QUANTITY-DISTANCE

PREDICTION MODEL

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This model provides a method for establishing the fragment hazard produced by the mass-detonation of stored ammunition stacks. Fragmentation characteristics used as input are derived from small-scale arena tests. In the case of projectiles, the small scale test may consist of one or more pallets positioned to yield a representative sample of an entire stack.

Hazardous fragmentation at any distance is currently defined as having a density equal to, or greater than, 1/600 fragments per square foot and each fragment making up the density having a kinetic energy at impact equal to, or greater than, 58 ft-lbs.

The unique feature of the model lies in the fact that a complete trajectory is calculated for each fragment recovered in the small scale arena tests. Using the Dahlgren main computer, approximately 200 fragments per minute can be processed.

Past tests have demonstrated that virtually all the fragmentation going down-range is produced by the ordnance (projectiles, bombs, etc.) on the face of the stack. Fragmentation from the ordnance in the interior of the stack is, for the most part, contained within the stack. When a stack is detonated, fragment jets are produced between adjacent items on the face of the stack. The width of the jet is dependent on the method of stack initiation. When all units are detonated simultaneously, the jet is typically 10 degrees wide. If only one or two donor projectiles are initially detonated, the jet width is more typically 20 degrees. These jets are referred to as interaction areas. The greatest densities and highest velocities are produced within the interaction areas. For safety reasons, the fragmentation characteristics of the interaction areas are used for input to the model. The interaction areas overlap at relatively short distances down-range and can therefore be added together to represent the cumulative effect of large stacks.

Figure 1 shows a single pallet of projectiles with a one degree azimuthal slice through an interaction area. The one degree slice has been selected for mathematical convenience. The slice could be as large as 10 or 20 degrees depending on the method of stack initiation. From arena tests, the fragmentation characteristics can be established for the full 90 degrees of ejection angle. Individual fragment trajectories can then be calculated to establish hazardous density versus range in terms of discrete range increments. The hazardous density equation is shown at the bottom of Figure 1.

Figure 2 shows the fragmentation input to the program. Each fragment recovered in the arena tests is assigned its own specific characteristics. The ejection zone and initial velocity for each fragment is obtained from the instrumented arena. Fragment weight is measured on a scale and fragment average presented area is measured on an icosahedron gage. Subsonic drag coefficient (Mach no. $<$ .75) has been correlated with the ratio of maximum to minimum fragment presented area. The remainder of the drag curve is approximated from the historically known shape of fragment drag curves.

The program has two options. The first uses average values for the variables shown in Figure 2. The second is a Monte-Carlo option where the uncertainty in ejection angle (E), initial velocity (V), and drag coefficient (C_D) are simulated by sampling from appropriate frequency distributions.

The fragment trajectory for each fragment is calculated using a fourth order Runge-Kutta routine (Figure 3). The trajectories are 3-D with 2-D wind velocities. Air density and sound speed are functions of altitude. The sound speed is used for calculating the C_D - Mach no. relationship. The distance and kinetic energy at impact are recorded for each fragment. The kinetic energy determines whether the fragment is hazardous. Summing the number of hazardous fragments in each distance increment and dividing by the area of the one degree distance increment yield the hazardous density. This is compared with the hazardous density criteria to see if the criteria has been met.

The program outputs a table as shown in Figure 4. In addition to the number of hazardous fragments and the hazardous fragment density, the table includes the same information for the total (hazardous and non-hazardous) fragments and the ratio of hazardous to total number of fragments.

From the output data, hazardous density may be plotted as a function of distance as shown on the left side of Figure 5. In this example the number of interaction areas (NIA - approximately the number of projectiles) is set to 50. The density is proportional to the number of interaction areas; that is, if the NIA were doubled then the density for all distances would also be doubled. Wind has a significant effect. A tailwind will increase both distance and impact kinetic energy as shown by the upward and right shift of the peak on Figure 5. The approximate increase in distance due to wind is equal to the wind velocity times the time of flight.

The density versus distance data may be translated into hazardous distance versus number of projectiles as shown on the right side of Figure 5. Knowing the hazardous density for an NIA of 50, the NIA for a density of 1/600 fragments per square foot can be calculated using proportions. The dotted lines on the plot at the right represent a current uncertainty for very short distances. Additional work with small ejection angles and lighter fragments is necessary to evaluate the contribution from hitting a standing man at short distances.

The essential characteristics of the program are as follows:

- Fragmentation characteristics derived from representative small scale arena tests

- Individual 3-D fragment trajectories

- 2-D wind (horizonal plane)

- 4th order Runge-Kutta Method

- Average value and Monte-Carlo options

- Air density a function of altitude

- Sound speed (Mach no.) a function of altitude

- Drag coefficient a function of the maximum to minimum fragment presented area ratio

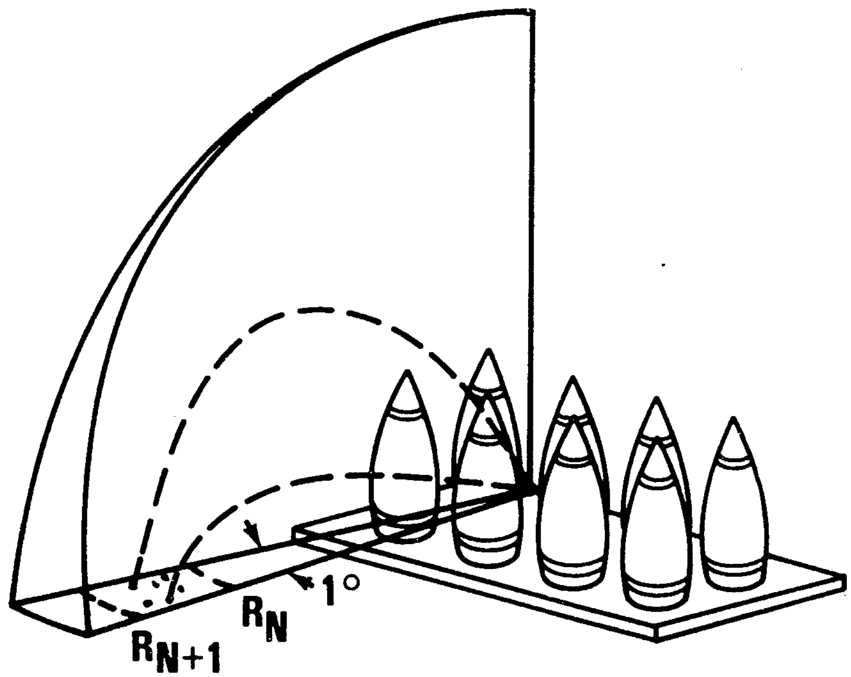
- Handle different hazard criteria

- Output

  Hazardous density versus distance

  Hazardous distance versus number of projectiles (bombs, warheads, etc.) on the face of the stack is determined from the density tables.

HAZARDOUS FRAGMENT DENSITY



$$\rho_H = \frac{N_H}{\frac{\pi}{360}\left(R^2_{N+1} - R^2_N\right)}$$

FIGURE 1

RAW FRAGMENT DATA

FRAG NO.	EJECTION ZONE	WEIGHT	DRAG $M < 0.75$	$\bar{A}/M$	INITIAL VELOCITY
1	0-5	623	1.3	10.2	6246
2	0-5	891	2.1	9.1	6246
89	30-35	1223	1.8	8.6	5614
90	30-35	826	1.2	9.4	5614
91	30-35	618	2.3	11.4	5614
92	35-40	1421	1.4	7.9	4817
231	80-85	1614	2.6	6.8	3216
232	85-90	972	0.90	8.3	2842
233	85-90	1167	2.3	7.7	2842

FIGURE 2

FRAGMENT TRAJECTORY

$$KE = \frac{W V_F^2}{2g}$$

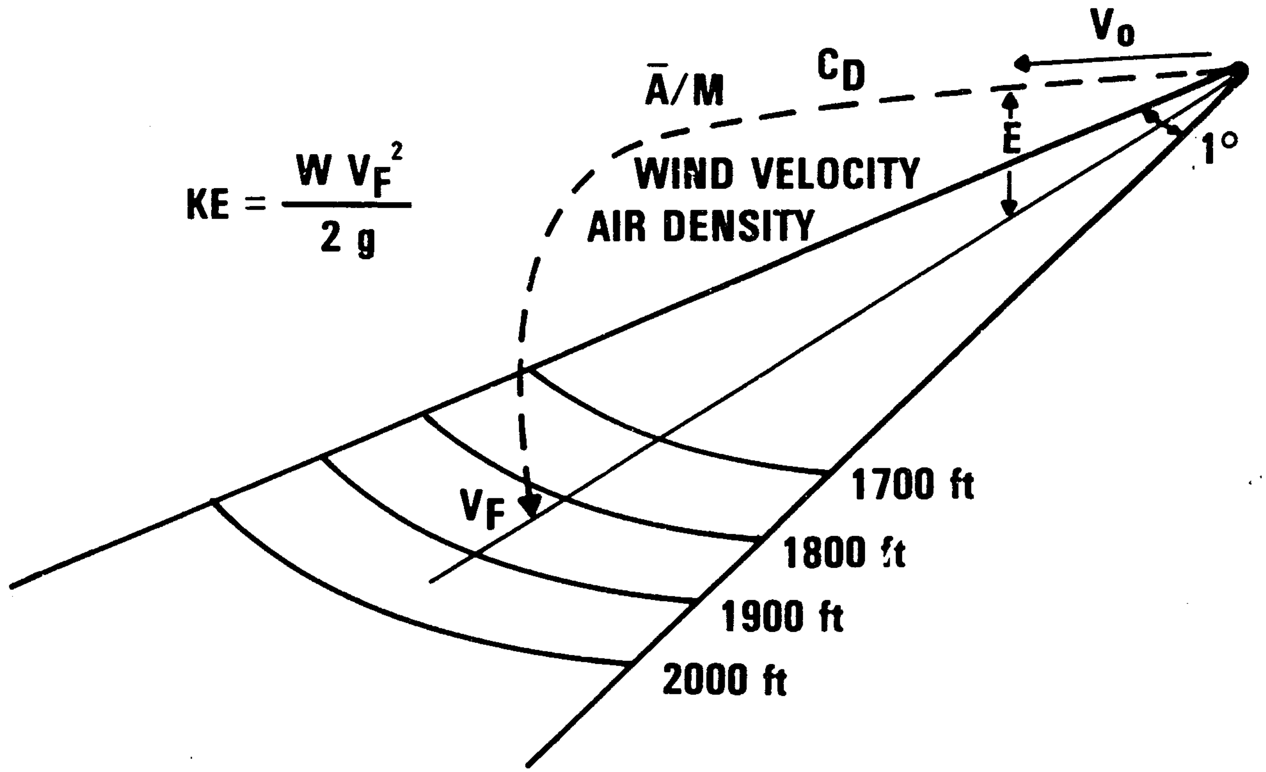


FIGURE 3

OUTPUT

RANGE	TOTAL FRAGMENTS	TOTAL DENSITY	HAZARDOUS FRAGMENTS	HAZARDOUS DENSITY	HAZARDOUS/ TOTAL
0-100	0.0	0.0	0.0	0.0	0.0
100-200	0.132	0.00042	0.0	0.0	0.0
1700-1800	0.614	0.00400	0.307	0.00200	0.50
1800-1900	0.800	0.00184	0.200	0.00046	0.25
1900-2000	0.848	0.00150	0.106	0.00019	0.125
4900-5000	0.0	0.0	0.0	0.0	0.0
5000-5100	0.0	0.0	0.0	0.0	0.0

FIGURE 4

HAZARDOUS QUANTITY - DISTANCE PREDICTION

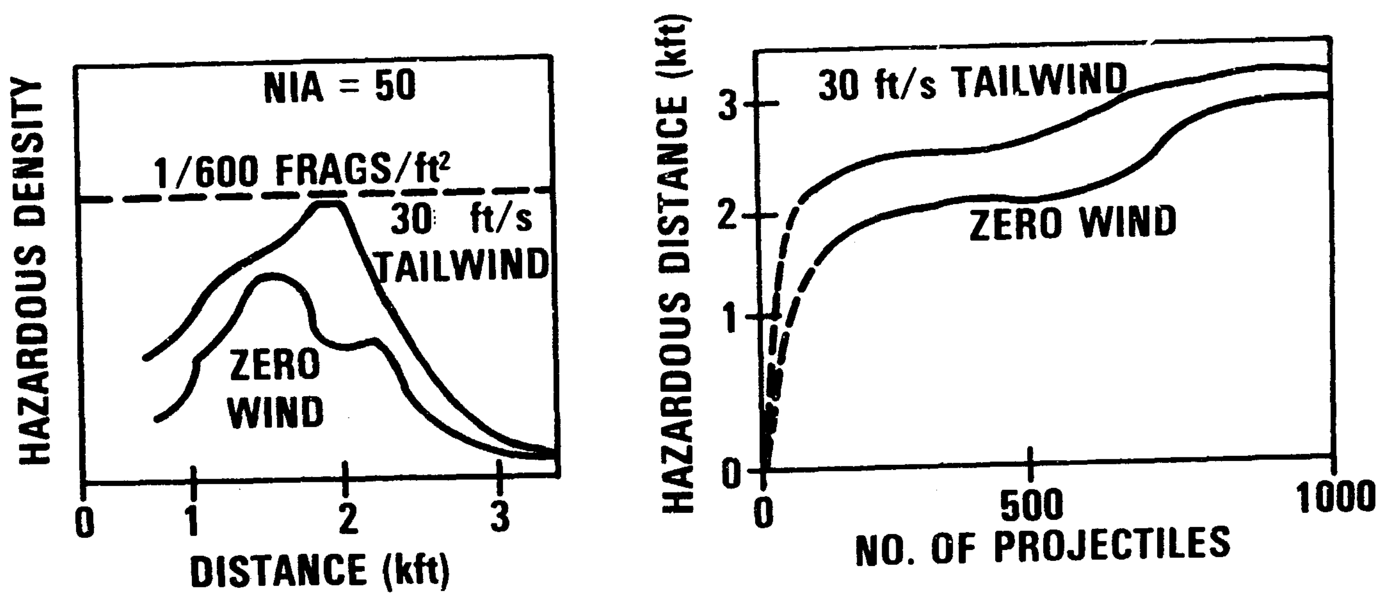


FIGURE 5