FRAGMENT HAZARD CRITERIA

by

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The following discussion relates to a review of data pertaining to the effects of fragments upon the human body and the rational development of a casualty criteria developed from this data. Finally the developed casualty criteria has been related to other existing criteria.

The effects of fragments on biological tissues were reviewed using available experimental evidence and including superficial, incapacitating, and near lethal categories of injury. Missiles consisted of glass, bullets, balls, and blunt objects. The parts of the body used were: skin, lower abdomen, thorax, limbs and skull.

Dose functions, consisting of missile mass, M, and velocity, V, were developed as a method to integrate evidence concerning casualty effects under differing terminal conditions. Here, extensive use of extrapolated and interpolated experimental results were utilized. Momentum MV, energy MV^2, and energy times velocity square MV^4, depending upon the mechanism of injury, were assigned as the dose functions. These three functions, applied to injuries, were primarily in the nature of: (1) impulse loading for momentum; (2) crushing or tearing for energy; and (3) cutting or penetrating for energy.

This method made possible digital computation of probable biological effects in a diverse missile environment interrelating the various kinds of experimental evidence available. The values estimated and formulas proposed served as a hypothesis for further experimental validation. Application of these formulas will reveal which mechanism of injury and missile environments are of greatest importance. How critical the assumptions can be revealed by variations of these parameters.

Four groups of data based upon experiments were considered: penetration of the lower abdomen of dogs by glass (Ref. 1), effects of missiles on human cadavers (Ref. 2), data on skull fracture (Ref. 3), and effects of missile impact on the chest (Ref. 4). There were considerable differences in the scope of these data groups and in the availability of raw observations for independent estimations of parameters. The probability of penetration or laceration by glass was related to the mass and velocity of the missile by MV^4. This statistic was then used to attempt to consistently account for other biological effects of missiles regarding injuries which primarily involve penetrating wounds. Some results concerning larger missiles, with biological effects primarily involving bones, did not fit this relationship. The data on skull fracture also proved the necessity for using another statistic. It was found that mass times velocity squared satisfied the requirements to explain crushing or tearing wounds such as most bone injuries or passage through regions of tissue. These injuries could be incurred with or without penetration of intervening tissues as in the case of skull fracture, bone breakage, or rib fracture complicated by internal lacerations. When the tissue has been penetrated, energy is the determining factor for estimating the probability of complete passage through a limb. It was found that even these two statistics did not correlate well for unilateral lung hemorrhage and simple rib fractures. It appeared from the data available that mass times velocity alone could be used to predict the occurrence of these injuries.

Table 1 summarizes the mass-velocity relationships obtained for the data reviewed. The dose relationship column indicates the criteria employed to relate biological response with missile characteristics at the time of impact. The last three columns in Table 1 present the value of the missile-velocity dose for 10, 50 and 90 percent probability of the specific effect occurring. For optimistic and pessimistic estimates of the 50 percent probability values indicated in Table 1, 70 and 140 percent of the values provided are suggested, based on the uncertainty of the data for the MV^4 doses, and 80 and 125 percent for the MV and MV^2 doses. Different probability values can be determined from Table 1 by the following relation

$$S^2 = \left(\frac{\log P90 - \log P50}{1.282}\right)^2$$

$$P_i\left\{x\right\} = \frac{1}{2\pi S}\int_{-\infty}^{x} e^{-(t-\log P(50)^2/2S^2)}dt$$

where P_i is the probability of the effect occurring.

Figure 1 is a graph of 50 percent probability thresholds for each effect in Table 1. The curves of Fig. 1 are obtained by applying the specific relationship of Table 1 between M and V to obtain the 50 percent probability of the effect occurring. For example, for rib fracture (MV relationship) the 50 percent probability is 31 x 10^3 gm ft/sec. Therefore, for a 1,000 gm mass, the missile velocity must be about 31 fps for 50 percent probability of rib fracture. If the mass of the missile is 100 gm, the velocity must be 310 fps. In a similar manner, the 50 percent values of the other effects at various velocities and ranges were determined.

Table 1

SUMMARY OF BIOLOGICAL EFFECTS OF MISSILE DATA

No.	Effect	Part of Body Tested	Type of Missile Used	Part of * Body for Application	Target Area		Dose Relation-ship	Units	Probability of Effect Occurring, percent			Severity
					% Body	ft^2			10	50	90*	
									Dose Required			
1	Laceration	Skin	Glass	General	100.0	4.20	MV^4	$gm \frac{ft^4}{sec^4}$	0.108×10^9	0.902×10^9	7.50×10^9	Superficial
2	Penetration	Abdomen	Glass	Abdomen and limbs	25.0	1.01	MV^4	$gm \frac{ft^4}{sec^4}$	0.569×10^9	3.83×10^9	25.9×10^9	Incapacitating
3	Laceration	Skin	Spherical Bullets	General	100.0	4.20	MV^4	$gm \frac{ft^4}{sec^4}$	4×10^9	11×10^9	30×10^9	Superficial
4	Penetration	Limb	Spherical Bullets	Abdomen (lower) and limbs	25.0	1.01	MV^4	$gm \frac{ft^4}{sec^4}$	9×10^9	24×10^9	64×10^9	Incapacitating
5	Bilateral Hemorrhage	Lung	Balls	Thorax	15.5	0.65	MV^4	$gm \frac{ft^4}{sec^4}$	65×10^9	175×10^9	475×10^9	Near Lethal
6	Fatality within 1 hr	Thorax	Balls	General	43.0	1.81	MV^4	$gm \frac{ft^4}{sec^4}$	225×10^9	625×10^9	1625×10^9	Lethal
7	Fracture	Skull	Blunt Objects	Head	8.0	0.33	MV^2	$gm \frac{ft^2}{sec^2}$	0.974×10^6	1.37×10^6	1.93×10^6	Near Lethal
8	Bone Abrasion and Cracking	Limbs	Spherical Bullets	Not including ribs	35.0	1.47	MV^2	$gm \frac{ft^2}{sec^2}$	0.6×10^6	0.9×10^6	1.3×10^6	Incapacitating
9	Passage	Thigh	Spherical Bullets	Abdomen and limbs	25.0	1.01	MV^2	$gm \frac{ft^2}{sec^2}$	1.4×10^6	2.0×10^6	2.8×10^6	Near Lethal
10	Fractures Large Bones	Limbs	Bullets	Not including ribs	35.0	1.47	MV^2	$gm \frac{ft^2}{sec^2}$	2.3×10^6	3.4×10^6	5.0×10^6	Near Lethal
11	Internal Lacerations on Fractured Ribs	Thorax	Balls	Thorax	15.5	0.65	MV^2	$gm \frac{ft^2}{sec^2}$	3.1×10^6	4.5×10^6	6.6×10^6	Incapacitating
12	Unilateral Hemorrhage	Lung	Balls	Thorax	15.5	0.65	MV	$gm \frac{ft}{sec}$	16×10^3	22×10^3	29×10^3	Superficial
13	Rib Fractures	Thorax	Balls	Thorax	15.5	0.65	MV	$gm \frac{ft}{sec}$	24×10^3	31×10^3	40×10^3	Superficial

* Thus for a glass missile imparting skin with $7.5 \times 10^9 gm\ ft^4/sec^4$ the probability of laceration occurring is 90 percent.

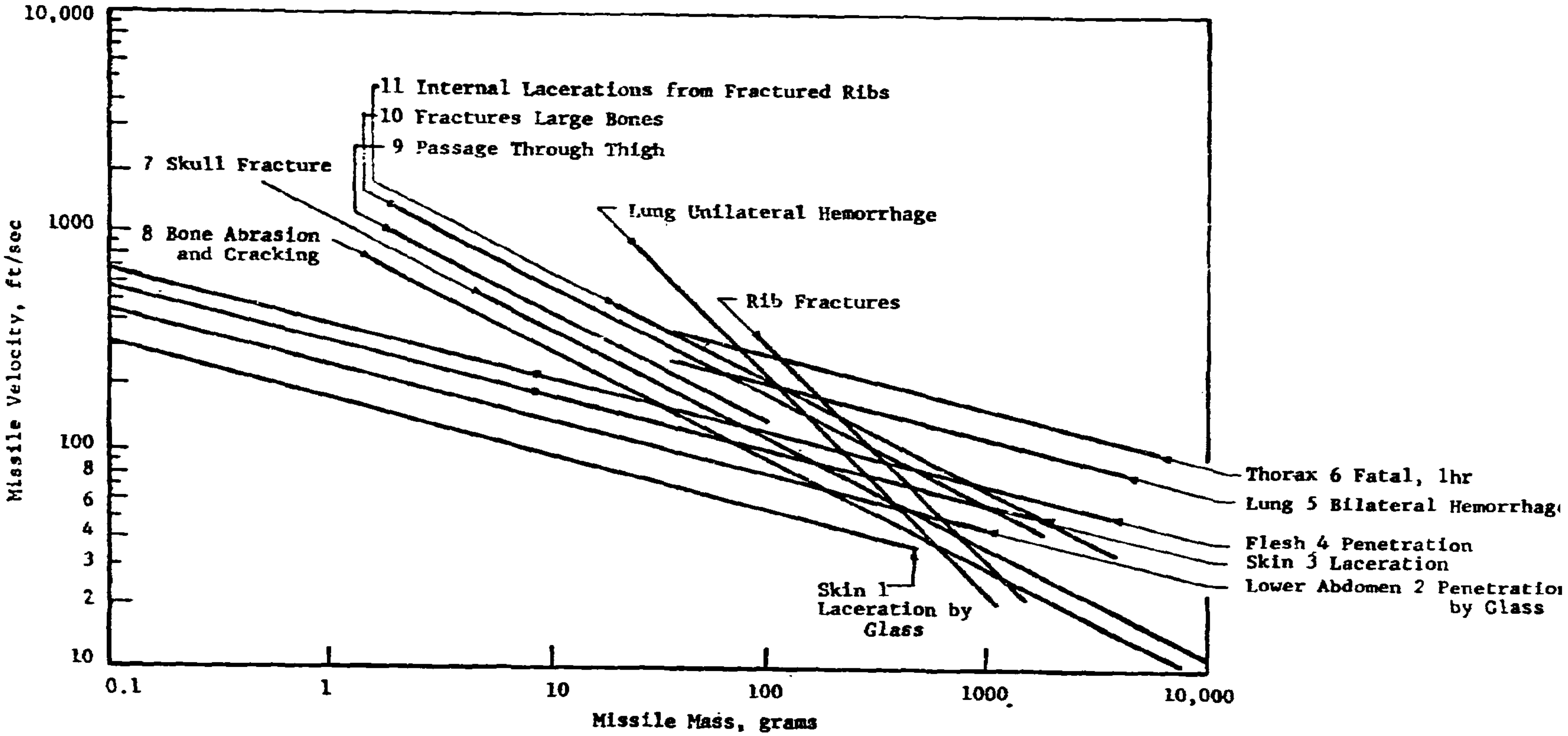

Fig. 1 VARIOUS BIOLOGICAL EFFECTS OF MISSILES

The goal here was to isolate casualty criteria which could be used to analyze hazards due to fragments. A series of functions have been developed relating missile characteristics to probability of injury. The severity of injuries and associated probability of mortality based on severity have also been estimated. However, even at this stage functions are of limited value. Therefore, the effects of severity and probability of occurrence for each effect have been combined, averaged and extrapolated as necessary to obtain one continuous relationship covering the complete range of missile masses and velocities which might be of interest where data were available. For example, in Case 1 of Table 1 the effect of penetrating glass is classified as a superficial wound and is estimated at 10 percent mortality. The probability of a glass fragment missile mass-velocity combination producing mortality can subsequently be determined by multiplying the probability of its producing the effect by the mortality probability. If the probability of producing a superficial wound is 10 percent, then the probability of producing mortality from the same missile mass-velocity combination is only 1 percent. In a similar manner, each of the effect relationships was changed to mortality and plotted on one graph for each applicable body region (head, thorax, abdomen and limbs). Those relations marked "general" were applied to each graph, while those indicated for a specific region were only used when that region applied. An example of the former is the category of skin laceration, which can be used for each region. Three graphs resulted similar to Fig. 1 with almost as many lines. Effects requiring the least velocity were selected in each mass region, and then various relations were averaged visually (at this point it hardly seemed worth the effort to do more).

Table 2 provides an estimate of total body projected area as well as vulnerable areas of various body regions. This date was useful later when complete consideration of fragment coverage areas, fragment characteristics and body areas were used in making casualty descriptions. However, it was used in making qualitative estimates of mortality based on the injuries reported in the data summarized in Table 1. The type and size of missiles has a definite effect on vulnerable areas. Future research on missile casualties might consider some of these effects when reporting data.

Table 2

BODY TARGET AND VULNERABLE AREAS (REF. 5 AND 6)

Region	Area ft²	% of Total	Vulnerable Area		
			Area ft²	% of Region	% of Body
Head and Neck	0.5	12	0.15	30	3.5
Thorax	0.67	16	0.65	97	15.5
Abdomen	0.46	11	0.45	97	10.5
Upper Limbs	0.92	22	0.19	20	4.5
Lower Limbs	1.65	39	0.38	23	9.0

Kneeling presents approx. 55% of field projected area
Sidewise presents approx. 45-50% of field projected area
End of prone presents 25% of field projected area.

Three sets of curves emerged, one (each) for MV, MV^2 and MV^4, and separate ones for 10, 50 and 90 percent mortality probability. These were made continuous by using the lowest velocity curves for each mass and cutting off the curves at the intersection points. The results are illustrated by Fig. 2. As an afterthought, the casualty criteria employed in World War II was plotted on each of these figures, and the similarity was gratifying. It is highly recommended that future research in the areas of casualty criteria and mortality be aimed at covering the full range of mass and velocity of interest to explosive safety problems, and further that an attempt be made to verify the estimates made in conducting this study.

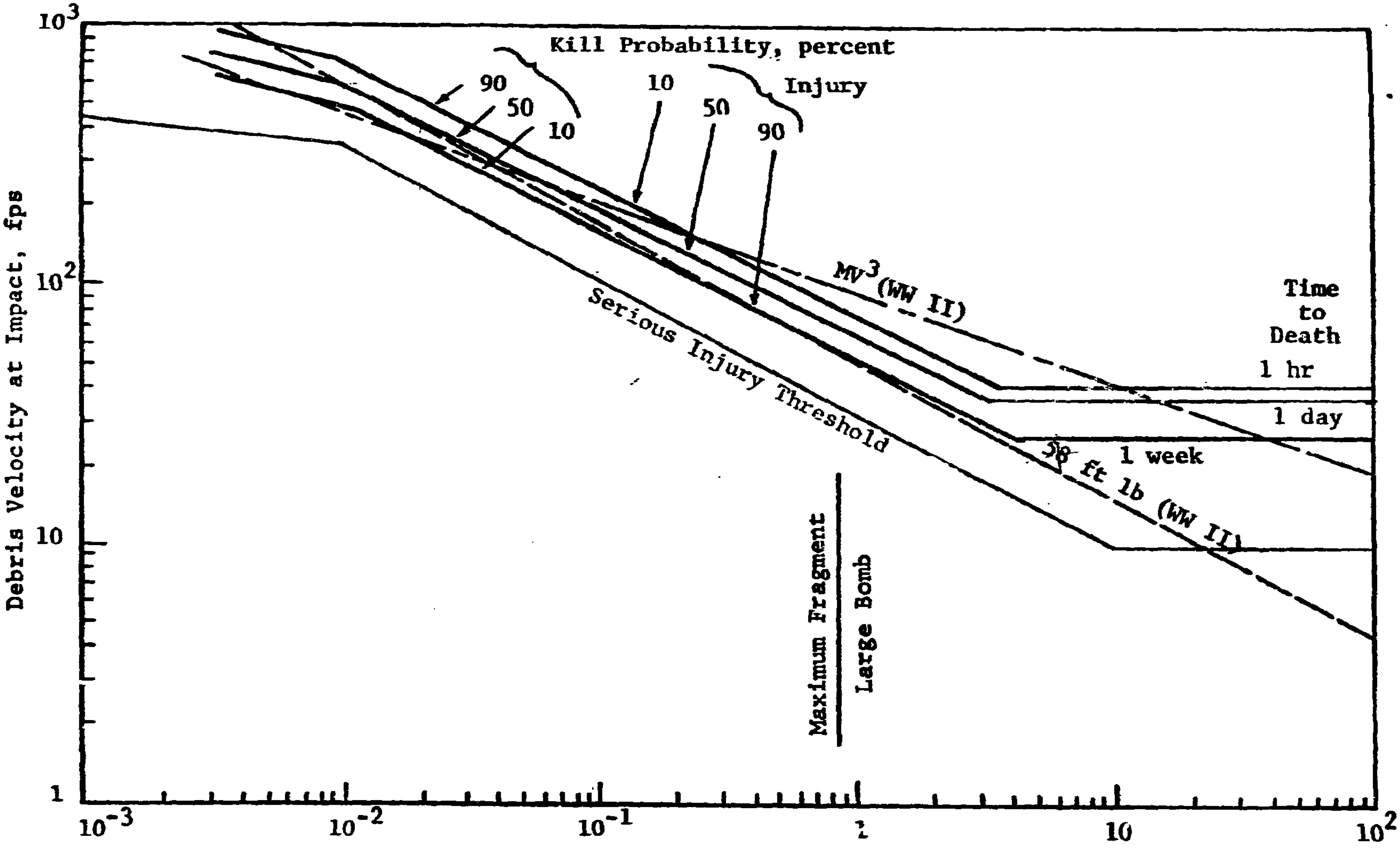

Fig. 2 KILL PROBABILITY FROM DEBRIS IMPACTS (Head)

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