3</td>
<td>- (53) 49 (54) 54 (54)</td>
</tr>
<tr>
<td>2.0</td>
<td>- (62) 58 (64) 64 (65)</td>
</tr>
</tbody>
</table>

$^a$Numbers not between parentheses represent speeds of hits on building 9 only. Numbers between parentheses represent speeds of hits on any of the buildings 1 through 9.
Ib. $V_{torn} = 300 \text{ mph} \left( V_H^{\text{max}} \right) \text{ per NBSIR 76-1050: 52 m/s}$

Ibl. Basic Case, and Influence of Target Area$^a$

$10^7 \times \text{Probability}$

<table>
<thead>
<tr>
<th>$k$</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>22</td>
<td>31</td>
<td>35</td>
</tr>
<tr>
<td>0.5</td>
<td>22 (22)</td>
<td>33 (33)</td>
<td>37 (37)</td>
</tr>
<tr>
<td>0.9</td>
<td>38 (38)</td>
<td>46 (41)</td>
<td>48 (47)</td>
</tr>
<tr>
<td>1.3</td>
<td>52 (−)</td>
<td>53 (47)</td>
<td>54 (54)</td>
</tr>
<tr>
<td>2.0</td>
<td>59 (−)</td>
<td>60 (55)</td>
<td>60 (60)</td>
</tr>
</tbody>
</table>

$^a$Numbers not between parentheses represent speeds of hits on any of buildings 1 through 9.
Numbers between parentheses represent speeds of hits on building 9 only.

Ib2. Influence of Location of Lot IV

$10^7 \times \text{Probability}$

<table>
<thead>
<tr>
<th>$k$</th>
<th>$x_o^a$, $y_o^a$</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>60, −100</td>
<td>38</td>
<td>46</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>60, −200</td>
<td>38</td>
<td>39</td>
<td>40</td>
</tr>
</tbody>
</table>

$^a$Meters
Ic.  $V_{\text{torn}} = 240 \text{ mph} \left( V_{\text{H}}^{\text{max}} \text{ per NBSIR 76-1050: 41 m/s} \right)$

Ic1. Basic Case$^a$

<table>
<thead>
<tr>
<th>$k$</th>
<th>$1.0$</th>
<th>$0.5$</th>
<th>$0.06$</th>
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</thead>
<tbody>
<tr>
<td>$0.3$</td>
<td>$22$</td>
<td>$26$</td>
<td>$31$</td>
</tr>
<tr>
<td>$0.5$</td>
<td>$16$</td>
<td>$33$</td>
<td>$34$</td>
</tr>
<tr>
<td>$0.9$</td>
<td>$33$</td>
<td>$44$</td>
<td>$46$</td>
</tr>
<tr>
<td>$1.3$</td>
<td>$47$ (35) [-]</td>
<td>$50$ (50) [50]</td>
<td>$41$ (51) [52]</td>
</tr>
<tr>
<td>$2.0$</td>
<td>$53$</td>
<td>$53$</td>
<td>$54$</td>
</tr>
</tbody>
</table>

$^a$Numbers between parentheses correspond to tornado direction $\alpha = 1^\circ$
Numbers between brackets correspond to tornado direction $\alpha = 45^\circ$

Ic2. Influence of Location of Lot IV

<table>
<thead>
<tr>
<th>$k$</th>
<th>$x_0^\prime$, $y_0^\prime$ $^a$</th>
<th>$1.0$</th>
<th>$0.5$</th>
<th>$0.06$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$60$, $-100$</td>
<td>$33$</td>
<td>$44$</td>
<td>$46$</td>
<td></td>
</tr>
<tr>
<td>$60$, $-200$</td>
<td>$32$</td>
<td>$33$</td>
<td>$45$</td>
<td></td>
</tr>
<tr>
<td>$0.9$</td>
<td>$160$, $-200$</td>
<td>$43$</td>
<td>$44$</td>
<td>$45$</td>
</tr>
<tr>
<td>$60$, $-200$</td>
<td>$32$</td>
<td>$33$</td>
<td>$33$</td>
<td></td>
</tr>
<tr>
<td>$60$, $-100$</td>
<td>$53$</td>
<td>$50$</td>
<td>$54$</td>
<td></td>
</tr>
<tr>
<td>$2.0$</td>
<td>$60$, $-200$</td>
<td>$-33$</td>
<td>$49$</td>
<td></td>
</tr>
<tr>
<td>$160$, $-200$</td>
<td>$-21$</td>
<td>$35$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$meters

Ic3. Influence of Number of Missiles

<table>
<thead>
<tr>
<th>$k$</th>
<th>$n/n_{\text{typ}}$</th>
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<th>$0.5$</th>
<th>$0.06$</th>
</tr>
</thead>
<tbody>
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<td>$44$</td>
<td>$46$</td>
<td></td>
</tr>
<tr>
<td>$0.9$</td>
<td>$1/8$</td>
<td>$33$</td>
<td>$44$</td>
<td>$46$</td>
</tr>
<tr>
<td>$1/50$</td>
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<td></td>
</tr>
<tr>
<td>$1$</td>
<td>$53$</td>
<td>$53$</td>
<td>$54$</td>
<td></td>
</tr>
<tr>
<td>$2.0$</td>
<td>$1/8$</td>
<td>$47$</td>
<td>$55$</td>
<td>$54$</td>
</tr>
<tr>
<td>$1/50$</td>
<td>$-21$</td>
<td>$54$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Idl. $V_{\text{torn}} = 380$ mph

Idl. Basic Case

$10^7 \times \text{Probability}$

<table>
<thead>
<tr>
<th>k</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>42</td>
<td>44</td>
<td>47</td>
</tr>
<tr>
<td>2.0</td>
<td>64</td>
<td>65</td>
<td>66</td>
</tr>
</tbody>
</table>

Iel. $V_{\text{torn}} = 200$ mph

Iel. Basic Case

$10^7 \times \text{Probability}$

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<th>0.06</th>
</tr>
</thead>
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<tr>
<td>0.5</td>
<td>34</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>0.9</td>
<td>40</td>
<td>42</td>
<td>43</td>
</tr>
<tr>
<td>1.3</td>
<td>44</td>
<td>45</td>
<td>46</td>
</tr>
<tr>
<td>2.0</td>
<td>-</td>
<td>-</td>
<td>45</td>
</tr>
</tbody>
</table>
II Automobile with $C_D = 1.5, A = 3.8 \text{ m}^2, m = 1810 \text{ kg}$

IIa. $V_{\text{torn}} = 360 \text{ mph} \left( V_{\text{H}}^\text{max} \right) \text{ per NBSIR 76-1050: 46 m/s}$

IIa1. Basic Case

<table>
<thead>
<tr>
<th>$k$</th>
<th>$1.0 \times \text{Probability}$</th>
<th>$0.5 \times \text{Probability}$</th>
<th>$0.06 \times \text{Probability}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>-</td>
<td>44</td>
<td>48</td>
</tr>
<tr>
<td>0.5</td>
<td>27</td>
<td>58</td>
<td>60</td>
</tr>
<tr>
<td>0.9</td>
<td>55</td>
<td>64</td>
<td>69</td>
</tr>
<tr>
<td>1.3</td>
<td>62 (38) [39]</td>
<td>68 (63) [55]</td>
<td>71 (70) [56]</td>
</tr>
<tr>
<td>2.0</td>
<td>67</td>
<td>71</td>
<td>74</td>
</tr>
</tbody>
</table>

$^a$Numbers between parentheses correspond to tornado direction $\alpha = 1^\circ$

Numbers between brackets correspond to tornado direction $\alpha = 45^\circ$

IIa2. Influence of Location of Lot IV

<table>
<thead>
<tr>
<th>$k$</th>
<th>$x_0''$, $y_0''$ $^a$</th>
<th>$1.0 \times \text{Probability}$</th>
<th>$0.5 \times \text{Probability}$</th>
<th>$0.06 \times \text{Probability}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>60, - 100</td>
<td>55</td>
<td>64</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>60, - 100</td>
<td>-</td>
<td>64</td>
<td>68</td>
</tr>
<tr>
<td>2.0</td>
<td>160, - 200</td>
<td>64</td>
<td>65</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>60, - 500</td>
<td>-</td>
<td>-</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>60, - 100</td>
<td>67</td>
<td>71</td>
<td>74</td>
</tr>
<tr>
<td>2.0</td>
<td>60, - 200</td>
<td>-</td>
<td>74</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>160, - 200</td>
<td>66</td>
<td>70</td>
<td>74</td>
</tr>
</tbody>
</table>

$^a$meters
IIa3. Influence of Number of Missiles

<table>
<thead>
<tr>
<th>k</th>
<th>( \frac{n}{n_{\text{typ}}} )</th>
<th>( x_0', y_0' )</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>55</td>
<td>64</td>
<td>69</td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>60, - 100</td>
<td>-</td>
<td>54</td>
<td>63</td>
<td>66</td>
</tr>
<tr>
<td>1/50</td>
<td></td>
<td>-</td>
<td>-</td>
<td>55</td>
<td>66</td>
</tr>
<tr>
<td>0.9</td>
<td></td>
<td>64</td>
<td>68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>60, - 200</td>
<td>-</td>
<td>49</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>60, - 200</td>
<td>64</td>
<td>66</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>1/50</td>
<td></td>
<td>63</td>
<td>66</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>60, - 500</td>
<td>-</td>
<td>-</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>60, - 500</td>
<td>-</td>
<td>-</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>67</td>
<td>71</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>60, - 100</td>
<td>57</td>
<td>71</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>1/50</td>
<td></td>
<td>-</td>
<td>51</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td>64</td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>60, - 200</td>
<td>-</td>
<td>64</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>60, - 200</td>
<td>66</td>
<td>70</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>160, - 200</td>
<td>63</td>
<td>70</td>
<td>74</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)meters

IIa4. Influence of Target Area

<table>
<thead>
<tr>
<th>k</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>27</td>
<td>(27)</td>
<td>44</td>
</tr>
<tr>
<td>0.9</td>
<td>41</td>
<td>(55)</td>
<td>54</td>
</tr>
<tr>
<td>1.3</td>
<td>40</td>
<td>(62)</td>
<td>63</td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td></td>
<td>(67)</td>
</tr>
</tbody>
</table>

\(^a\)Numbers not between parentheses represent speeds of hits on building 9 only. Numbers between parentheses represent speeds of hits on any of the buildings 1 through 9.
IIb. \( V_{\text{torn}} = 300 \text{ mph} \) (\( V_{H}^{\text{max}} \) per NBSIR 76-1050: 27 m/s)

IIbl. Basic Case, and Influence of Target Area\(^a\)

\[
\begin{array}{cccc}
  k & 1.0 & 0.5 & 0.06 \\
  0.3 & 42 & 46 & 48 \\
  0.5 & 44 (-) & 53 (45) & 56 (54) \\
  0.9 & 52 (30) & 57 (57) & 61 (61) \\
  1.3 & 56 (-) & 60 (60) & 62 (62) \\
  2.0 & 53 (-) & 54 (55) & 55 (56) \\
\end{array}
\]

\(^a\)Number not between parentheses represent speeds of hits on any of buildings 1 through 9.
Number between parentheses represent speeds of hits on buildings 9 only.

IIb2. Influence of Location of Lot IV

\[
\begin{array}{cccc}
  k & x_0^a, y_0^a & 1.0 & 0.5 & 0.06 \\
  0.9 & 60, -100 & 52 & 57 & 61 \\
  60, -500 & 30 & 30 & 30 \\
\end{array}
\]

\(^a\)meters

23
IIc. \( V_{\text{torn}} = 240 \text{ mph} \) (\( V_m \) per NBSIR 76-1050: 7 m/s)

IIcl. Basic Case\(^a\)

\[
\begin{array}{ccc}
\text{k} & 1.0 & 0.5 & 0.06 \\
0.3 & 35 & 42 & 46 \\
0.5 & 40 & 46 & 49 \\
0.9 & 46 & 47 & 51 \\
1.3 & 45 (39) (30) & 45 (55) [45] & 45 (56) [46] \\
2.0 & - & - & - \\
\end{array}
\]

\(^a\)Numbers between parentheses correspond to tornado direction \( \alpha = 1^\circ \)
Numbers between brackets correspond to tornado direction \( \alpha = 45^\circ \)

IIc2. Influence of Location of Lot IV

\[
\begin{array}{cccc}
\text{k} & x_0'', y_0'' \text{\(^a\)} & 1.0 & 0.5 & 0.06 \\
0.9 & 60, - 100 & 46 & 47 & 52 \\
& 60, - 200 & 26 & 51 & 52 \\
& 160, - 200 & 26 & 51 & 52 \\
& 60, - 500 & 26 & 28 & 31 \\
2.0 & 60, - 100 & - & - & - \\
& 60, - 200 & - & - & - \\
& 160, - 200 & - & - & - \\
\end{array}
\]

\(^a\)meters

IIc3. Influence of Number of Missiles

\[
\begin{array}{cccc}
\text{k} & n/n_{\text{typ}} & 1.0 & 0.5 & 0.06 \\
1 & 46 & 47 & 51 \\
0.9 & 1/8 & 40 & 47 & 49 \\
& 1/50 & 26 & 40 & 48 \\
2.0 & 1/8 & - & - & - \\
& 1/50 & - & - & - \\
\end{array}
\]
IId. \( V_{\text{torn}} = 380 \text{ mph} \)

IId1. Basic Case

\[
\begin{array}{cccc}
10^7 \times \text{Probability} \\
\hline
k & 1.0 & 0.5 & 0.06 \\
0.9 & 62 & 65 & 70 \\
2.0 & 71 & 74 & 77 \\
\end{array}
\]

IId. \( V_{\text{torn}} = 200 \text{ mph} \)

IIIda. Basic Case

\[
\begin{array}{cccc}
10^7 \times \text{Probability} \\
\hline
k & 1.0 & 0.5 & 0.06 \\
0.5 & 37 & 40 & 41 \\
0.9 & 19 & 35 & 38 \\
1.3 & - & 37 & 42 \\
2.0 & - & - & - \\
\end{array}
\]
III Plank with $C_D = 2.0$, $A = 0.7 \text{ m}^2$, $m = 51.9 \text{ kg}$

IIIa. $V_{torn} = 360 \text{ mph} \left( V_{H}^{\text{max}} \text{ per NBSIR 76-1050: } 83 \text{ m/s} \right)$

IIIa1. Basic Case$^a$

$10^7 \times \text{Probability}$

<table>
<thead>
<tr>
<th>k</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>26</td>
<td>27</td>
<td>29</td>
</tr>
<tr>
<td>0.5</td>
<td>40</td>
<td>54</td>
<td>63</td>
</tr>
<tr>
<td>0.9</td>
<td>40</td>
<td>55</td>
<td>62</td>
</tr>
<tr>
<td>1.3</td>
<td>40 (-) [28]</td>
<td>55 (50) [53]</td>
<td>62 (58) [60]</td>
</tr>
<tr>
<td>2.0</td>
<td>31</td>
<td>55</td>
<td>62</td>
</tr>
<tr>
<td>5.0</td>
<td>34 (-) [28]</td>
<td>55 (-) [53]</td>
<td>62 (58) [60]</td>
</tr>
</tbody>
</table>

$^a$Numbers between parentheses correspond to tornado direction $\alpha = 1^\circ$

Numbers between bracket correspond to tornado direction $\alpha = 45^\circ$

IIIa2. Influence of Location of Lot IV

$10^7 \times \text{Probability}$

<table>
<thead>
<tr>
<th>k</th>
<th>$x_o^{\alpha}$, $y_o^{\alpha}$</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>60, - 100</td>
<td>40</td>
<td>55</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>60, - 200</td>
<td>38</td>
<td>55</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>160, - 200</td>
<td>40</td>
<td>53</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>60, - 500</td>
<td>21</td>
<td>55</td>
<td>61</td>
</tr>
<tr>
<td>2.0</td>
<td>60, - 100</td>
<td>31</td>
<td>55</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>60, - 200</td>
<td>40</td>
<td>61</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>160, - 200</td>
<td>32</td>
<td>55</td>
<td>62</td>
</tr>
<tr>
<td>5.0</td>
<td>60, - 100</td>
<td>34</td>
<td>55</td>
<td>62</td>
</tr>
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<td>60, - 200</td>
<td>33</td>
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<td>62</td>
</tr>
<tr>
<td></td>
<td>160, - 200</td>
<td>34</td>
<td>55</td>
<td>62</td>
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</tbody>
</table>

$^a$meters
### IIIa3. Influence of Numbers of Missiles

<table>
<thead>
<tr>
<th>k</th>
<th>n/n_{typ}</th>
<th>x_\alpha'' \ y_\alpha'' \text{^a}</th>
<th>1.0</th>
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<th>0.06</th>
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</thead>
<tbody>
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<td>-----</td>
<td>------</td>
</tr>
<tr>
<td>0.9</td>
<td>1</td>
<td>60, - 100</td>
<td>40</td>
<td>55</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>1/8</td>
<td></td>
<td>40</td>
<td>55</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>1/50</td>
<td></td>
<td>40</td>
<td>55</td>
<td>61</td>
</tr>
<tr>
<td>2.0</td>
<td>1</td>
<td>60, - 200</td>
<td>38</td>
<td>55</td>
<td>62</td>
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<tr>
<td></td>
<td>1/8</td>
<td></td>
<td>38</td>
<td>55</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>160, - 200</td>
<td>40</td>
<td>53</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>1/8</td>
<td></td>
<td>37</td>
<td>53</td>
<td>61</td>
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<td>31</td>
<td>55</td>
<td>62</td>
</tr>
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<td>4</td>
<td>60, - 100</td>
<td>31</td>
<td>55</td>
<td>62</td>
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<tr>
<td></td>
<td>1/8</td>
<td></td>
<td>31</td>
<td>53</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>1/50</td>
<td></td>
<td>31</td>
<td>53</td>
<td>62</td>
</tr>
<tr>
<td>5.0</td>
<td>1</td>
<td>60, - 200</td>
<td>33</td>
<td>55</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>1/8</td>
<td></td>
<td>33</td>
<td>55</td>
<td>62</td>
</tr>
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<td>34</td>
<td>55</td>
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</tr>
<tr>
<td></td>
<td>1/8</td>
<td></td>
<td>34</td>
<td>55</td>
<td>62</td>
</tr>
</tbody>
</table>

\text{^a} \text{meters}
### IIIa4. Influence of Target Area

\begin{align*}
\text{\(10^7\) x Probability} \\
\begin{array}{|c|c|c|c|}
\hline
k & 1.0 & 0.5 & 0.06 \\
\hline
0.9 & (40) & 50 (55) & 58 (62) \\
2.0 & 30 (31) & 50 (55) & 57 (62) \\
5.0 & (34) & 49 (55) & 57 (62) \\
\hline
\end{array}
\end{align*}

*Numbers not between parentheses represent speeds of hits on building 9 only. Numbers between parentheses represent speeds of hits on any of the buildings 1 through 9.*

### IIIb. \(V_{torn} = 300\text{ mph (}\nu^\text{max}_{H}\text{ per NBSIR 76-1050: 70 m/s)}\)

#### IIIba. Basic Case, and Influences of Target Area

\begin{align*}
\text{\(10^7\) x Probability} \\
\begin{array}{|c|c|c|c|}
\hline
k & 1.0 & 0.5 & 0.06 \\
\hline
0.3 & 22 & 23 & 25 \\
0.5 & 35 & 50 & 58 \\
0.9 & 20 (-) & 52 (50) & 58 (58) \\
1.3 & 25 & 52 & 58 \\
2.0 & 38 (33) & 52 (50) & 58 (57) \\
5.0 & (-) & 52 (49) & 58 (57) \\
\hline
\end{array}
\end{align*}

*Numbers not between parentheses represent speeds of hits on any of buildings 1 through 9. Numbers between parentheses represent speeds of hits a building 9 only.*

### IIIb2. Influence of Location of Lot IV

\begin{align*}
\text{\(10^7\) x Probability} \\
\begin{array}{|c|c|c|c|}
\hline
k & x_o^a, y_o^a & 1.0 & 0.5 & 0.06 \\
\hline
0.9 & 60, -100 & 20 & 52 & 58 \\
& 60, -500 & 20 & 52 & 57 \\
\hline
\end{array}
\end{align*}

*a meters*
IIIc. $V_{\text{torn}} = 240 \text{ mph} \ (V_{H}^{\text{max}} \ \text{per NBSIR 76-1050:} \ 58 \text{ m/s})$

IIIch. Basic Case$^a$

<table>
<thead>
<tr>
<th>$k$</th>
<th>$1.0$</th>
<th>$0.5$</th>
<th>$0.06$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>19</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>0.5</td>
<td>16</td>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td>0.9</td>
<td>30</td>
<td>46</td>
<td>50</td>
</tr>
<tr>
<td>1.3</td>
<td>32 (33) [33]</td>
<td>47 (38) [49]</td>
<td>50 (50) [51]</td>
</tr>
<tr>
<td>2.0</td>
<td>35</td>
<td>47</td>
<td>50</td>
</tr>
<tr>
<td>5.0</td>
<td>- (–) [45]</td>
<td>47 (–) [49]</td>
<td>50 (49) [53]</td>
</tr>
</tbody>
</table>

$^a$Numbers between parentheses correspond to tornado direction $\alpha = 1^\circ$

Numbers between brackets correspond to tornado direction $\alpha = 45^\circ$

IIIc2. Influence of Location of Lot IV

<table>
<thead>
<tr>
<th>$k$</th>
<th>$x_{o''}, y_{o''}$</th>
<th>$1.0$</th>
<th>$0.5$</th>
<th>$0.06$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>60, - 100</td>
<td>30</td>
<td>46</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>60, - 200</td>
<td>29</td>
<td>46</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>160, - 200</td>
<td>31</td>
<td>46</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>60, - 500</td>
<td>38</td>
<td>47</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>60, - 100</td>
<td>35</td>
<td>47</td>
<td>50</td>
</tr>
<tr>
<td>2.0</td>
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<td>-</td>
<td>47</td>
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<tr>
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<td>-</td>
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<td>-</td>
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</tr>
<tr>
<td></td>
<td>160, - 200</td>
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</tbody>
</table>

$^a$meters
### IIIc3. Influence of Number of Missiles

<table>
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<tr>
<th>$k$</th>
<th>$n/n_{typ}$</th>
<th>1.0</th>
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<th>0.06</th>
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<td></td>
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<td>32</td>
<td>47</td>
<td>51</td>
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<tr>
<td></td>
<td>1/8</td>
<td>30</td>
<td>46</td>
<td>50</td>
</tr>
<tr>
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<td>50</td>
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<td>-</td>
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<td>1/50</td>
<td>-</td>
<td>46</td>
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<td>47</td>
<td>50</td>
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<td></td>
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<td>-</td>
<td>46</td>
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<tr>
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<td>-</td>
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<td>-</td>
<td>47</td>
<td>50</td>
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<tr>
<td></td>
<td>1/50</td>
<td>-</td>
<td>46</td>
<td>50</td>
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</tbody>
</table>

### IIId. $V_{torn} = 380$ mph

#### IIIIdl. Basic Case

<table>
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<tr>
<th>$k$</th>
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<th>0.06</th>
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<td>2.0</td>
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<td>63</td>
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<td>5.0</td>
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<td>54</td>
<td>63</td>
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</table>

### IIIe. $V_{torn} = 380$ mph

#### IIIel. Basic Case

<table>
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<th>0.06</th>
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<tr>
<td>0.9</td>
<td>27</td>
<td>39</td>
<td>45</td>
</tr>
<tr>
<td>1.3</td>
<td>28</td>
<td>39</td>
<td>45</td>
</tr>
<tr>
<td>2.0</td>
<td>32</td>
<td>42</td>
<td>45</td>
</tr>
<tr>
<td>5.0</td>
<td>-</td>
<td>42</td>
<td>45</td>
</tr>
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</table>
IV 12" Pipe with $C_D = 0.7$, $A = 1.6 \text{ m}^2$, $m = 341 \text{ kg}$

IVa. $V_{torn} = 360 \text{ mph} \left( v_{H}^{\text{max}} \right.$ per NBSIR 76-1050: 47 m/s)

IVa1. Basic Case

<table>
<thead>
<tr>
<th>k</th>
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<th>0.06</th>
</tr>
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<td>0.3</td>
<td>-</td>
<td>36</td>
<td>45</td>
</tr>
<tr>
<td>0.5</td>
<td>29</td>
<td>57</td>
<td>59</td>
</tr>
<tr>
<td>0.9</td>
<td>55</td>
<td>64</td>
<td>68</td>
</tr>
<tr>
<td>1.3</td>
<td>61 (40) [36]</td>
<td>68 (63) [70]</td>
<td>71 (71) [71]</td>
</tr>
<tr>
<td>2.0</td>
<td>70</td>
<td>73</td>
<td>75</td>
</tr>
</tbody>
</table>

*Number between parentheses correspond to tornado direction $\alpha = 1^\circ$
Number between brackets correspond to tornado direction $\alpha = 45^\circ$

IVa2. Influence of Location of Lot IV

<table>
<thead>
<tr>
<th>k</th>
<th>$x_0$, $y_0$</th>
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<th>0.06</th>
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</thead>
<tbody>
<tr>
<td>60, - 100</td>
<td>55</td>
<td>64</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>60, - 200</td>
<td>-</td>
<td>65</td>
<td>67</td>
</tr>
<tr>
<td>160, - 200</td>
<td>-</td>
<td>66</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>60, - 500</td>
<td>-</td>
<td>-</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>60, - 100</td>
<td>-</td>
<td>68</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>60, - 200</td>
<td>-</td>
<td>71</td>
<td>73</td>
</tr>
<tr>
<td>160, - 200</td>
<td>-</td>
<td>-</td>
<td>73</td>
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</tr>
</tbody>
</table>

*a meters
### IVa3. Influence of Number of Missiles

<table>
<thead>
<tr>
<th>k</th>
<th>n/n\textsubscript{typ}</th>
<th>x\textsubscript{o}, y\textsubscript{o}\textsuperscript{a}</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td></td>
<td>55</td>
<td>64</td>
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</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>58</td>
<td>66</td>
<td>68</td>
</tr>
<tr>
<td>1/4</td>
<td></td>
<td></td>
<td>-</td>
<td>61</td>
<td>67</td>
</tr>
<tr>
<td>1/16</td>
<td></td>
<td></td>
<td>-</td>
<td>52</td>
<td>67</td>
</tr>
<tr>
<td>0.9</td>
<td>1</td>
<td>60, - 200</td>
<td>-</td>
<td>65</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>1/4</td>
<td></td>
<td>-</td>
<td>41</td>
<td>66</td>
</tr>
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<td>67</td>
</tr>
<tr>
<td></td>
<td>1/4</td>
<td></td>
<td>-</td>
<td>65</td>
<td>67</td>
</tr>
<tr>
<td>2.0</td>
<td>1</td>
<td>60, - 100</td>
<td>70</td>
<td>73</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>1/4</td>
<td></td>
<td>70</td>
<td>73</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>1/16</td>
<td></td>
<td>56</td>
<td>69</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>62</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>60, - 200</td>
<td>-</td>
<td>71</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>1/4</td>
<td></td>
<td>-</td>
<td>71</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>1/4</td>
<td>160, - 200</td>
<td>70</td>
<td>71</td>
<td>72</td>
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</tbody>
</table>

\textsuperscript{a}meters

### IVa4. Influence of Target Area\textsuperscript{a}

<table>
<thead>
<tr>
<th>k</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>- (55)</td>
<td>54 (64)</td>
<td>61 (68)</td>
</tr>
<tr>
<td>2.0</td>
<td>61 (70)</td>
<td>62 (73)</td>
<td>62 (75)</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Numbers not between parentheses represent speeds of hits on building 9 only. Numbers between parentheses represent speeds of hits on any of the buildings 1 through 9.
IVb. \( V_{\text{torn}} = 300 \text{ mph} \left(V_{\text{H}}^\text{max} \right) \text{ per NBSIR 76-1050: } 28 \text{ m/s} \)

IVb1. Basic Case, and Influence of Target Area\(^a\)

<table>
<thead>
<tr>
<th>( k )</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>45</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>27</td>
<td>53</td>
<td>56</td>
</tr>
<tr>
<td>0.9</td>
<td>52 (−)</td>
<td>57 (54)</td>
<td>59 (61)</td>
</tr>
<tr>
<td>1.3</td>
<td>58</td>
<td>60</td>
<td>62</td>
</tr>
<tr>
<td>2.0</td>
<td>62 (61)</td>
<td>62 (62)</td>
<td>62 (62)</td>
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</tbody>
</table>

\(^a\)Numbers not between parentheses represent speeds of hits on any of buildings 1 through 9. Numbers in parentheses represent speeds of hits on building 9 only.

IVb2. Influence of Location of Lot IV

<table>
<thead>
<tr>
<th>( k )</th>
<th>( x_0^\circ, y_0^\circ )</th>
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<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>60, −100 (52) 57 59</td>
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</tr>
<tr>
<td></td>
<td>60, −500 (52) − 30</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)meters

IVc. \( V_{\text{torn}} = 240 \text{ mph} \left(V_{\text{H}}^\text{max} \right) \text{ per NBSIR 76-1050: } 7 \text{ m/s} \)

IVc1. Basic Case\(^a\)

<table>
<thead>
<tr>
<th>( k )</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>23</td>
<td>26</td>
<td>31</td>
</tr>
<tr>
<td>0.5</td>
<td>39</td>
<td>45</td>
<td>49</td>
</tr>
<tr>
<td>0.9</td>
<td>45</td>
<td>47</td>
<td>52</td>
</tr>
<tr>
<td>1.3</td>
<td>52 (26) [50] 52 (52) [52] 53 (52) [53]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
</tbody>
</table>

\(^a\)Numbers between parentheses correspond to tornado direction \( \alpha = 1^\circ \). Numbers between brackets correspond to tornado direction \( \alpha = 45^\circ \).
IVc2. Influence of Location of Lot IV

\[ 10^7 \times \text{Probability} \]

<table>
<thead>
<tr>
<th>k</th>
<th>( x_0^<em>, y_0^</em> )</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>60, - 100</td>
<td>45</td>
<td>47</td>
<td>52</td>
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<tr>
<td></td>
<td>60, - 200</td>
<td>26</td>
<td>47</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>160, - 200</td>
<td>26</td>
<td>47</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>60, - 500</td>
<td>26</td>
<td>28</td>
<td>30</td>
</tr>
<tr>
<td>2.0</td>
<td>60, - 100</td>
<td>52</td>
<td>52</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>60, - 200</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>160, - 200</td>
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<td>-</td>
<td>-</td>
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\(^a\text{meters}\)

IVc3. Influence of Number of Missiles

\[ 10^7 \times \text{Probability} \]

<table>
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<tr>
<th>k</th>
<th>( n/n_{\text{typ}} )</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>1</td>
<td>45</td>
<td>47</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>46</td>
<td>50</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>1/8</td>
<td>39</td>
<td>47</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>1/50</td>
<td>26</td>
<td>40</td>
<td>47</td>
</tr>
<tr>
<td>2.0</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1/8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1/50</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</table>

IVd1. \( V_{\text{torn}} = 380 \) mph

Idl. Basic Case

\[ 10^7 \times \text{Probability} \]

<table>
<thead>
<tr>
<th>k</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>-</td>
<td>65</td>
<td>69</td>
</tr>
<tr>
<td>2.0</td>
<td>-</td>
<td>74</td>
<td>77</td>
</tr>
</tbody>
</table>
IVel. \( V_{\text{torn}} = 200 \text{ mph} \)

Iel. **Basic Case**

\[
\begin{array}{cccc}
10^7 \times \text{Probability} \\

k & 1.0 & 0.5 & 0.06 \\
0.5 & 34 & 35 & 35 \\
0.9 & 40 & 42 & 43 \\
1.3 & 44 & 45 & 46 \\
2.0 & - & - & 45 \\
\end{array}
\]

V. 12" Pipe with \( C_D = 0.7, A = 1.16 \text{ m}^2, m = 341 \text{ kg} \)

Va. \( V_{\text{torn}} = 360 \text{ mph} \) (\( V_{\text{max}} \) per NBSIR 76-050: 38 m/s)

Val. **Basic Case\(^a\)**

\[
\begin{array}{cccc}
10^7 \times \text{Probability} \\

k & 1.0 & 0.5 & 0.06 \\
0.3 & - & 53 & 57 \\
0.9 & 55(-) & 62 (55) & 67 (64) \\
2.0 & - & 65 & 67 \\
\end{array}
\]

\(^a\) Numbers in parentheses represent speeds corresponding to \( n/n_{\text{typ}} = 1/50 \)
Vb. \( V_{\text{torn}} = 300 \text{ mph} \) (\( V_{H}^{\text{max}} \) per NBSIR 76-1050 = 15 m/s)

Vbl. Basic Case

\[ 10^7 \times \text{Probability} \]

<table>
<thead>
<tr>
<th>k</th>
<th>1.0</th>
<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>37</td>
<td>47</td>
<td>51</td>
</tr>
<tr>
<td>0.9</td>
<td>-(−)</td>
<td>52(−)</td>
<td>57(57)</td>
</tr>
<tr>
<td>2.0</td>
<td>−</td>
<td>−</td>
<td>43</td>
</tr>
</tbody>
</table>

\( a \) Numbers in parentheses represent speeds corresponding to \( n/n_{\text{typ}} = 1/50 \)

Vc. \( V_{\text{torn}} = 240 \text{ mph} \) (\( V_{H}^{\text{max}} \) per NBSIR 76-1050 = 6 m/s)

Vcl. Basic Case

\[ 10^7 \times \text{Probability} \]

<table>
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<tr>
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<th>0.5</th>
<th>0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>34</td>
<td>41</td>
<td>44</td>
</tr>
<tr>
<td>0.9</td>
<td>20(−)</td>
<td>45(34)</td>
<td>46(46)</td>
</tr>
<tr>
<td>2.0</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
</tbody>
</table>

36
Figure 1

Schematic Representation of a Tornado Path
Figure 3
Plan View of Nuclear Power Plant
(Courtesy of Don Mehta, Bechtel Corporation, Gaithersburg)
APPENDIX A1

PROBABILITY DENSITY FUNCTIONS OF MAXIMUM TORNADO WIND SPEED

In this Appendix an approximate representation, consistent with the assumptions implicit in Ref. 2, will be given for the probability density function of the maximum tornado wind speed \( V_{\text{torn}} \) at a location where the probability \( P(T, V_{\text{torn}}) \), that a tornado with speed \( V_{\text{torn}} \geq 360 \) mph will occur is \( 10^{-7} \) /year. Let \( P(T) \) and \( P(V_{\text{torn}}) \) denote the probability that a tornado will hit the location in question, and the probability that the maximum wind in a tornado is higher than \( V_{\text{torn}} \), respectively. Then

\[
P(T, V_{\text{torn}}) = P(T) P(V_{\text{torn}})
\]

(A1)

From Figs. A1 and A2 it follows that, in the regions where, nominally, \( P(T, V_{\text{torn}}) = 10^{-7} \) /year, the following approximate probabilities \( P(T) \) and \( P(V_{\text{torn}}) \) are assumed in Ref. 2:

<table>
<thead>
<tr>
<th>( V_{\text{torn}} ) (mph)</th>
<th>( P(T) )</th>
<th>( P(V_{\text{torn}}) = 10^{-7} / P(T) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>380</td>
<td>190 \times 10^{-5}</td>
<td>1/(190 \times 10^2)</td>
</tr>
<tr>
<td>370</td>
<td>130 \times 10^{-5}</td>
<td>1/(130 \times 10^2)</td>
</tr>
<tr>
<td>360</td>
<td>105 \times 10^{-5}</td>
<td>1/(105 \times 10^2)</td>
</tr>
<tr>
<td>350</td>
<td>70 \times 10^{-5}</td>
<td>1/(70 \times 10^2)</td>
</tr>
<tr>
<td>340</td>
<td>45 \times 10^{-5}</td>
<td>1/(45 \times 10^2)</td>
</tr>
<tr>
<td>330</td>
<td>33 \times 10^{-5}</td>
<td>1/(33 \times 10^2)</td>
</tr>
<tr>
<td>320</td>
<td>23 \times 10^{-5}</td>
<td>1/(23 \times 10^2)</td>
</tr>
<tr>
<td>310</td>
<td>16 \times 10^{-5}</td>
<td>1/(16 \times 10^2)</td>
</tr>
</tbody>
</table>

Since, in Ref. 2, \( P(V_{\text{torn}}) \) is assumed to be independent of geographical location, it follows from Eq. A1 that, at a location where \( P(T, 360) = 10^{-7} \), \( P(T, V_{\text{torn}}) = 105 \times 10^{-5} P(V_{\text{torn}}) \). For various values of \( V_{\text{torn}} \), \( P(T, V_{\text{torn}}) \) will then have the values tabulated below:

<table>
<thead>
<tr>
<th>( V_{\text{torn}} ) (mph)</th>
<th>( P(T, V_{\text{torn}}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>380</td>
<td>(105/190) \times 10^{-7} ~ 0.55 \times 10^{-7}</td>
</tr>
<tr>
<td>370</td>
<td>(105/130) \times 10^{-7} ~ 0.80 \times 10^{-7}</td>
</tr>
<tr>
<td>360</td>
<td>\times 10^{-7} = 1.00 \times 10^{-7}</td>
</tr>
<tr>
<td>350</td>
<td>(105/70) \times 10^{-7} ~ 1.50 \times 10^{-7}</td>
</tr>
<tr>
<td>340</td>
<td>(105/45) \times 10^{-7} ~ 2.33 \times 10^{-7}</td>
</tr>
<tr>
<td>330</td>
<td>(105/33) \times 10^{-7} ~ 3.30 \times 10^{-7}</td>
</tr>
<tr>
<td>320</td>
<td>(105/23) \times 10^{-7} ~ 4.50 \times 10^{-7}</td>
</tr>
<tr>
<td>310</td>
<td>(105/16) \times 10^{-7} ~ 6.00 \times 10^{-7}</td>
</tr>
</tbody>
</table>

Remembering that \( P(T, V_{\text{torn}}) = 1 - P_{\text{cum}}(T, V_{\text{torn}}) \), where \( P_{\text{cum}}(T, V_{\text{torn}}) \) = cumulative distribution function of hit with speed \( V_{\text{torn}} \) (i.e., probability
that a hit with maximum less than speed $V_{torn}$ will occur), it follows that the tail of the probability density function $p(T, V_{torn})$ corresponding to $P_{cum}(T, V_{torn})$ may be represented approximately as in Fig. A3.

Similar calculations can be made for regions where $P(T, V_{torn}) = 10^{-7}$ for $V_{torn} = 300$ mph and $V_{torn} = 240$ mph.

Note that the calculations presented in this Appendix are merely illustrative. Indeed, values of $P(T)$ and $P(V_{torn})$ somewhat different from those of Ref. 2 may be assumed, as indicated, e.g., in Ref. A1.

REFERENCE

Figure A2
Calculated Tornado Wind Speed by Five-Degree Squares for $10^{-7}$ Probability per Year (Ref. 2)
Estimated Probability Density Function of Tornado Wind Speeds

Fig. A3
NOTE: Computer program is available on tape from the National Technical Information Service, Springfield, Virginia, 22151
### Description of Input Data for Stage 1 Program

<table>
<thead>
<tr>
<th>Group</th>
<th>Module</th>
<th>Type</th>
<th>Variable Name(s)</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MAIN</td>
<td>Integer</td>
<td>PLEVEL</td>
<td>I2</td>
<td>Determines the amount of output to the printer.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Note:</strong> Each group of output starts with a preface of the form (P&lt;Level&gt; - &lt;Module&gt;)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Here, &lt;Level&gt; is the minimum value that PLEVEL must have in order for that particular output to occur.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;Module&gt; is the name of the module where the printing is done.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-2 ≤ No output (except for warnings and fatal errors).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1 = Tornado landing distances and widths, number of hits, and hit counts by surface and face.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 = (more than -1) Good level of descriptive output about the input.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 = (more than 0) Short summary of each basis trajectory, summary of each hit.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 = (more than 1) Summary of each event.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 = (more than 2) Long summary of each basis trajectory.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4 ≥ (more than 3) Full output of each basis trajectory.</td>
</tr>
<tr>
<td>2</td>
<td>PRBDEF</td>
<td>Integer</td>
<td>JPN, JSA, JHS, JMT, IIAM, ITT, IAD, ITD, IBM</td>
<td>913</td>
<td>Problem definition indices.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Note:</strong> These values do not affect the operation of the program. They may be used for documentation purposes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JPN = Problem number.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JSA = Site number.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JHS = Hit surface distribution number.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JMT = Missile type number.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IIAM = Distribution number of missile sets.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ITT = Tornado type distribution number.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IAD = Angle of tornado direction distribution number.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ITD = Translation axes distribution number.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IBM = Basis distribution number.</td>
</tr>
<tr>
<td>3</td>
<td>SITE</td>
<td>Real</td>
<td>DELYTN</td>
<td>F8.0</td>
<td>DELYTN = Distance between y translation lines in meters.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real</td>
<td></td>
<td>6F8.0</td>
<td>(Note: y translation lines are parallel to the OY1 axis, axis of the OXY1Z1 coordinate system defined below. They are used internally to locate efficiently regions where missile trajectories may intersect targets.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>XC, YC, ZC, LX, LY, LZ</td>
<td></td>
<td>XC,YC,LC = Coordinates of the point Oy (in meters) respect to the origin O of the reference OxOyOz coordinate system. Oy is the center of the rectangular region that includes all the potential missiles at their initial positions. The system OxOyOz is chosen arbitrarily for convenience.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LX,LY,LZ = Length of the sides parallel to the Ox, Oy, Oz axes (in meters) respectively of the parallelepiped containing all the potential missiles at their initial positions. Ox, Oy, Oz are parallel to Ox, Oy, Oz, respectively.</td>
</tr>
</tbody>
</table>
**Description of Input Data for Stage 1 Program**

<table>
<thead>
<tr>
<th>Group</th>
<th>Module</th>
<th>Type</th>
<th>Variable Name(s)</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>HTSKF</td>
<td>Integer</td>
<td>NHR</td>
<td>13</td>
<td>NHR = number of hit regions [for example, Figure 4 of the report contains 9 hit regions numbered 1 through 9]. For each hit region:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real</td>
<td>[XCR, YCR, ZCR, NC(I)]</td>
<td>[7F8.0]*</td>
<td>XCR, YCR, ZCR = coordinates with respect to point 0 (in meters) of one of the 4 corners of the rectangular base of the hit region. It is always assumed that this base is in a horizontal plane.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>THETDX, LX, LY, LZ</td>
<td></td>
<td>The 3 lines that form the corner are denoted by $0_x, 0_y, 0_z$. $0_z$ is parallel to the axis $0_y$ of the reference system Oxys. The coordinate system $0_x, 0_y, 0_z$ must be right handed.</td>
</tr>
<tr>
<td>5</td>
<td>NSLYW</td>
<td>Real</td>
<td>CDRAG, AREA, MASS, RFC</td>
<td>4F8.0</td>
<td>Missile description.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CDRAG = Drag coefficient (nondimensional).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AREA = Effective area (in meters$^2$).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MASS = Mass (in kilograms).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RFC = Horizontal restraining force factor (nondimensional) [RFC is denoted by $k$ in the text, see Eq. 2 of the report].</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NIAM = the number of missile set-ups [denoted by $N_i$ in the report].</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integer</td>
<td>NIAM</td>
<td>13</td>
<td>Note: The $i$-th missile set-up is a union of $NC(I)$ component lattices. Each component lattice has $NX<em>NY</em>NZ$ missiles where $NX, NY, NZ$ may be different for each lattice [for example, in Figure 4 of the report there are $NC(I) = 4$ component lattices, denoted by I, II, III, IV].</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integer</td>
<td>[I, NC(I)]</td>
<td>13,16</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integer</td>
<td>[NX, NY, NZ]</td>
<td>[3I3]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real</td>
<td>NTT [PTT(I)]</td>
<td>[5E12.5]</td>
<td>PAM(I) = The probability of occurrence of the $i$-th missile set-up [denoted by $P(S_{3i}$) in the report].</td>
</tr>
<tr>
<td>6</td>
<td>AMDDEF</td>
<td>Integer</td>
<td>NIAM</td>
<td>13</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Integer</td>
<td>[I, NC(I)]</td>
<td>13,16</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Integer</td>
<td>[NX, NY, NZ]</td>
<td>[3I3]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real</td>
<td>NTT [PTT(I)]</td>
<td>[5E12.5]</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>TTDEF</td>
<td>Real, Integer</td>
<td>LUSER, RMXRTS, NTT</td>
<td>2F8.0, 13</td>
<td>LUSER = Distance (in meters) between tornado touchdown point and first line of potential missiles. This is used in the program only if RFC is so small that potential missiles would be swept off the ground even if tornado were at a very large distance from the site. (Recall that the theoretical wind speed at the site is equal to the tornado translation velocity, even if the tornado is at an infinite distance from the site.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real</td>
<td>NTT [SOEV(I)]</td>
<td>[10F8.0]</td>
<td>RMXRTS = Radius of maximum wind velocity (in meters).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real</td>
<td>NTT [PTT(I)]</td>
<td>[5E12.5]</td>
<td>NTT = Number of tornado types [Denoted by $N_3$ in the report].</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SOEV(I) = Maximum wind velocity for the $i$-th tornado type (in miles/hour) [Denoted by $V_{torn}$ in the report].</td>
</tr>
</tbody>
</table>

* [...] = means that this format is used repeatedly.
<table>
<thead>
<tr>
<th>Group</th>
<th>Module</th>
<th>Type</th>
<th>Variable Name(s)</th>
<th>Format</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>7</td>
<td>ITDEF</td>
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</tr>
<tr>
<td>8</td>
<td>ATDF</td>
<td>Integer</td>
<td>NAD</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real</td>
<td>[AD(I)]</td>
<td>[10F8.0]*</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real</td>
<td>[PAD(I)]</td>
<td>[5E12.5]</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>VMODE</td>
<td>Real</td>
<td>USXORG, USYORG</td>
<td>2F8.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real</td>
<td>LPTTD, DELTD</td>
<td>2F8.0, 13</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integer</td>
<td>NTD</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real</td>
<td>[PTD(I)]</td>
<td>[5E12.5]</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>MODEF</td>
<td>Integer</td>
<td>WAUSER</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integer</td>
<td>TYPXBM,</td>
<td>13, 8.0</td>
<td></td>
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<tr>
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<td></td>
<td>Real</td>
<td>DELXBM</td>
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<td></td>
<td>Integer</td>
<td>TYPXBM,</td>
<td>13, 8.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real</td>
<td>DELLUH</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real</td>
<td>T0, TDEL</td>
<td>2F8.0</td>
<td></td>
</tr>
</tbody>
</table>

PTT(I) = Probability of occurrence of the I-th tornado type, divided by 10^-7 [denoted in the report by P(T_1L)/10^-7].

NAD = Number of directions of tornado axis of translation [denoted in the report by N_d].

AD(I) = The angle (in degrees) defining the I-th direction of the tornado axis of translation [this angle is denoted in the report by a_1]. AD(I) are the counterclockwise angles [denoted in report by a_1] by which the vector O'y must be rotated in order to be parallel to and have the same direction as the tornado translation velocity vector.

PAD(I) = Probability of occurrence of the I-th angle [denoted in the report by Pl(o_1)].

(USXORG, USYORG) = Coordinates x,y (in system Oxyz) of point O (in meters) of segment O'B. O'B is normal to and intersects the tornado axes of translation. The direction of O'B is such that the tornado translation velocity vector must be rotated counterclockwise by 90° in order to be parallel to and have the same direction as O'B.

LPTTD = Length (in meters) of segment O'B [denoted in the report by b].

DELTD = Distance (in meters) equal to LPTTD/ (NTD-1), where NAD is defined below [denoted in the report by AD].

NTD = The number of translation axes [denoted in the report by N_1].

Note: NAD is same for all angles AD(I).

PTD(I) = Probability of occurrence of the I-th tornado translation axis [denoted in the report by P(T_1)].

WAUSER = The user specified tornado left or right width (in meters). It is used in the program only if no (finite) left or right width distances can be computed internally (see comment for variable LUSER, Group 7).

Note: The left (right) widths is in the maximum orthogonal distance (in meters) to the left (right) of the tornado translation axis such that a stationary missile could still be moved (horizontally or vertically) by the tornado wind field.

TYPXBM = 1 (Variable used internally in the program, indicating a set of basis missiles equally spaced on a straight line normal to tornado direction).

DELXBM = Horizontal distance (in meters) between basis missiles.

TYPXBM = 1 (Variable used internally in the program, indicating a set of basis missiles equally spaced on a vertical line).

DELLUH = Vertical distance (in meters) between basis missiles.

* [ .. ] = means that this format is used repeatedly.
### Description of Input Data for Stage 1 Program

<table>
<thead>
<tr>
<th>Group</th>
<th>Module</th>
<th>Type</th>
<th>Variable Name(s)</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>BMDEF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>AMD</td>
<td>Integer</td>
<td>I, NC(I)</td>
<td>13, 16</td>
<td>T0 = Initial time (in seconds) to start a trajectory integration (suggested value T0 = 0.0).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RC</td>
<td>NC(I) [XCT, YCT, ZCT]</td>
<td></td>
<td>TDEL = Time interval (in seconds) between stored trajectory points (suggested value TDEL = 0.1 sec).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integer</td>
<td>NX, NY, NZ</td>
<td></td>
<td>Note: This essentially repeats group 6 but with complete information about the lattices. There are NIAM sets of data. The I-th set of data has NC(I) descriptors. Each descriptor describes a component lattice of NX<em>NY</em>NZ missiles.</td>
</tr>
</tbody>
</table>

XCT, YCT, ZCT = Coordinates in Oxyz system (in meters) of one of the 4 corners of bottom horizontal plane of the lattice

THETDX = A system of coordinates Ox'y'z' is defined for each lattice, analogous to the system Ox'y'z' for each hit region. THETDX is the counterclockwise angle (in degrees) for which the vector Ox must be rotated in order to be parallel and have the same direction as the vector Ox'.

DELY, DELZ = Missile separations in the lattice (in the z', y', z' directions, respectively).
## Description of Input Data for Stage 2 Program

<table>
<thead>
<tr>
<th>Output</th>
<th>Module</th>
<th>Type</th>
<th>Variable Name(s)</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Data</td>
<td>Integer,</td>
<td>PLEVEL,</td>
<td>I2,</td>
<td>PLEVEL = Determines the amount of output to the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real,</td>
<td>VCUT,</td>
<td>E12.5,</td>
<td>printer.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integer,</td>
<td>MXHVD,</td>
<td>I12,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real,</td>
<td>DELHV,</td>
<td>E12.5,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integer</td>
<td>NHVI</td>
<td>I12</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Each group of output starts with a preface of the form (P Level - Module).

- **PLEVEL** is the minimum value that PLEVEL must have in order for that particular output to occur. If PLEVEL is null, the output will always occur.
- **Module** is the name of the module where the printing is done.

-1 = Summary of all results
0 = (more output than -1) input probabilities are listed.
1 - (more output than 0) hit velocities by distribution are listed.

**VCUT** = Smallest value (in meters/sec) considered in histograms of hit velocities.

**MXHVD** = Maximum number of velocities of hitting missiles being listed (starting from largest velocity).

**DELHV** = Interval (in meters/sec) in the velocity histogram.

**NHVI** = The number of intervals in the velocity histograms starting from I.U.

**Note:** One extra interval is added at the high end to handle any velocities exceeding the velocity interval of the last bar.
PIORWD1-STGI

--- APPLICATIONS PROGRAM ---

FOR GENERAL USE.

ADDITIONAL ROUTINES REQUIRED.

FOR THIS APPLICATION.

AD  BMDIF  DSCPHS  HIT  INITRJ
ADDEF  CRTRHS  FLUSH  HITGND  INTRSC
AND  DELFCE  FVHRF  HITSRF  IXINT
ANDDEF  DIST  FVVRF  INDEX  LINTRP
BINARY  DRAG  GENTRY  INTRJ  MARK
NOVXY  PRBDEF  ROUNDD  TO  TRNXY
MSLTYP  PRNTED  ROUNDU  TODEF  TTDDEF
OUTBUF  PRV2D  SEARCH  TED  TYP
PIV2D  RHS  SITE  TFHS  XBMJLJU
PKRA  ROTXY  STORE  TORWDF

TOOLS.

OERT  RIMACH
INTRP  SSORY
IIMACH  STEP
OERT  ROOT

COMMON.

DECLARATIONS APPEARING IN MAIN ARE REPEATED IN ROUTINES.

AD  DRAG  HITSRF  TODEF  TTYP
ADDEF  FVHRF  MSLTYP  TED
AND  FVVRF  PRBDEF  TFHS
BMDEF  GENTRY  RHS  TORWDF
CRTRHS  HIT  TO  TTDDEF

MAXIMUM PROBLEM SIZE DEFINED.

PARAMETER = CURRENT VALUE

BUFSIZE = 2500  SIZE OF OUTPUT BUFFER.

EFFECTS ARRAYS.

BUFFER
**NUMBER OF ANGULAR DIRECTIONS.**

**EFFECTS ARRAYS.**

IN MAIN ----

PDA

IN COMMON ----

ARF V

AOFTV

**NUMBER OF MISSILES IN ANY ACTUAL MISSILE DISTRIBUTION.**

**EFFECTS ARRAYS.**

IN MAIN ----

PRMAAM

PRMGM AM

XAM

YAM

ZAM

XAMTF

YAMTF

**MISSILE DISTRIBUTION.**

**NUMBER OF HIT REGIONS.**

**EFFECTS ARRAYS.**

IN MAIN ----

HSFCNT

IFTR J

ILTR J

LKLS HS

PER MHS

KCHR

YCHR

ZCHR

XCHRTF

YCHRTF

IN COMMON ----

AFHS

BFHS

CFHS

AFHSTF

BFHSTF

COEFS H

XFHS

YFHS

ZFHS

XFHSTF

YFHSTF

**NUMBER OF ACTUAL MISSILE DISTRIBUTIONS.**

**EFFECTS ARRAYS.**

IN MAIN ----

NAM

PAM
EFFECTS

- * MXNLM = 20
  NUMBER OF LEVELS (IN Z) OF BASIS MISSILES.

- EFFECTS ARRAYS.
  IN MAIN ---
    LAM
    LCBM
    LPNT
    MXNMPJ
    MXNMPJ
    YTRJLM

- MXNLD = 20
  NUMBER OF TRANSLATION DISTANCES.

- EFFECTS ARRAYS.
  IN MAIN ---
    PTD
    TDFV

- * MXNTRJ = 1500
  NUMBER OF TRAJECTORY POINTS IN ANY BASIS MISSILE TRAJECTORY.

- EFFECTS ARRAYS.
  IN MAIN ---
    TRJ

- MXNTT = 10
  NUMBER OF TORNADO TYPES.

- EFFECTS ARRAYS.
  IN MAIN ---
    PIT
    TLWTH
    TRWTH
    TMNSST
    TMNTV
    T0EV

- * MXNKM = 1000
  NUMBER OF BASIS MISSILES ALONG THE X AXIS.

- EFFECTS ARRAYS.
  IN MAIN ---
    XCBM
    XCBM

- MXNYTN = 100
  NUMBER OF Y TRANSLATION INTERVALS.

- EFFECTS ARRAYS.
  IN MAIN ---
    IFYTN
    XLYTN
    XMNYTN
    XMXYTN
    ZMNYTN
    ZMXYTN
NOTE. * MEANS THAT THESE PARAMETERS ARE SET IN DATA STATEMENTS AND MUST BE CHANGED IF THE CURRENT VALUES ARE CHANGED.

ARRAY DIMENSION INFORMATION. (ADJUST TO MAXIMUM PROBLEM SIZE)

<table>
<thead>
<tr>
<th>NAME</th>
<th>SIZE</th>
<th>HOLDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R) BUFFER(*) BUFSIZE</td>
<td></td>
<td>SORTED HIT INFORMATION READY TO BE WRITTEN TO MASS STORAGE FOR STAGE 2.</td>
</tr>
<tr>
<td>I) HSFCNT(*, MXNHR)</td>
<td></td>
<td>THE NUMBER OF HITS WHICH STRUCK EACH FACE OF EACH HIT SURFACE.</td>
</tr>
<tr>
<td>R) IFTRJ(*) MXNHR + 1</td>
<td></td>
<td>THE INDEX OF THE FIRST TRAJECTORY POINT TO CONSIDER FOR A HIT WITH EACH OF THE HIT REGIONS.</td>
</tr>
<tr>
<td>ILTRJ(*) MXNHR + 1</td>
<td></td>
<td>LIKE IFTRJ(*) EXCEPT THEY ARE THE LAST INDICES.</td>
</tr>
<tr>
<td>I) IFYTN(*) MXNYTN</td>
<td></td>
<td>THE INDICES OF THE FIRST POINT OF THE TRAJECTORY THAT ENTERS EACH Y TRANSLATION INTERVAL.</td>
</tr>
<tr>
<td>ILYTN(*) MXNYTN</td>
<td></td>
<td>THE INDICES OF THE LAST POINT OF THE TRAJECTORY THAT LEAVES EACH Y TRANSLATION INTERVAL.</td>
</tr>
<tr>
<td>I) LAM(*) MXNLBM</td>
<td></td>
<td>THE INDICES OF THE BASIS MISSILE LEVELS NEEDED TO HANDLE ALL ACTUAL MISSILES FOR THE CURRENT ACTUAL MISSILE DISTRIBUTION.</td>
</tr>
<tr>
<td>R) LC3M(*) MXNLBM + 2</td>
<td></td>
<td>THE Z COORDINATES OF EACH LEVEL.</td>
</tr>
<tr>
<td>I) LKLSHS(*) MXNHR</td>
<td></td>
<td>A WORK VECTOR PASSED TO SUBROUTINE HIT WHICH IS USED TO STORE A ONE WAY LINKED LIST THAT CONNECTS TOGETHER THE SECTIONS OF TRAJECTORY TO SEARCH FOR A POSSIBLE HIT.</td>
</tr>
<tr>
<td>I) LPNT(*) MXNLBM + 1</td>
<td></td>
<td>THE INDICES OF THE START OF EACH GROUP OF ACTUAL MISSILE COORDINATES IN XAM, YAM, AND ZAM ASSOCIATED WITH EACH REQUIRED BASIS MISSILE LEVEL.</td>
</tr>
<tr>
<td>R) MNXMPJ(*) MXNLBM</td>
<td></td>
<td>THE minimum X projection of all actual missiles within.</td>
</tr>
</tbody>
</table>
C

MXMPJ(*) MXNLBM

EACH OCCUPIED Z LEVEL FOR ALL
ANGLES OF ATTACK.

LIKE MXMPJ(*) EXCEPT THEY ARE
MAXIMUM X PROJECTIONS.

I) KAJ(*) MXNIAW

THE NUMBER OF ACTUAL MISSILES
IN EACH DISTRIBUTION.

R) PAO(*) MXNAD

THE PROBABILITY OF OCCURRENCE
OF EACH ANGULAR DIRECTION.

R) PAN(*) MXNIAW

THE PROBABILITY OF OCCURRENCE
OF EACH ACTUAL MISSILE
DISTRIBUTION.

R) PRMAAM(*) MXNAM

THE PERMUTATION VECTOR THAT
REFLECTS THE REORDERING BY
INCREASING Z OF ALL THE
MISSILES IN THE CURRENT SET OF
ACTUAL MISSILES.

R) PRGAM(*) MXNAM

THE PERMUTATION VECTOR
THAT REFLECTS THE REORDERING
BY INCREASING X OF THE ACTUAL
MISSILES ASSOCIATED WITH THE
CURRENT BASIS MISSILE LEVEL.

R) PERMHS(*) MXNHFR

A WORK VECTOR PASSED TO
SUBROUTINE HFT WHICH IS USED
AS A PERMUTATION VECTOR THAT
REFLECTS THE REORDERING BY
INCREASING Y OF THE SECTIONS
OF TRAJECTORY EACH
CORRESPONDING TO A HIT
SURFACE TO SEARCH FOR A
POSSIBLE HIT.

R) PTO(*) MXNTD

THE PROBABILITY OF OCCURRENCE
OF EACH TRANSLATION DISTANCE.

R) PTT(*) MXNTT

THE PROBABILITY OF OCCURRENCE
OF EACH TORNADO TYPE.

R) TLWIDTH(*) MXNTT

THE WIDTH OF THE TORNADO PATH
TO THE LEFT OF THE CENTER LINE
FOR EACH TORNADO TYPE.

LIKE TLWIDTH(*) EXCEPT THEY ARE
WIDTHS TO THE RIGHT OF THE
CENTER LINE.

R) TMNSD(*) MXNTT

THE MINIMUM TOUCHDOWN DISTANCE
FOR EACH TORNADO TYPE.

R) TMNTT(*) MXNTT

THE MINIMUM TORNADO TRAVEL
TIME BEFORE A MISSILE CAN BE
DECLARED TO BE STATIONARY.
<table>
<thead>
<tr>
<th>Line</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>290</td>
<td>C</td>
</tr>
<tr>
<td>297</td>
<td>C</td>
</tr>
<tr>
<td>302</td>
<td>C</td>
</tr>
<tr>
<td>303</td>
<td>C</td>
</tr>
<tr>
<td>308</td>
<td>C</td>
</tr>
<tr>
<td>313</td>
<td>C</td>
</tr>
<tr>
<td>320</td>
<td>C</td>
</tr>
<tr>
<td>325</td>
<td>C</td>
</tr>
<tr>
<td>331</td>
<td>C</td>
</tr>
<tr>
<td>336</td>
<td>C</td>
</tr>
<tr>
<td>341</td>
<td>C</td>
</tr>
<tr>
<td>346</td>
<td>C</td>
</tr>
</tbody>
</table>
R) XMNYTN(*)  MXNYTN  
THE MINIMUM X VALUE OF THE
TRAJECTORY POINTS IN EACH Y
TRANSLATION INTERVAL.

R) XMNYTN(*)  MXNYTN  
LIKE XMNYTN(*) EXCEPT THEY ARE
MAXIMUM X VALUES.

R) YTRJLM(*)  MXNLM  
THE Y TRAJECTORY LIMIT OF A
BASIS MISSILE TRAJECTORY AT
EACH REQUIRED BASIS MISSILE
LEVEL.

R) ZMNYTN(*)  MXNYTN  
THE MINIMUM Z VALUE OF THE
TRAJECTORY POINTS IN EACH Y
TRANSLATION INTERVAL.

R) ZMNYTN(*)  MXNYTN  
LIKE ZMNYTN(*) EXCEPT THEY ARE
MAXIMUM Z VALUES.

COMMON.

R) ARTFV(*)  MXNAD  
EACH ANGLE (IN RADIANS)
CORRESPONDING TO EACH ANGLE OF
TORNADO ATTACK THAT ALL POINTS
MUST BE ROTATED BY IN ORDER
FOR THE TORNADO TO ALWAYS
TRANSLATE ALONG THE + Y AXIS
IN THE MISSILE REGION CENTERED
COORDINATE SYSTEM.

R) AOFTFV(*)  MXNAD  
THE OFFSET FOR EACH ANGLE THAT
MUST BE ADDED TO EACH OF THE
TRANSLATION DISTANCES IN
TOTFV(*) TO CONVERT THE
TRANSLATION DISTANCES THAT
ASSUME A TORNADO TRANSLATING
ALONG THE + Y AXIIS FROM A USER
COORDINATE SYSTEM TO A MISSILE
REGION CENTERED COORDINATE
SYSTEM.

R) AFHFS(*)  6 * MXNHR  
BLOCKS OF 6 X DIRECTION
NUMBERS FOR EACH OF THE 6
FACES OF EACH COMPONENT HIT
SURFACE.

R) BFHFS(*)  6 * MXNHR  
LIKE AFHFS(*) EXCEPT THEY ARE
Y DIRECTION NUMBERS.

R) CFHFS(*)  6 * MXNHR  
LIKE AFHFS(*) EXCEPT THEY ARE
Z DIRECTION NUMBERS.

R) AFHSTF(*)  6 * MXNHR  
THE TRANSFORMED BLOCKS OF 6 X
DIRECTION NUMBERS FOR EACH OF
THE 6 FACES OF EACH COMPONENT
HIT SURFACE.

R) BFHSTF(*)  6 * MXNHR  
LIKE AFHSTF(*) EXCEPT THEY ARE
Y DIRECTION NUMBERS.

R) COEFHS(*) (4 * 6 * MXNHR) A WORK VECTOR USED BY
SUBROUTINE HIT TO HOLD BLOCKS
OF 4 * 6 = 24 COEFFICIENTS
REQUIRED FOR DESCRIBING THE
5 FACIAL PLANES OF EACH HIT
SURFACE THAT COULD POSSIBLY
BE HIT BY THE CURRENT
TRAJECTORY. THE ORDER OF THE
HIT SURFACES IS GIVEN BY THE
PERMUTATION VECTOR PERMHS(*)
DECLARED IN MAIN.

R) SDEV(*) MXNTT
MAXIMUM WIND VELOCITY (IN
MILES PER HOUR) FOR EACH
TORNADO TYPE.

R) TDTFV(*) MXNTD
EACH TRANSLATION DISTANCE
TAKEN ALONG THE X AXIS
ASSUMING A TORNADO TRANSLATING
ALONG THE + Y AXIS IN A USER
COORDINATE SYSTEM TRANSLATED
FROM THEREFERENCE COORDINATE
SYSTEM.

R) XFHS(*) 6 * MXNHR
BLOCKS OF 6 X COORDINATES FOR
EACH OF THE 6 FACES OF EACH
COMPONENT HIT SURFACE.

YPHS(*) 6 * MXNHR
LIKE XFHS(*) EXCEPT THEY ARE
Y COORDINATES.

ZFHS(*) 6 * MXNHR
LIKE XFHS(*) EXCEPT THEY ARE
Z COORDINATES.

R) XPHSTF(*) 6 * MXNHR
THE TRANSFORMED BLOCKS OF 6 X
COORDINATES FOR EACH OF THE 6
FACES OF EACH COMPONENT HIT
SURFACE.

YPHSTF(*) 6 * MXNHR
LIKE XPHSTF(*) EXCEPT THEY ARE
Y COORDINATES.

FILES.

UNIT DESCRIPTION
5 STANDARD INPUT FILE.
6 STANDARD OUTPUT FILE.
8 MASS STORAGE FILE TO WHICH ALL TRAJECTORY INFORMATION IS
WRITTEN IN BINARY FORM TO BE READ BY THE STAGE 2
PROGRAM.

USAGE NOTES.
C BEFORE Compiling --

1) Adjust array sizes as required to conform to the maximum
size problem you plan to run.

2) In routines I1MACH and R1MACH the desired set of data
statements appropriate to your machine must be activated by
removing the C from column 1. If data statements do not exit
for your machine use the documentation in each routine and
your machine reference manual to determine the constants.

Remember:  A) I1MACH and R1MACH contain the only machine
dependent constants in the whole program.

B) Do not forget that the data statement for
I1MACH(17) at the bottom of I1MACH defines
output unit 8.

By, Martin Corde
Center for Applied Mathematics
National Bureau of Standards
Washington, D.C., 20234
(301) 921-2631

version 1 December 1979
Update 1 March 1980

C COMMON declarations.

C REAL SOEVE(20), ARTFV(20), AQFTVF(20), TDFV(20),
* XFHS(60), YFHS(60), ZFHS(60), XHSTF(60), YHSTF(60),
* AFHS(60), BFHS(60), CFHS(60), AHSTF(60), BHSTF(60),
* CQEFHS(240)
REAL CCRAG, AREMA, MASS, RFC, RMYXRTS, SO, STF, VXTF, VYTF, THETAC,
* XOTF, YOTF, TOTF
INTEGER JPN, JSA, JHS, JMT, I1AM, IJF, IAD, ITD, IBM

C COMMON /PRBPB/ JPN, JSA, JHS, JMT, I1AM, IJF, IAD, ITD, IBM
C COMMON /TRBPB/ CCRAG, AREMA, MASS, RFC,
* RMYXRTS, SO, STF, VXTF, VYTF, THETAC,
* XOTF, YOTF, TOTF
C COMMON /VECPF/ SOEVE, ARTFV, AQFTVF, TDFV
C COMMON /HRSF/ XFHS, YFHS, ZFHS, XHSTF, YHSTF,
* AFHS, BFHS, CFHS, AHSTF, BHSTF,
* CQEFHS

C CODE.

C REAL XCMR(4), YCMR(4), ZCMR(2), XCHR(44), YCHR(44), ZCHR(22),
* PAM(10), PTT(20), TLWATD(20), TRWATD(20),
* TMNSTD(20), TMMTNTD(20), PAD(20), PDT(13), XCMR(1002),
* LCMR(22), XAM(1500), YAM(1500), ZAM(1500), YTRJL(20),
* XAMTF(1500), YAMTF(1500), PRMAAM(1500), XCHR(44),
* YCHR(44), TRJ(9001), XMNYTN(100), XMXYTN(100), ZMNYTN(100),
* \text{MNXMPJ(20), MXXMPJ(20), XCBML(1002), IFTRJ(11), ILTRJ(11),}
* \text{PERHS(10), PRMGAM(1500), HPT(3), ZMXYTN(100), BUFFER(2500)}
* \text{REAL DELTYN, TNYORG, TNORG, TO, TDEL, ADTF, DTF, YMNTRJ, YMXTRJ,}
* \text{DELXAM, DELYA4, DELZAM, HV, HITFAC, WMNTRJ, WMXTRJ,}
* \text{SUMM, VMX, VMX, XJAM, YJAM, ZJAM, C, S, XM, YM, ZM}
* \text{INTEGER HSFCTN(6, 10), LAM(20), LPNT(21), IFYN(100), ILYTN(100), NAM(10),}
* \text{LKLSHS(10), SIU, SOU, BUF1NT, PLEVEL, NHK, NIAM, NTT, NAD, NDT, NXBM,}
* \text{NBM, IAM, NMM, NTM, NMT, NLAM, JTT, NH, I, JLAM,}
* \text{JLM, JXM, JAD, NAML, IXLM, NCRM, JTO, ILXAM, IUAM,}
* \text{NTRJ, FGRTRJ, JNYTN, IMXYTN, JPAM, JZAM, TM,}
* \text{JDN, TWRST, JHSRF, JFACE, JAN, JHTRJ, J}
* \text{LOGICAL GEMBM}
* \text{C}
* \text{INTEGER IIMACH}
* \text{INTEGER BUFSZE, MXNAM, MXNLBM, MXNTRJ, MXNXBM}
* \text{DATA BUFSZE / 2500/,}
* \text{* MXNAM / 1500/,}
* \text{* MXNLBM / 20/,}
* \text{* MXNTRJ / 1500/,}
* \text{* MXNXBM / 1000/}
* \text{C}
* \text{SIU = IIMACH(1)}
* \text{SOU = IIMACH(2)}
* \text{BUF1NT = 0}
* \text{C}
* \text{C ---}
* \text{C INPUT PRINT LEVEL.}
* \text{C ---}
* \text{C}
* \text{READ (SIU, 1100) PLEVEL}
* \text{1100 FORMAT (I2)}
* \text{C}
* \text{DEFINE PROBLEM.}
* \text{C}
* \text{CALL PRBDEF (PLEVEL)}
* \text{CALL SITE (PLEVEL, DELTYN, TNXORG, TNYORG, XCMR, YCMR, ZCMR)}
* \text{CALL HITSRF (PLEVEL, NHK, XCMR, YCMR, ZCMR)}
* \text{CALL MSLTYP (PLEVEL)}
* \text{CALL AMODEF (PLEVEL, MXNAM, NIAM, NAM, PAM)}
* \text{CALL TDDF (PLEVEL, NTT, PT, TWRST, TMNSTD, TMNTVT)}
* \text{CALL ADDEF (PLEVEL, NAD, PAD)}
* \text{CALL TDDEF (PLEVEL, TNXORG, TNYORG, NAD, NDT, PTD)}
* \text{CALL BMDEF (PLEVEL, MXNXBM, MXNLBM, TWRST, XCMR, YCMR, ZCMR, NTT,}
* \text{* NAD, NDT, TLWTH, TRWTH, MNTNMR, MXTNMR, NXBM, XCBM,}
* \text{* NLBM, LCBM, TO, TDEL)}
* \text{C}
* \text{C ---}
* \text{C OUTPUT TORNADO PATH INFORMATION.}
* \text{C ---}
* \text{C}
* \text{IF (PLEVEL \geq -1)}
* \text{* WRITE (SOU, 1150) (1, TMNSTD(I), TLWTH(I), TRWTH(I),}
* \text{* I = 1, NTT)}
* \text{1150 FORMAT (11HO(P-1-MAIN) / 1H, 3X, 19HNOTE, THE FOLLOWING,}
* 32^2 VALUES ARE ALWAYS OVERESTIMATES / IHQ, 5X,
* 7HTORDAN, 5X, 25STARTING MINIMUM DISTANCE, 10X,
* 20EFFECTIVE LEFT WIDTH, 9X,
* 21EFFECTIVE RIGHT WIDTH // (IH , I12, J1 (13,
* 1PE12.5))
C -------
C OUTPUT PROBLEM HEADING.
C -------
C
C IF (PLEVEL ,GE, -I)
C 1200 FORMAT (12H0P-1-MAIN) / IH , 3X, P0BROBLEM , I12,
C 10H --- START / IHQ , 6X, 9X, 3H1AM, 4X, 8HNM4(IAM), 9X,
C 3HNMH , 9X, 3HNMT , 8X, 4HNMTS, 6X, 6HMIFAC)
C
C INITIALIZATIONS.
C
C DO 1250 J = 1, NHR
C DO 1225 I = 1, 6
C HSCNT(I, J) = 0
C 1225 CONTINUE
C 1250 CONTINUE
C
C LOOP 0, FOR EACH SET OF BASIS MISSILES.
C
C DO 2300 IAM = 1, N IAM
C
C NMH = 0
C NMT = 0
C NMTS = 0
C
C GET ACTUAL MISSILE DISTRIBUTION.
C
C CALL AMD (PLEVEL, IAM, NAM, TNXORG, TNYORG, XCHR, YCHR, NLBM,
C * LCBM, NAD, XAM, YAM, ZAM, NLAM, LAM, LPNT, MXMPJ,
C * MXMPJ, YTRLM, PRMAAM)
C
C LOOP 1, FOR EACH TORNADO TYPE.
C
C DO 2200 JTT = 1, NTT
C
C NH = 0
C
C CALL TTYP (PLEVEL, TWMSTD(JTT), JTT)
C
C LOOP 2, FOR EACH BASIS MISSILE LEVEL (IN Z) NEEDED TO COVER THE
C ACTUAL MISSILES,
C
C DO 2100 JLM = 1, NLAM
C
C JLBM = LAM(JLAM)
C CALL XBMJLM (PLEVEL, NXM4, XCBM, TLWIDTH(JTT),
C * TLW4TH(JTT), NYTAMR, MXTRMR, MXMPJ(JLAM),
C * MXMPJ(JLAM), NXBM, XCBM)
C
C LOOP 3, FOR EACH BASIS MISSILE (IN X) NEEDED TO COVER ALL THE ANGLES
C AND TRANSLATIONS,
DO 2000 JXB = 1, N XBML
GENSH = .FALSE.
LOOP 4, FOR EACH ANGULAR DIRECTION.
DO 1900 JAD = 1, NAD
CALL AD (PLEVEL, JAD, ADTF)
MOVE, TRANSLATE TO THE MISSILE REGION CENTERED COORDINATE SYSTEM, AND
ROTATE THE INITIAL POSITIONS OF THE ACTUAL MISSILES ASSOCIATED WITH
LEVEL JLBM. NEXT, SORT THEIR X POSITIONS IN ASCENDING ORDER. THE SORT
CARRIES ALONG THE Y POSITIONS AND A PERMUTATION VECTOR.
NAJL = LPNT(JLAM + 1) - LPNT(JLAM)
IXJL = LPNT(JLAM)
CALL MOVXY (NAJL, XAM(IXJL), YAM(IXJL), XAMTF, YAMTF)
CALL TRNX (TNXORG, TNYORG, NAJL, XAMTF, YAMTF)
CALL ROTXY (ADTF, NAJL, XAMTF, YAMTF)
CALL SSORT (XAMTF, YAMTF, DUMMY, PRMGAM, NAJL, 3)
MOVE, TRANSLATE TO THE MISSILE REGION CENTERED COORDINATE SYSTEM, AND
ROTATE ALL COVERING HIT REGIONS.
NCHR = (NHR + 1) * 4
CALL MOVXY (NCHR, XCHR, YCHR, XCHRTF, YCHRTF)
CALL TRNX (TNXORG, TNYORG, NCHR, XCHRTF, YCHRTF)
CALL ROTXY (ADTF, NCHR, XCHRTF, YCHRTF)
MOVE, TRANSLATE TO THE MISSILE REGION CENTERED COORDINATE SYSTEM, AND
ROTATE ALL HIT SURFACES.
CALL TFHS (TNXORG, TNYORG, ADTF, NHR)
LOOP 5, FOR EACH TRANSLATION DIRECTION.
DO 1800 JTD = 1, NTD
CALL TD (PLEVEL, JAD, JTD, TDTF)
SEARCH FOR THE SUBSET OF ACTUAL MISSILES THAT HAVE X COORDINATES
CLOSE ENOUGH TO THE X COORDINATE OF THE STARTING POINT OF THE
GENERATED BASIS TRAJECTORY.
CALL SEARCH (PLEVEL, JXBML, XCBML, NAJL, XAMTF,
YAMTF, TDTF, ILXAM, IUXAM)
IF THE INTERVAL IS EMPTY BRANCH TO THE END OF LOOP 5.
IF ((ILXAM .EQ. 0) .AND. (IUXAM .EQ. 0))
GO TO 1800
IF (GENSH) GO TO 1400
C INITIALIZE TRAJECTORY INFORMATION, GENERATE THE TRAJECTORY, AND
C GENERATE AUXILIARY INFORMATION ABOUT THE TRAJECTORY.
C
GENBM = .TRUE.,
    CALL INITRJ (JLAM, LCBM, JXB4, XCBML,
    *          TRJ, TNSTD(JTT)),
C
    CALL GENTRJ (PLEVEL, TO, T'0EL),
    *          TMNTRJ(TJT), YTRJLML(JLAM),
    *          YKNTRJ, NTRJ, TRJ, YMTRJ,
    *          YMXTRJ, VMX, VVMX, FGTRJ)
C
C -------
C OUTPUT TRAJECTORY INFORMATION.
C -------
C
IF (PLEVEL *GE* 1)
  *          WRITE (SOU, 1350) IAM, JTT, JLAM, JXB4,
  *          NTRJ, FGTRJ, TRJ(1),
  *          TRJ(2), TRJ(3),
  *          YMTRJ, YMTRJ, VHMX,
  *          VXMX
  1350
    FORMAT (10HO(P1-MAIN) / IH, 6X, 3HIAM,
    * 1X, 3HJTT, 1X, 4HJLBM, 1X,
    * 4HJXBM, 1X, 4HNTRJ, 1X,
    * 5HFGTRJ, 10X, 2H06, 10X, 2HY6,
    * 10X, 2H06, 6X, 6HYMTRJ, 6X,
    * 6HYMXTRJ, 8X, 4HVMX, 8X,
    * 4HVX / IH, 6X, 13, 6X, 13,
    * 1X, 14, 1X, 14, 5X, 11,
    * 7(1PE12,5)/)
  275
C
IF (FGTRJ *EQ* 3) GO TO 1400
    CALL INFTRJ (PLEVEL, NTRJ, TRJ, YMTRJ,
    *          YMTRJ, DLYTN, IMNYTN,
    *          XMXYTN, IFYN, ILYTN, XMXYTN,
    *          XMXYTN, ZMNYTN, ZMXYTN)
  293
C LOOP 6, FOR EACH ACTUAL MISSILE.
C
  303
    DO 1700 JPAW = ILXAM, IUXAM
    1400
C DETERMINE THE INTERVAL OF THE TRAJECTORY TO SEARCH FOR A HIT FOR THE
C GLOBAL COVERING HIT REGION AND IF THIS IS NONZER FOR EACH COMPONENT
C HIT REGION.
C
    JJZ = IFIX (PRMGAM(JPAW)) + IXJL - 1
    CALL INDEX (PLEVEL, XANTF(JPAW),
    *          HNR, XCHRTF, YCHRTF, ZCHR,
    *          DLEYTN, NTRJ, TRJ,
    *          IMNYTN, XMXYTN, IFYN, ILYTN,
    *          XMXYTN, XMXYTN, ZMNYTN,
    *          ZMXYTN, FGTRJ, TM, IFTRJ,
    *          ILTRJ, DLYXAM, DLEYAM, DLZAM)
    349
C
    IF (TM *EQ* 0) GO TO 1410
    NMTS = NMTS + 1
    HV = 0.0
    GO TO 1600
1410  IF ((IIFX (IPTRJ) ) EQ, 0) AN). 
145  (IIFX (ILTRJ) ) EQ, 0) GO TO 1500 
146  C 
147  A HIT SEEMS POSSIBLE SO DETERMINE IF IT DOES OCCUR AND RETURN THE 
148  REQUIRED COLLISION INFORMATION, 
150  CALL HIT (PLEVEL, TDTF, NHR, IPTRJ(2), 
151  * 
152  ILTRJ(2), DELXAM, DELYAM, 
153  * 
154  DELZAM, KTRJ, TRJ, HV, JHSRF, 
155  * 
156  JFACF, MPT, JHTRJ, PERMHS, 
157  * 
158  LKLSHS) 
159  C 
160  IF (HV EQ. 0, 0) GC TO 1600 
161  C 
162  THERE WAS A HIT, 
163  C 
164  NH = NH + 1 
165  IDN = NTD * NAD * NTT * (IAM - 1) + 
166  * 
167  NTD * NAD * (JTT - 1) + 
168  * 
169  NTD * (JAD - 1) + 
170  * 
171  JTD 
172  NMH = NMH + 1 
173  C 
174  PASS THE DISTRIBUTION NUMBER AND THE HIT VELOCITY TO BE PACKED IN THE 
175  BUFFER AND UPDATE THE HIT COUNTS BY SURFACE AND FACE, 
176  CALL STORE (PLEVEL, IDN, HV, BUFPT, 
177  + 
178  BUFSZ, BUFFER) 
179  C 
180  THERE WAS NOT A HIT. 
181  C 
182  1500 
183  HV = 0.0 
184  1600 
185  NMT = NMT + 1 
186  C 
187  COMPUTE QUANTITIES FOR EVENT DESCRIPTOR, 
188  C 
189  JAM = IIFX (PRMAAM(JZAM)) 
190  C = COS (- ADTF) 
191  S = SIN (- ADTF) 
192  XJAM = C * XAMTF(JPAM) - S * YAMTF(JPAM) 
193  - TNXORG 
194  YJAM = S * XAMTF(JPAM) + C * YAMTF(JPAM) 
195  - TNYORG 
196  ZJAM = ZAM(JZAM) 
197  XH = C * (HPT(1) - TDTF) - S * HPT(2) 
198  - TNXORG 
199  YH = S * (HPT(1) - TDTF) + C * HPT(2) 
200  - TNYORG 
201  ZH = HPT(3) 
202  C 
203  CALL PRNSTD (PLEVEL, NMT, IAM, JTT, JAD, 
204  JTD, JAM, XJAM, YJAM, ZJAM, 
205  TM, HV, JHSRF, JFACF, XH, YH, 
206  ZH, JHTRJ)
C ALL EVENTS FOR THE LAST NTD * NAD DISTRIBUTIONS HAVE BEEN GENERATED.
C IF THERE AS AT LEAST ONE HIT THEN PACK THE BUFFER WITH A SPECIAL
C MARKING DESCRIPTOR,
C
IF (NM, NE, 0) CALL MARK (BUFPNT, BUFSIZE, BUFFER)
2200 CONTINUE
C COMPUTE THE HIT FACTOR.
2204 HITFAC = FLOAT (NMH) / FLOAT (NTD * NAD * ATT * NAM(IAM))
2208 C -----
2210 C OUTPUT RESULTS FOR ONE ACTUAL MISSILE DISTRIBUTION.
2212 C -----
C
IF (PLEVEL > GE, -1)
2230 * WRITE (SOU, 2250) IAM, NAM(IAM), NMH, NMT, NMTS, HITFAC
2234 2250 FORMAT (1H, 6X, 5112, 1PE12.5)
2238 C 2300 CONTINUE
C PACK THE BUFFER WITH THE TERMINATING DESCRIPTOR AND THEN FLUSH THE
C BUFFER BEFORE FINISHING.
C
CALL FLUSH (BUFPNT, BUFSIZE, BUFFER)
C -----
C OUTPUT THE HIT COUNTS BY SURFACE AND FACE.
C -----
C
IF (PLEVEL > GE, -1)
2350 * WRITE (SOU, 2350) (J, (MSFCNT(I, J)) = 1, 6), J = 1, NMR
2354 2350 FORMAT (1H, 8X, 3H, 25MHIT COUNTS BY SURFACE AND,
2358 * 5H FACE / 1H, 3X, 7MSURFACE, 5X, 6MFACE 1, 3X,
2362 * 6MFACE 2, 3X, 6MFACE 3, 3X, 6MFACE 4, 3X, 6MFACE 5, 3X,
2366 * 6MFACE 6 // (1H, 7X, 1X, 2X, 6(3X, 16)))
2370 C -----
C OUTPUT PROBLEM ENDING.
2380 C -----
C
IF (PLEVEL > GE, -1)
2390 * WRITE (SOU, 2400) JP
2394 2400 FORMAT (1H, 3X, 8HPROBLEM = 112, 9H --- STOP)
2398 C
2402 STOP
2404 END
END PRT

BPRT,5 PTOLDFDOC,MARKEDDAA1/CASES
SIHUW#PIUKWDF-DOC(1) MARKEDDATA/CASES(1)
1   1) MAIN  <C1 , L1 > -1
2   2) PRODEF <C1 , L1 >  0  0  0  0  0  0  0  0
3   3) SITE  <C1 , L2 >  50.0
4   4) MTSRF <C2 , L2 >  1
   * >  3.5  50.0  0.0  0.0  40.0  40.0  60.0
5   5) MSLTP <C21 , L1 >  1.5  3.8  18.0  0.5
6   6) AMDDE <C2 , L7 >  1
   * >  1  4
10  * >  2  1  1
11  * >  15  2  1
12  * >  1  1  1
13  * >  14  20  1
14  * >  1.0E0
15  7) TDEX <C1 , L3 >  14.0  46.0  1
16  * >  360.0
17  * >  1.000E0
18  8) ADDE <C1 , L3 >  1
19  * >  22.0
20  * >  1.0E0
21  9) TDF <C1 , L6 >  135.0  -100.0
22  * >  1.0E0  10.0  16
23  * >  0.06E0  0.06E0  0.06E0  0.06E0
24  * >  0.06E0  0.06E0  0.06E0  0.06E0
25  * >  0.06E0  0.06E0  0.07E0  0.07E0
26  * >  0.07E0
27  10) DWE <C1 , L4 >  600.0
28  * >  1  5.0
29  * >  1  40.0
30  * >  0.0  0.1
31  11) AMOD <C11 , L5 >  1  4
32  * >  170.0  -120.0  0.0  0.0  30.0  0.0  0.0  2  1  1
33  * >  120.0  -100.0  0.0  0.0  3.0  2.0  0.0  15  2  1
34  * >  -70.0  -25.0  0.0  0.0  0.0  0.0  0.0  1  1  1
35  * >  60.0  -100.0  0.0  0.0  11.0  3.0  0.0  14  20  1
END

09 SIHUW#PIUKWDF-DOC.DATAT/CASES

09 SIHUW#PIUKWDF-DOC.DATAT/CASES
VALUES ARE ALWAYS OVERESTIMATES

<table>
<thead>
<tr>
<th>SURFACE</th>
<th>FACE 1</th>
<th>FACE 2</th>
<th>FACE 3</th>
<th>FACE 4</th>
<th>FACE 5</th>
<th>FACE 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAM</td>
<td>313</td>
<td>506</td>
<td>5009</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
PTORWDI-STG2

--- APPLICATIONS PROGRAM ---

FOR GENERAL USE.

ADDITIONAL ROUTINES REQUIRED.

FOR THIS APPLICATION.

GETMV3  PIV2D
GETPRB  PRV2D
HPRBD   UNPKRA
INBUFF
POIST

TOOLS.

IMACH
SSORT

MAXIMUM PROBLEM SIZE DEFINED.

PARAMETER = CURRENT VALUE

* MX9FSZ = 2500

SIZE OF INPUT BUFFER.

NOTE: THIS MUST BE AS LARGE AS
BUF5ZE USED IN THE STAGE 1
PROGRAM.

EFFECTS ARRAYS.

IN MAIN ---
BUFFER

MXHVI = 500

NUMBER OF HIT VELOCITY INTERVALS.

EFFECTS ARRAYS.

IN MAIN ---
HVCPB
HVICNT

MXNAD = 20

NUMBER OF ANGULAR DIRECTIONS.

EFFECTS ARRAYS.

IN MAIN ---
PAD

* MXNHV = 20000

NUMBER OF HIT VELOCITIES.
**EFFECTS ARRAYS.**

*IN MAIN ---*

AMON

AMHV

**MXNIAK = 10**

**NUMBER OF ACTUAL MISSILE DISTRIBUTIONS.**

**EFFECTS ARRAYS.**

*IN MAIN ---*

AM

PAK

**MXNTO = 20**

**NUMBER OF TRANSLATION DISTANCES.**

**EFFECTS ARRAYS.**

*IN MAIN ---*

PTD

**MXNIT = 10**

**NUMBER OF TORNADO TYPES.**

**EFFECTS ARRAYS.**

*IN MAIN ---*

PTT

---

**NOTE.** *MEANS THAT THESE PARAMETERS ARE SET IN DATA STATEMENTS AND MUST BE CHANGED IF THE CURRENT VALUES ARE CHANGED.*

**ARRAY DIMENSION INFORMATION.** (ADJUST TO MAXIMUM PROBLEM SIZE)

<table>
<thead>
<tr>
<th>NAME</th>
<th>SIZE</th>
<th>HOLDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R) AMON(*)</td>
<td>MXNHV</td>
<td>MISSILE DISTRIBUTION NUMBERS OF ALL MISSILES WITH HIT VELOCITIES ABOVE CUTOFF.</td>
</tr>
<tr>
<td>R) AMHV(*)</td>
<td>MXNHV</td>
<td>ALL HIT VELOCITIES ABOVE CUTOFF SORTED IN DESCENDING ORDER.</td>
</tr>
<tr>
<td>R) BUFFER(*)</td>
<td>MXBFSZ</td>
<td>SORTED HIT INFORMATION READ FROM MASS STORAGE.</td>
</tr>
<tr>
<td>R) HVCPB(*)</td>
<td>(MXHVI + 1)</td>
<td>FOR EACH HIT VELOCITY INTERVAL THE PROBABILITY THAT A HIT WILL HAVE A VELOCITY IN OR EXCEEDING THE INTERVAL.</td>
</tr>
<tr>
<td>I) HVICNT(*)</td>
<td>(MXHVI + 1)</td>
<td>HIT VELOCITY INTERVAL COUNTS.</td>
</tr>
<tr>
<td>I) NAM(*)</td>
<td>MXNIAM</td>
<td>THE NUMBER OF ACTUAL MISSILES IN EACH DISTRIBUTION.</td>
</tr>
<tr>
<td>I) NAD(*)</td>
<td>MXNAD</td>
<td>THE PROBABILITY OF OCCURRENCE OF EACH ANGULAR DIRECTION.</td>
</tr>
</tbody>
</table>
R) MAN(*), MXNIA
THE PROBABILITY OF OCCURRENCE
OF EACH ACTUAL MISSILE
DISTRIBUTION.

R) PT3(*), MXNTO
THE PROBABILITY OF OCCURRENCE
OF EACH TRANSLATION DISTANCE.

R) PTT(*), MXNTT
THE PROBABILITY OF OCCURRENCE
OF EACH TORNADO TYPE.

FILES.
UNIT
DESCRIPTION
5
STANDARD INPUT FILE.
6
STANDARD OUTPUT FILE.
8
MASS STORAGE FILE CREATED BY THE STAGE I PROGRAM FROM
WHICH TRAJECTORY INFORMATION IS READ IN BINARY FORM.

USAGE NOTES.
BEFORE Compiling --

1) ADJUST ARRAY SIZES AS REQUIRED TO MEET YOUR OUTPUT
REQUESTS AND TO CONFORM TO THE MAXIMUM SIZE PROBLEM
TO BE RUN BY THE STAGE 1 PROGRAM.

2) IN ROUTINE IIMACH THE DESIRED SET OF DATA STATEMENTS
APPROPRIATE TO YOUR MACHINE MUST BE ACTIVATED BY REMOVING
THE C FROM COLUMN 1. IF DATA STATEMENTS DO NOT EXIT FOR YOUR
MACHINE USE THE DOCUMENTATION IN THE ROUTINE AND YOUR
MACHINE REFERENCE MANUAL TO DETERMINE THE CONSTANTS.

REMEMBER. A) IIMACH CONTAINS THE ONLY MACHINE DEPENDENT
CONSTANTS IN THE WHOLE PROGRAM.

B) DO NOT FORGET THAT THE DATA STATEMENT FOR
IIMACH(17) AT THE BOTTOM OF IIMACH DEFINES
OUTPUT UNIT 8.

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(301) 921-2831

VERSION 1 DECEMBER 1979
UPDATE 1 MARCH 1980

CODE.

REAL PAM(10), PTT(10), PAD(20), PT3(20), AMHV(20000), AMDN(20000),
BUFFER(2500), HVCPB(501)
REAL VCU, DELMV, DUMMY, CPRB, PRB, LVI, RVI, TFM
INTEGER NAM(10), HVICNT(501)
INTEGER SIU, SOU, PLEVEL, MXNHV, NHVI, NIAM, NIT, NAD, NTD,
  * NHVIP1, I, NHV, TNH, NDWH, DELNHV, IX, NHVD, ON, JTD,
  * JAD, JTT, IAM, TNEVNT, ND, BJFPNT, BUFSZE, GPESON,
  * PNEXT, PLAST, L1, L2, L3, L4

C
C INTEGER IMACH
C INTEGER MXBFSZ, MXNHV
C DATA MXBFSZ / 2500/,
  * MXNHV / 20000/

C SIU = IMACH(1)
C SOU = IMACH(2)

C -----
C INPUT PARAMETERS TO SPECIFY HOW TO PROCESS THE DATA AND OUTPUT THE
C -----
C RESULTS.
C
C READ (SIU, 1100) PLEVEL, VCU, MXNHV, DELNH, NHVI
C 1100 FORMAT (I2, E12.5, I2, E12.5, I2)
C
C GET THE NUMBER OF ACTUAL MISSILES AND PROBABILITY OF OCCURRENCE
C ARRAYS.
C
C CALL GETPRB (PLEVLL, NIAM, NAM, PAM, NIT, NAD, NTD, PTD)
C
C INITIALIZATIONS.
C
C NHVIP1 = NHVI + 1
C DO 1200 I = 1, NHVIP1
C HVICNT(I) = 0
C HVCPB(I) = 0,0
C 1200 CONTINUE
C
C NHV = 0
C TNH = 0
C NDWM = 0
C
C PNEXT = 0
C PLAST = 0
C
C BJFPNT = 0
C BUFSZE = 0
C
C LOOP 0, PROCESS EACH DISTRIBUTION.
C
C 1300 CALL GETHYD (PLEVEL, MXNHV, NHV, PNEXT, PLAST, AMDN, AMHV, DELNHV,
C  * BJFPNT, MXBFSZ, BUFSZE, BUFFER)
C IF (DELNHV .EQ. 0) GO TO 1600
C NDWH = NDWH + 1
C
C UPDATE THE HIT VELOCITY HISTOGRAM.
C
C DO 1400 I = 1, DELNHV
C IX = INT (AMHV(NHV + I) / DELHV) + 1
C IF (IX .GT. NHVI) IX = NHVIP1
HVICNT(IX) = HVICNT(IX) + 1
1400 CONTINUE
C
C UPDATE THE HIT VELOCITY CUMULATIVE PROBABILITY HISTOGRAM.
C
IX = INT(AHV(NHV + 1) / UELHV) + 1
IF (IX .GT. NHVI) IX = NHVI
DN = IFIX (AMDN(NHV + 1))
CALL HPROB (DN, NIAM, PAM, NTT, PAD, NTD, PDT, IAM.
*  JTT, JAD, JTD, PROB)
DO 1450 I = 1, IX
HVCPR(I) = HVCPR(I) + PROB
1450 CONTINUE
C
TNHV = TNHV + DELNHV
C
THE LARGEST HIT VELOCITY MUST BE SINGLED OUT FOR LATER SPECIAL
TREATMENT.
C
AMDN(NHV + 1) = - AMDN(NHV + 1)
C
UPDATE THE NUMBER OF HIT VELOCITIES AND THEN DECREMENT IT UNTIL THE
HIT VELOCITY CUTOFF IS SATISFIED.
C
NHV = NHV + DELNHV
DO 1500 I = 1, DELNHV
IF (AMHV(NHV) .GE. VCUR) GO TO 1300
NHV = NHV - 1
1300 CONTINUE
GO TO 1300
C
SORT ALL THE HIT VELOCITIES IN DECREASING ORDER CARRYING ALONG THE
MISSILE DISTRIBUTION NUMBERS.
C
1500 IF (NHV .LE. 1) GO TO 1650
C
CALL SSORT (AMHV, AMDN, DUMMY, DUMMY, NHV, .-2)
C
RUN THROUGH THE SORTED LIST IN ORDER AND INTERCHANGE ENTRIES SUCH
THAT ANY GROUP OF EQUAL VELOCITIES WHEN DECENDING THROUGH THE LIST
START WITH ALL THE ENTRIES WITH NEGATIVE AMDN VALUES.
C
DO 1625 I = 2, NHV
J = I
1610 IF ((AMHV(J - 1) .NE. AMHV(J)) .OR.
* (SIGN (1.0, AMDN(J - 1)) .LE. SIGN (1.0, AMDN(J))))
* GO TO 1625
C
TEMP = AMHV(J - 1)
AMHV(J - 1) = AMHV(J)
AMHV(J) = TEMP
TEMP = AMDN(J - 1)
AMDN(J - 1) = AMDN(J)
AMDN(J) = TEMP
J = J - 1
1625 CONTINUE
C
C ----
C OUTPUT THE HIT ORDERING WITH PROBABILITIES.
C -----
C
150 NHV0 = MIN (NHV, 4XNHV0)
294 WRITE (50, 1700)
1700 FORMAT (9H0-P-MAIN) / 1H , 3X, 14H HIT ORDERING WITH ,
* 13H PROBABILITIES / 1H0, 3X, 5X, 1H1, 3X, 3H IAM, 3X, 3H JTT,
* 3X, 3H JAD, 3X, 3H JTD, 7X, 5H MV(1), 13X, 7H PROB(I), 2X,
* 18H PROB(V * GE, MV(I)), 1X, 6H GSEQN)
C
300 IF (NHV0 * GT, 0) GO TO 1750
301 IF (TNHV * NE, 0) GO TO 1720
302 WRITE (50, 1710)
1710 FORMAT (1H0, 6X, 7H------- / 1H , 6X, 7H NO HITS / 1H , 6X,
* 7H-------)
303 GO TO 1750
304* GO TO 1750
306 WRITE (50, 1730)
1730 FORMAT (1H0, 6X, 14H--------------- / 1H , 6X,
* 14H NO HITS LISTED / 1H , 6X, 14H---------------)
308 GO TO 1950
310 C
311 1750 CPNET = 0.0
312 GPSEQN = 1
313 C
314 DO 1900 I = 1, NHV0
316 C DETERMINE THE INDICES TO THE PROBABILITY OF OCCURRENCE ARRAYS AND
317 C THE EVENT PROBABILITY. UPDATE THE CUMULATIVE PROBABILITY IF THE
318 C DISTRIBUTION NUMBER HAS BEEN SET NEGATIVE.
319 C
320 C
321 C
322 C
323 C
324 C
325* GPSEQN = GPSEQN + 1
326 C
327 C
328 C
329 C
330 C
331 C
332 C DETERMINE THE TOTAL NUMBER OF EVENTS AND UPDATE THE HIT VELOCITY
333 C INTERVAL THAT INCLUDES ZERO WITH THE NUMBER OF NCN HITS.
334 C
335 C
336 C
337 C
338 C
339 C
340 C
341 C
342 C SET THE PROBABILITY OF THE FIRST INTERVAL (WHICH INCLUDES 0.0) OF THE
343 C HIT VELOCITY CUMULATIVE PROBABILITY HISTOGRAM TO THE TOTAL.
344 C
345 C
346 C
347 C
DO 2030 L3 = 1, NAD
DO 2040 L4 = 1, NTD
HVCPB(1) = HVCPB(1) + PAM(L1) * PTT(L2) * PA(L3) * PTO(L4)

2040 CONTINUE
2030 CONTINUE
2020 CONTINUE
2010 CONTINUE
C
C ------
C OUTPUT THE HIT VELOCITY HISTOGRAM AND THE HIT VELOCITY CUMULATIVE
C --------
C
C WRITE (5Q, 2100)
2100 FORMAT (9H0(P-MAIN) / IH, 3X, 22HIT VELOCITY HISTOGRAM / IH0,
* 3X, 8X, 17HVELOCITY INTERVAL / IH, 3X, 9X, 4HLEFT, 8X,
* 5HRIGHT, 3X, 16HNUMBER OF EVENTS, 3X,
* 17HMPC3(V *GE* LEFT))
C
DO 2300 I = 1, NHVI
LVI = FLOAT (I - 1) * DELHV
HV1 = FLOAT (I) * DELHV
WRITE (5Q, 2200) LVI, RVI, HVICNT(I), HVCPB(I)
2200 FORMAT (IH, 3X, 1PE12.5, 1X, 1PE12.5, 7X, 112, 8X, 1PE12.5)
2300 CONTINUE
C
LVI = RVI
WRITE (5Q, 2400) LVI, HVICNT(NHVPI), HVCPB(NHVPI)
2400 FORMAT (IH, 3X, 1PE12.5, 13X, 7X, 112, 8X, 1PE12.5)
C
C ------
C OUTPUT SUMMARY INFORMATION.
C
C -----
C
C ND = NIAM * NTT * NAD * NTD
C
WRITE (5Q, 2500) TNHV, NDWH, ND
2500 FORMAT (9H0(P-MAIN) / IH, 3X, 19HSUMMARY INFORMATION / IH0, 3X,
* 42HTOTAL NUMBER OF HITS = , 112 / IH,
* 3X, 42HTOTAL NUMBER OF DISTRIBUTIONS WITH HITS = , 112
* / IH, 3X, 42HTOTAL NUMBER OF DISTRIBUTIONS = ,
* 112)
C
C STOP
CEND
**4. TITLE AND SUBTITLE**

Probabilistic Assessment of Tornado-Borne Missile Speeds

**7. AUTHOR(S)**

Emil Simiu and Martin R. Cordes

**15. SUPPLEMENTARY NOTES**

☑ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

**16. ABSTRACT** (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

A procedure was developed for estimating speeds with which postulated missiles hit any given set of targets in a nuclear power plant or similar installation. Hit speeds corresponding to probabilities of occurrence of $10^{-7}$ were calculated for a given nuclear power plant under various assumptions concerning the magnitude of the force opposing missile take-off, direction of tornado axis of translation, number and location of missiles, and size of target area. The results of the calculations are shown to depend upon the parameters: $C_D A/m$, where $C_D =$ drag coefficient, $A =$ projected area, $m =$ mass of missiles, and the ratio, $k$, between the minimum aero-dynamic force required to cause missile take-off, and the weight of the missile.

**17. KEY WORDS** (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)

Missiles; engineering; structural engineering; tornadoes; wind.