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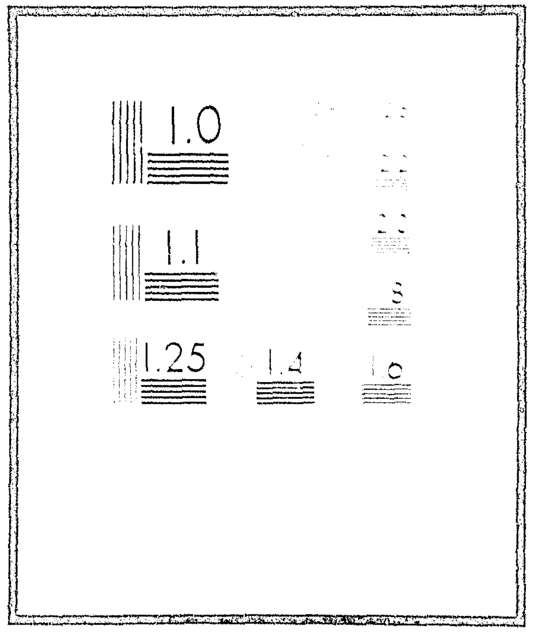

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BODY ARMOR

BLUNT TRAUMA DATA

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BODY ARMOR
BLUNT TRAUMA DATA

By

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This was a data correlation task.

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Blunt trauma	Discriminant	Model	Blunt impact
Soft armor	Dose	Serious injury	Correlation
Backface signature	Response	Physical parameter	Assessment
Multiplicative	Criteria	Physiological parameter	Nonpenetration

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

The purpose of this task was to assemble and correlate blunt trauma data with primary emphasis on the relevancy of the data to the goals and objectives of the overall Lightweight Soft Body Armor Program. Secondarily, the applicability of these data to projectile-induced blunt trauma generalizations was considered. The task was carried out in two related phases. The first was a review phase during which the data were evaluated by a mixed discipline team to establish the validity and applicability of each data set to the objectives of this task. The second phase involved the analysis of those data sets identified as most relevant during the review phase and resulted in two

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provisional multiplicative models. One, a four-parameter model, represents the maximum number of parameters common to all data sets and has suggested application for generalized projectile-induced blunt trauma to the thorax. It is predictive to the extent that all of the parameters which may be measured experimentally can also be assumed. The same model, with appropriate adjustment of the discriminant line intercept, was extended to fracture/no-fracture data for the liver. The second model incorporates the eight parameters measured in the Lightweight Soft Body Armor Program and provides better live/die discrimination in animals than the four-parameter model. Coupled with data derived through methodology developed in the Backface Signature Task of this program, it provides a behind-the-armor predictive (preexperimental) live/die capability for animals based on the "physical" parameters, and a more sensitive, though nonpredictive, discriminant capability given postexperimental "physiological" measures.

SUMMARY

Purpose

The purpose of this task was to assemble and correlate blunt trauma data with primary emphasis on the relevancy of the data to the goals and objectives of the overall Lightweight Soft Body Armor Program. Secondarily, the applicability of these data to projectile-induced blunt trauma generalizations was considered.

Scope

This correlation effort was centered around but not limited to data generated by the following organizations thought to be the most likely sources of relevant, projectile-induced blunt trauma data.

(1) Calspan Corporation, Buffalo, New York

(2) Edgewood Arsenal

(3) Land Warfare Laboratory, Aberdeen Proving Ground, Maryland

(4) Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico

(5) MB Associates, San Ramon, California

(6) United Kingdom

A list of the documents reviewed is contained in the bibliography.

Methodology

The task was carried out in two related phases. The first was a review phase during which the data were organized as to type (research, test, empirical, theoretical, etc.) and were evaluated by a mixed discipline team to establish the validity and applicability of each data set to the objectives of this task. This phase resulted in interim conclusions and recommendations within a 2-month period.

The second phase involved the analysis of those data sets identified as most relevant during the review phase and resulted in two provisional multiplicative (parameters multiplied rather than added) models. The correlation analysis involved objective functions based on misclassifications and/or zones of mixed results for positive (death) and negative (survival) responses in animals struck in the thorax by nonpenetrating projectiles. The starting point for the analysis was with two parameters (minimum logical parameters) and proceeded through successive combinations of "physical" parameters to a level of five (maximum available). Three "physiological" parameters were also correlated with response. The models were validated using available, independently obtained data for similar and dissimilar projectiles as well as for different animal species. Extension of the four-parameter model to liver impact data was attempted and validation within the limits of available data was accomplished.

Results and Conclusions

The four-parameter model represented the maximum number of parameters common to all data sets. These data sets include three animal species and twelve projectile variations. The model has suggested application for generalized projectile-induced blunt trauma to the thorax and is predictive to the extent that all of the parameters which may be measured experimentally can also be assumed. The model is of the form:

$$P(r) = f(MV^2/WD)$$

where

$P(r)$ = probability of response (death, serious injury, etc.)

M = mass of the projectile in grams

V = impact velocity of the projectile in meters per second

W = body mass of the animal in kilograms

D = diameter of the projectile in centimeters

The same model, with appropriate adjustment of the discriminant line intercept, was extended to fracture/no-fracture data for the liver. The model discriminated low, mid, and high regions of response/no response. These data spanned three animal species and twelve projectile variations.

The second model, consisting of eight parameters, is one of three that initially resulted from an Army Materiel Command-Edgewood Arsenal basic research program in projectile-induced blunt trauma of the thorax. A modification (the substitution of projectile diameter D for projectile area A) suggested by the current correlation effort resulted in a model with "physical" measures of MV^2/TWD and "physiological" measures of $L/W \times \%APO_2 \times \%VPO_2$.

where

M = mass of the projectile in grams

V = impact velocity of the projectile in meters per second

T = tissue thickness over the vital organ impacted in centimeters

W = body mass of the animal in kilograms

D = diameter of the projectile in centimeters

L/W = total lung mass/body mass of the animal in grams per kilogram

$\%APO_2$ = maximum deviation in arterial oxygen pressure from control value

$\%VPO_2$ = maximum deviation in venous oxygen pressure from control value

This model incorporates the parameters measured in the Lightweight Soft Body Armor Program and provides better live/die discrimination in animals than the four-parameter model. Coupled with data derived through methodology developed in the Backface Signature Task of this program, it provides a behind-the-armor predictive (preexperimental) live/die capability for animals based on the "physical" parameters and a more sensitive discriminant capability given postexperimental "physiological" measures.

Although the above models represent the best correlations thought possible with the available data base, the insufficiency and inconsistency within that data base permit only restricted model formulation and validation. For this reason, pending availability of additional data for further validation, the models presented in this report should be considered provisional.

PREFACE

The data correlation task described in this report was authorized under contract LEAA-J-IAA-005-4. The task was started in November 1973 and completed in May 1974. Data sources reviewed are listed in the bibliography; sources of data used in the actual correlation are listed on the individual data tables.

Acknowledgments

We wish to acknowledge the assistance of the following personnel of the Biophysics Division who participated in the review of the literature sources of the currently available information and test results relevant to blunt trauma.

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BLUNT TRAUMA DATA CORRELATION

I. INTRODUCTION.

Blunt trauma literature, as evidenced by the review efforts by MB Associates, Land Warfare Laboratory, Biophysics Division, and others, is to a large part made up of data applicable to auto crashes and blast, typically with total body and total or even multiple organ involvement. The differences in mass, velocity, and perhaps dose and dose application times* provide reasonable doubt as to the applicability of these data to projectile-induced blunt trauma with nontotal body involvement or even, more typically, with only discrete areas of single organs involved.

This Blunt Trauma Correlation Task was, therefore, carried out with primary emphasis on the relevancy of the overall Lightweight Soft Body Armor Program, ongoing under Interagency Agreement No. LEAA-J-IAA-005-4. The goals are to have protective garments that will withstand the threats of a .38 caliber special and a .22 caliber handgun and to characterize and reduce the blunt trauma effects. The objective of the program is to develop lightweight protective garments for use by public officials and law enforcement personnel. Secondarily, the applicability of these data and analyses to projectile-induced blunt trauma generalizations was considered.

II. PROCEDURE.

This task was carried out in two related phases, a review phase and an analysis phase.

A. Review.

During the review phase, blunt trauma data were acquired, organized as to type (research, test, empirical, theoretical, etc.), and reviewed by the mixed discipline team to establish the validity and applicability of each data set to the objectives of this task. In this manner, consensus-determined interim conclusions and recommendations were available and presented from a large volume of data within the 2-month period as required. Interim conclusions and recommendations were necessary early in the program so that any modifications to the methodology of the other tasks indicated as a result of the correlation task could be accomplished before program termination. The interim conclusions and recommendations are given in appendixes A and B, respectively.

B. Analysis.

The analysis phase used only those data sets identified as most relevant during the review phase and was carried out in the following steps:

1. Correlation Model Selection. A multiplicative (parameters multiplied rather than added) discriminant model format was chosen based on experience gained during a segment of an Army Materiel Command (AMC) basic research program in blunt trauma conducted by the Biophysics Division during FY73. From this study, data for 30 impacts on live goat thoraces by four noncompliant, nonpenetrating projectiles, each impact having five "physical" and three "physiological" measurements, were chosen as the basic data set. Since this AMC program was specifically designed for basic research in projectile-induced blunt trauma, it had available the greatest number (eight) of related parameters recorded for any given impact of any of the studies reviewed. Obviously, models with fewer parameters could also be derived from this data set.

* The bioresponse-to-trauma problem is essentially one of a dose/response nature where the input "dose" is some injury-producing quantity and the "response" is the occurrence of an adverse effect on the human, such as tissue damage, incapacitation, or lethality. As used in this report, projectile-induced blunt trauma "dose" is a multiparametered relationship consisting of at least the projectile impact velocity multiplied by the projectile mass in various combinations with the other parameters of: projectile diameter, body (target) mass, and wall thickness. Although it is felt that other parameters may also have relevancy to projectile-induced blunt trauma "dose," they were not determinable within the scope of this study.

The two-parameter model, using projectile mass (M) and velocity (V), was chosen as the starting point (minimum logical parameters) for the correlation analyses. Successive combinations of increasing "physical" parameters up to the maximum available (five) were fitted (i.e., placed in the numerator or denominator) in their proper relationship according to theory. The values of these five parameters can either be measured or assumed; the model therefore represents a predictive capability for generalized projectile-induced blunt trauma. The three "physiological" parameters are not merely different assorted parameters but are different measures of blunt trauma to the thorax. Since these parameters must be determined experimentally, that portion of the model, though giving good discrimination, does not have predictive capability. Since the set of eight parameters, initially established during the AMC-Edgewood Arsenal (EA) effort, are available elsewhere only in the Soft Armor Program, the correlation effort on an eight-parameter basis is limited in sample size and obviously is not appropriate for some parameter sets found in other studies.

2. Determination of Parameter Relevancy. As tasked, the correlation was for existing data only with applicability to:

a. Generalized projectile-induced blunt trauma

b. Blunt trauma behind soft armor (Kevlar)

The objective functions of "fewest misclassifications" (MC) and/or "smallest zone of mixed results" (ZMR) were used throughout the analyses to determine the best model fit of existing data. The best model fit at each combination level was assumed to contain those parameters most relevant to blunt trauma response discrimination. Throughout the AMC-EA data correlation plots (figures 1 through 6) the solid line, which is an "eyeball" fit, is the discriminant line with the dashed line(s) demarking the zones of mixed results.

3. Determination of Relative Powers of Parameters. Physical theory and empirical data fit were combined throughout the analyses to arrive at the two provisional models. To facilitate this, natural log units were used for all of the plots. In this manner, the slope of the discriminant line provided an indicator of the exponent of the velocity parameter relative to the other parameters.

4. Validation of Models. Once the relevancy and relative exponent of the available blunt trauma parameters of the AMC-EA data set were established, the model which provided the best discrimination was assumed to represent the best available correlation. Necessary validation for the generalized model was achieved by subjecting live/die and liver fracture/no-fracture responses from independently obtained, nonarmored, projectile impact data sets to the model and observing if discrimination misclassifications and zones of mixed results were maintained at reasonable levels.

The substitution of the projectile diameter for area in the four-parameter model was also applied to the eight-parameter soft armor application model. Independently obtained data to prove this model were available only from the Backface Signature Task and, despite the small sample size, validated the model reasonably well. Subsequent application of the model in the continuing Backface Signature Task should provide additional validation.

III. RESULTS.

The results of the correlation analyses by parameter level are presented in figures 1 through 6. Throughout this series of plots, the same n = 30 data set is used (see table 1). Animals surviving for a 24-hour period after the nonpenetrating impact to the thorax are represented by an open symbol; and nonsurvivors, by a solid symbol. The fraction beside each symbol denotes the mass of the projectile in the numerator and the diameter of the impact surface in the denominator (e.g., 50/40 = 50 grams/40 mm). In all cases, the projectiles were noncompliant cylinders. The discriminant (solid) line was fitted to the data to separate positive and negative responses with the fewest misclassifications consistent with the theory of the relationship. The zone of mixed results is denoted by the dashed line(s) parallel to the discriminant line.

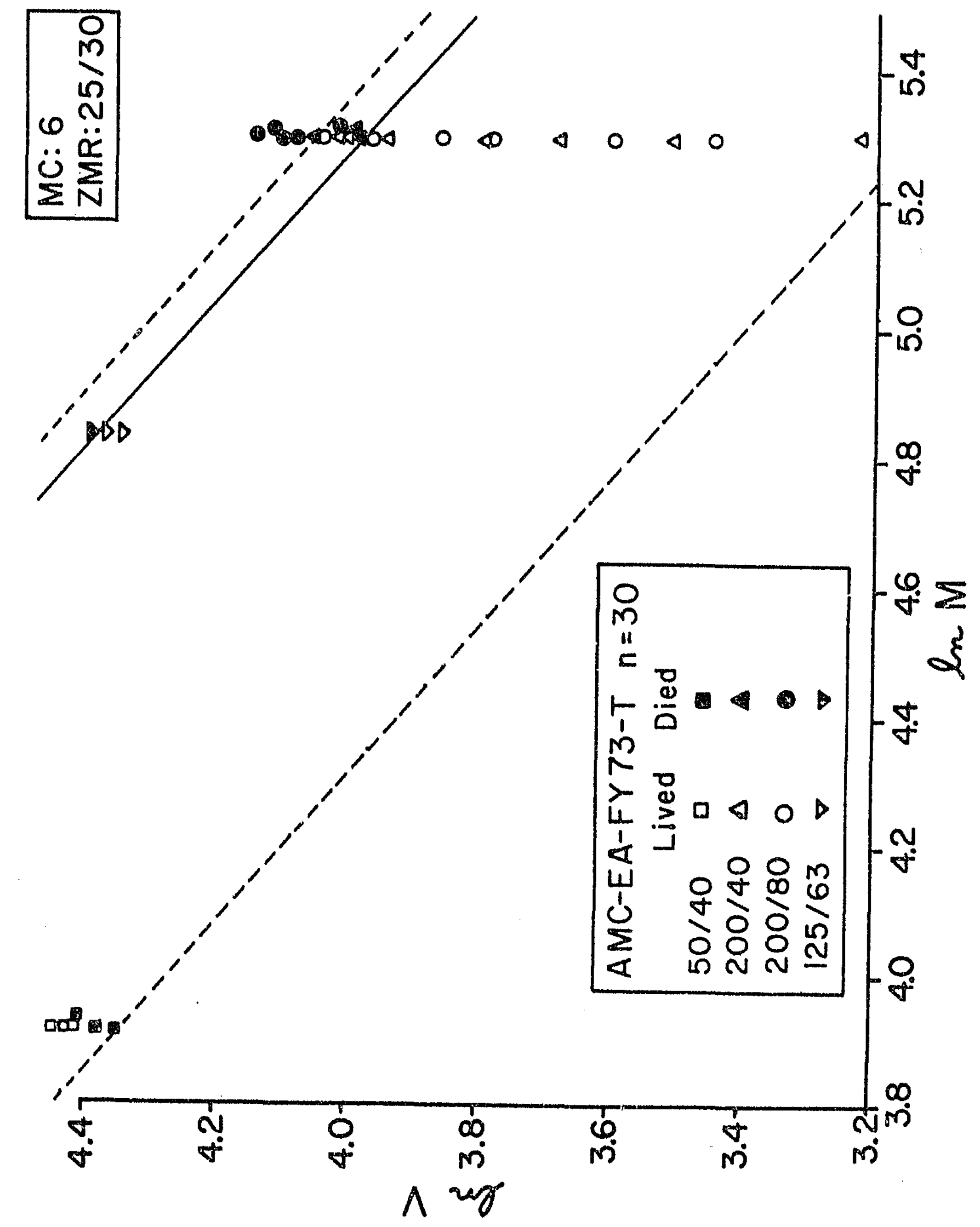
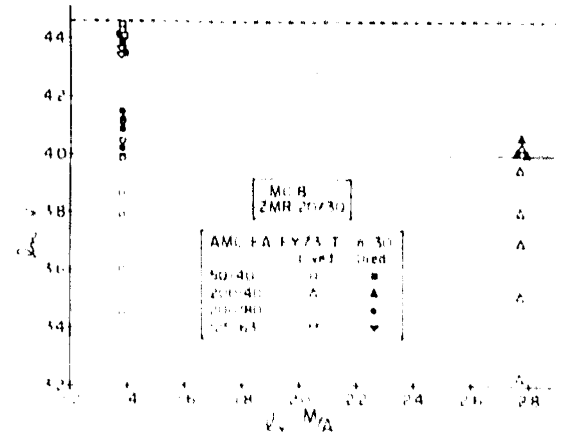


Figure 1. Two-Parameter Discriminant Correlation Model - Thorax



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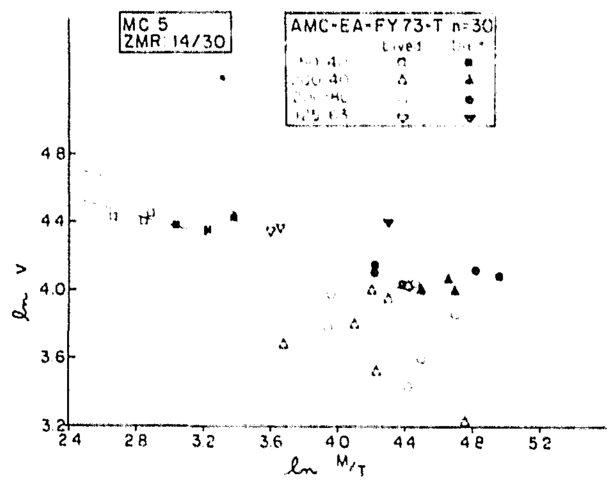

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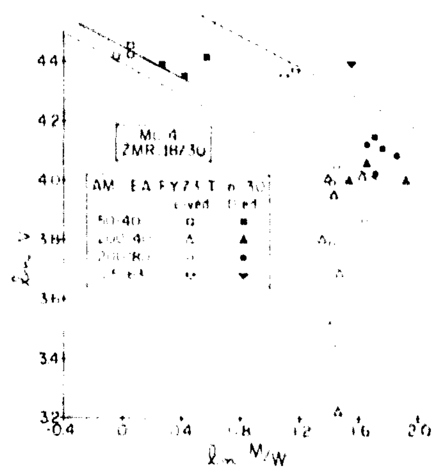

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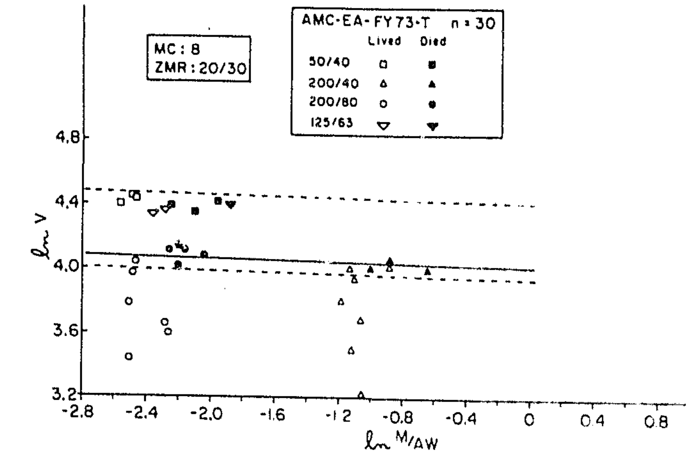
Figure 2. Three-Parameter Discriminant Correlation Model - Thorax



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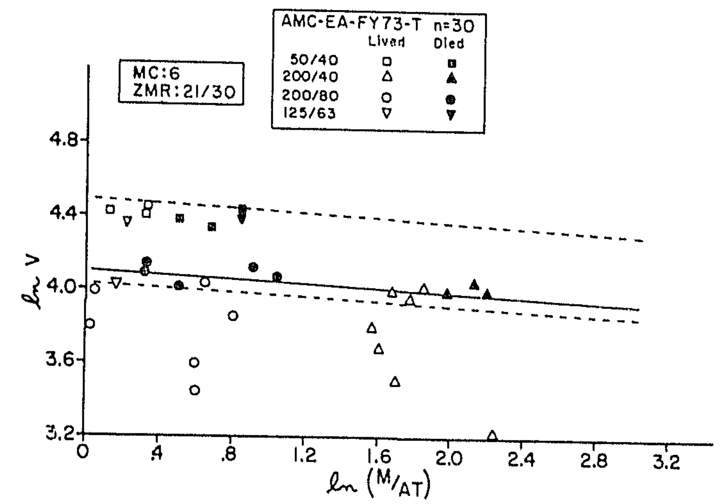

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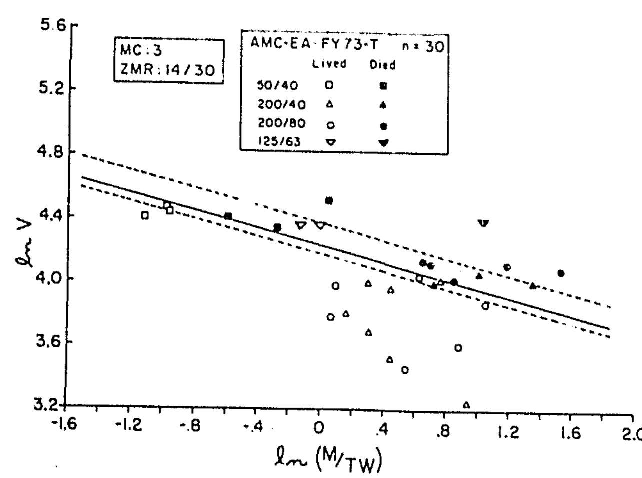

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Figure 3. Four-Parameter Discriminant Correlation Model - Thorax

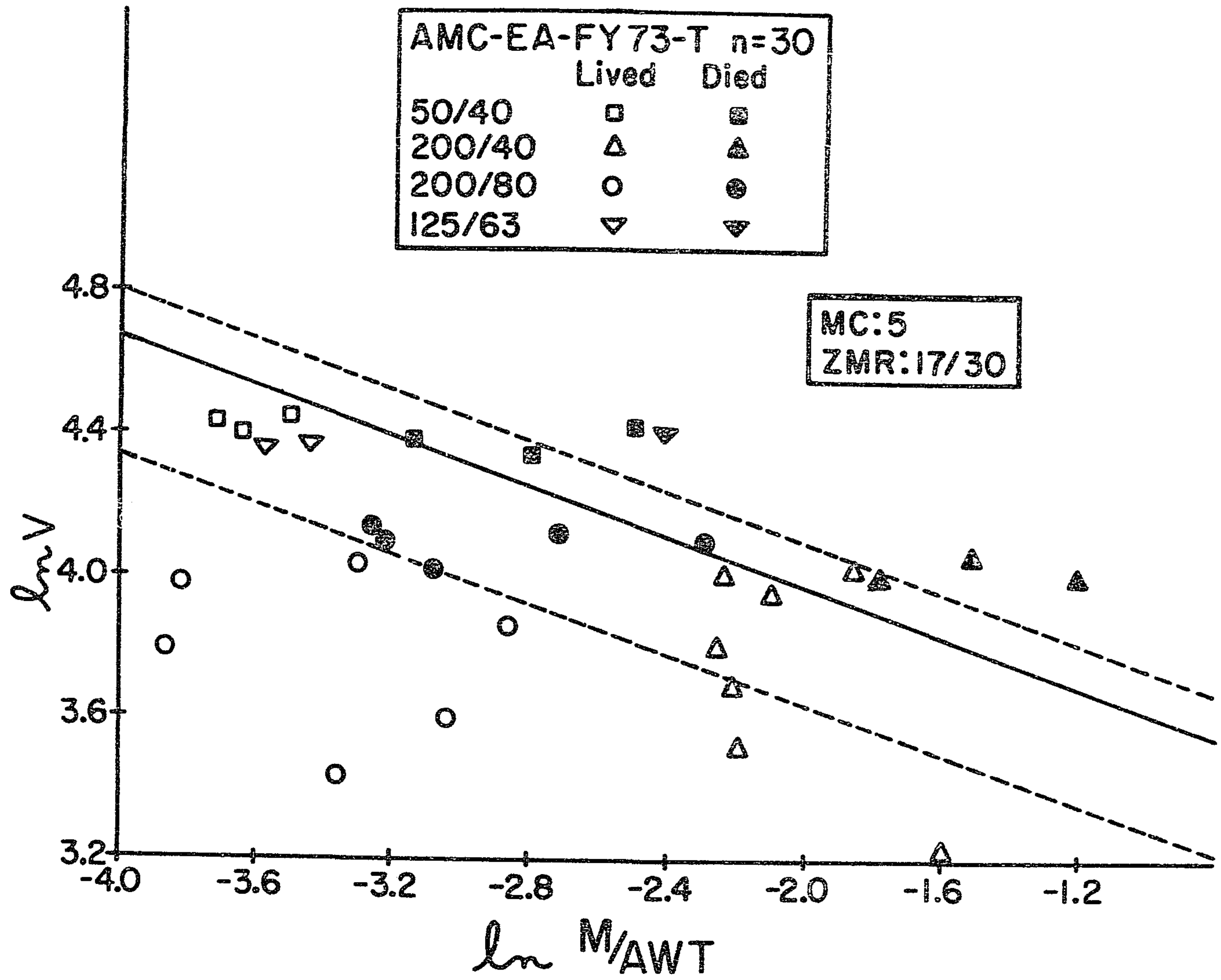

Figure 4. Five-Parameter Discriminant Correlation Model - Thorax

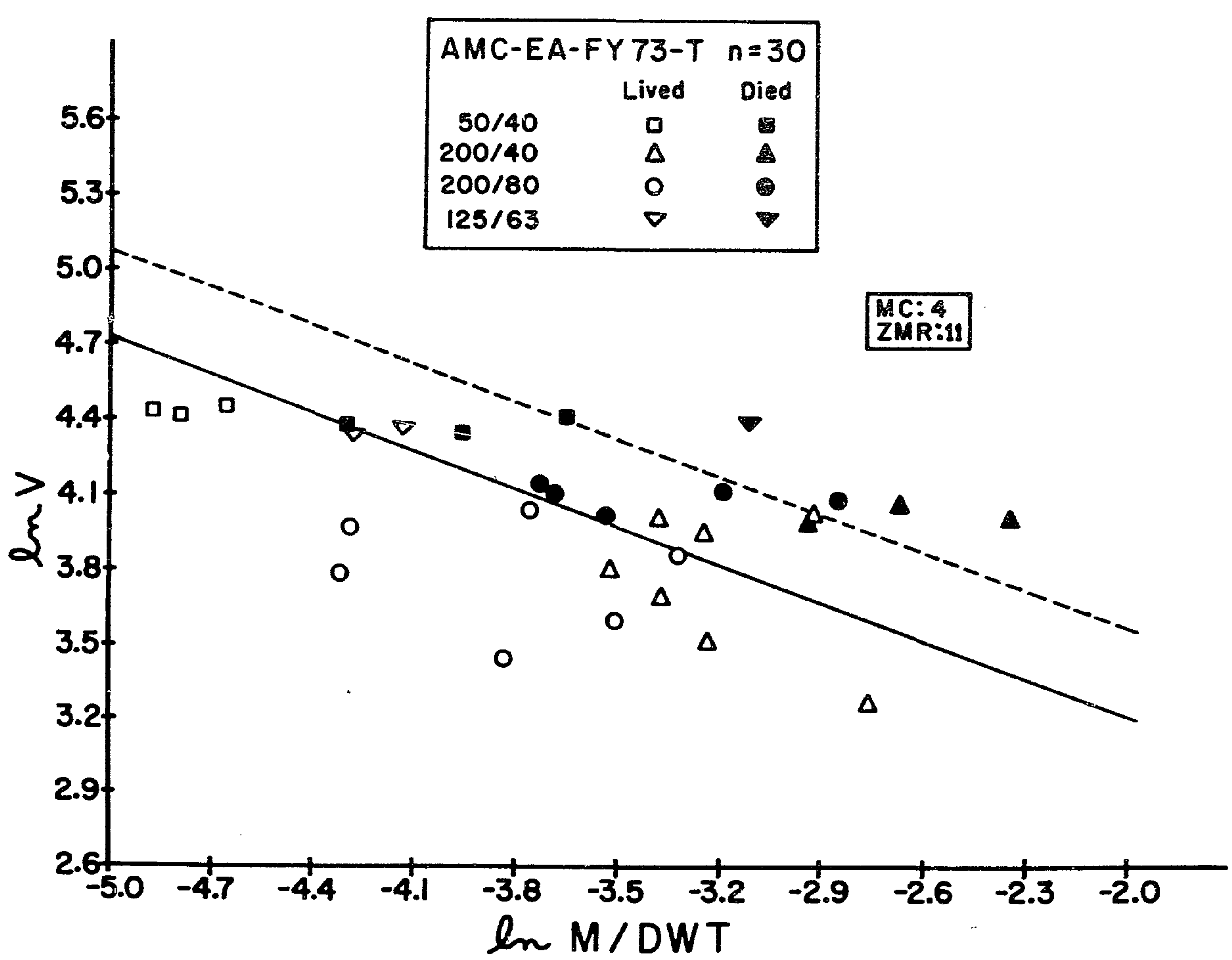

Figure 5. Modified Five-Parameter Discriminant Correlation Model - Thorax

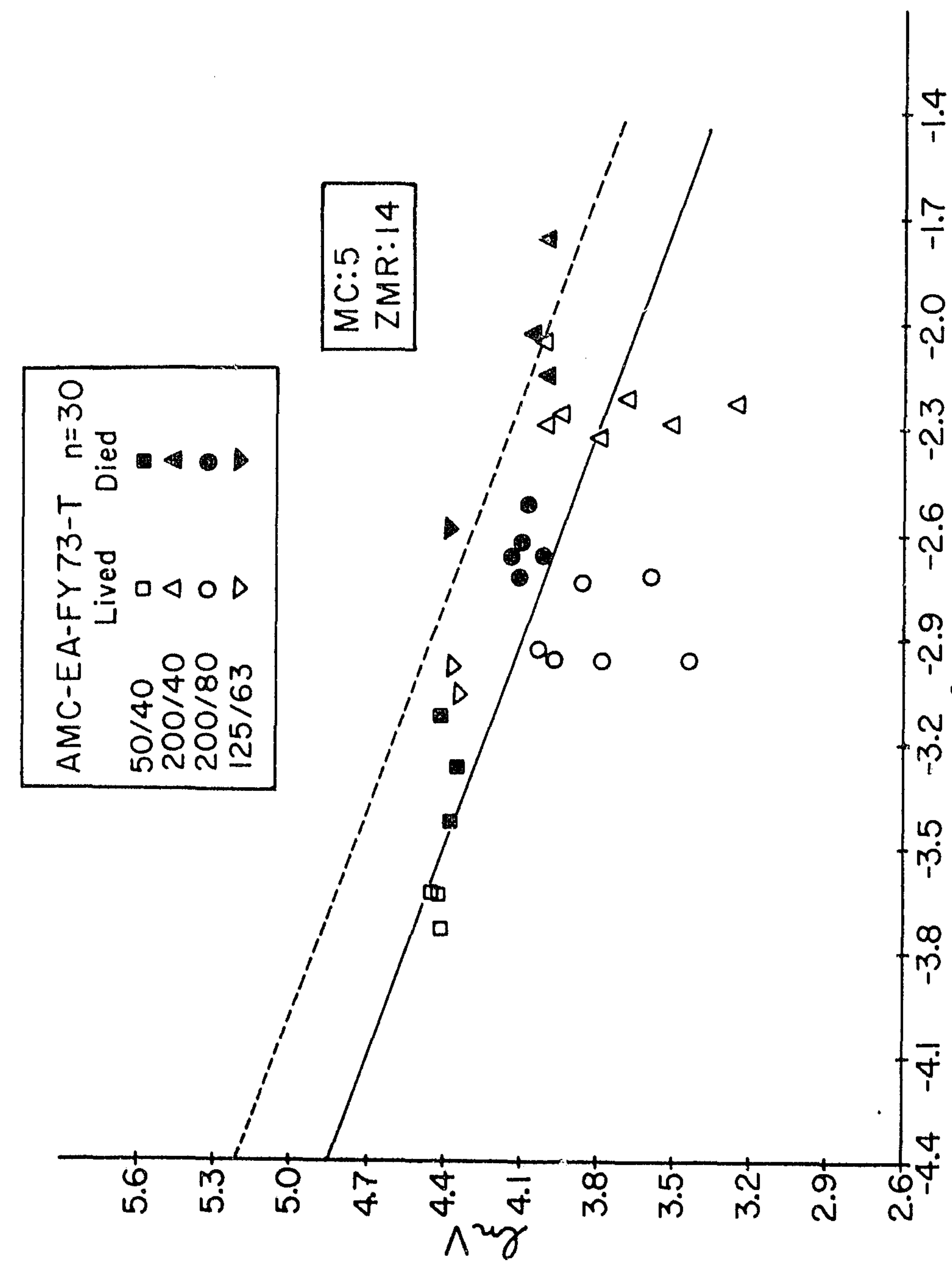

Figure 6. Provisional Generalized Blunt Trauma Model - Thorax
(Modified Four-Parameter Discriminant Model)

Table 1. Biophysics Division Thoracic Impact Data
(Noncompliant Cylinder – Goat, Basic Set)

Data source: BIOPHYSICS DIV-AMC-EA-FY73-T (reference 2)

Animal species: GOAT

Projectile: NONCOMPLIANT CYLINDERS

PLOTTED: Figures 1, 2 (A, B, and C), 3 (A, B, and C), 4, 5, 6, 7, 11, 12, 13, 17, 18, 19, 20, 21, 22

Animal No.	Projectile: Mass (M)	Projectile: Velocity (V)	Projectile: Diameter (D)	Target: Weight (mass) (W)	Target: Tissue thickness (T)	Target: Lung weight / Body weight (L/W)	Target: Arterial O_2 deviation (APO_2)	Target: Venous O_2 deviation (VPO_2)	Response, death	Plot symbol
	gm	m/sec	mm	kg	cm	gm/kg				
19909	50	82.62	40	52.2	2.9	7.39	5.0	27.3	-	□
19908	50	84.05	40	47.0	3.5	8.83	10.1	5.5	-	
19911	50	85.70	40	47.2	2.8	10.04	21.6	12.0	-	
19871	50	77.79	40	32.8	2.0	12.20	37.8	33.3	+	■
19907	50	79.87	40	38.4	2.4	13.93	39.2	42.3	+	
19850	50	82.93	40	28.4	1.7	14.65	95.6	94.2	+	
19875	200	25.18	40	46.5	1.7	6.62	4.3	29.4	-	△
19889	200	33.61	40	49.2	2.6	7.89	22.2	7.3	-	
19890	200	40.13	40	45.9	3.2	8.71	14.5	15.8	-	
19891	200	44.76	40	51.5	3.3	5.73	16.3	18.4	-	
19899	200	51.97	40	48.0	2.7	12.04	41.8	33.0	-	
19901	200	55.16	40	49.4	3.0	10.04	12.9	17.5	-	
19905	200	56.13	40	38.9	2.4	13.62	25.3	40.4	-	
19904	200	54.73	40	43.0	2.2	18.37	82.4	88.7	+	▲
19906	200	54.93	40	29.2	1.8	16.95	92.0	88.9	+	
19000	200	58.04	40	38.2	1.9	12.33	66.1	58.9	+	
19877	200	31.52	80	48.3	2.4	12.42	1.2	13.1	-	○
19878	200	36.73	80	38.0	2.2	8.00	10.3	14.7	-	
19892	200	44.38	80	48.4	3.9	10.95	40.6	23.7	-	
19893	200	47.90	80	38.7	1.8	11.94	41.7	36.7	-	
19894	200	53.42	80	48.2	3.8	9.75	42.0	30.0	-	
19903	200	57.21	80	46.8	2.3	10.81	15.1	27.3	-	
19915	200	55.87	80	35.9	2.4	18.88	43.8	63.2	+	●
19919	200	59.59	80	31.0	1.4	17.10	58*	62.8	+	
19897	200	60.92	80	34.4	2.9	19.62	71.4	69.6	+	
19896	200	61.64	80	38.2	1.6	20.26	71.9	49.6	+	
19898	200	63.34	80	36.0	2.9	21.89	86.0	87.2	+	
19926	125	77.46	63	42.2	3.4	11.21	10.9	34.6	-	▽
19928	125	79.06	63	38.8	3.2	15.46	51.5	54.7	-	
19927	125	81.17	63	26.4	1.7	22.20	85.3	86.1	+	▼

* No control reading. Calculated value from mean control of 83.0.

A. Parameter Relevancy.

1. Two-Parameter Fit.

The MV plot (figure 1) resulted in six misclassifications with 25 of the 30 points falling in the zone of mixed results. The grouping of the three discrete projectile masses of 50, 125, and 200 grams is quite obvious at this two-parameter level. Of additional interest are the six points at the extreme upper left portion of the plot representing the 50/40 projectile. These data indicate that the three animals (□) that survived were subjected to higher velocity impacts than the three animals (■) that died. This would appear to be contrary both to logic and theory. Further examination of these data points revealed that the three surviving animals had body masses of 47.0, 47.2, and 52.2 kg, whereas the animals that died had body masses of 28.4, 32.8, and 38.4 kg. This was an experimental verification that body mass scaling is indeed relevant to blunt trauma response assessment.

2. Three-Parameter Fits.

Three fits consistent with theory were possible at the three-parameter level: MV/A, MV/T, and MV/W.

The MV/A plot (figure 2, A) showed eight misclassifications (two greater than the two-parameter plot) and a 20/30 ZMR value (five less than the two-parameter plot). The addition of A, the area of the projectile impact surface, though adding a third parameter and thereby increasing generalized applicability of the model, actually decreased live/die discrimination capability.

In figure 2, B, tissue thickness at the point of impact, T, was substituted for area and the resultant MV/T plot showed improved discrimination with five misclassifications and 14/30 as the ZMR value.

The MV/W combination (figure 2, C) gave four misclassifications with 18/30 in the ZMR, the best at this level.

At the three-parameter level, then, in combination with MV, the best correlation was achieved using body mass with the poorest discrimination arising from the area correlation. Tissue thickness ranks between these two. It should be noted that regardless of the combination of the other parameters (M/A, M/T, or M/W) there was a marked dependence on velocity, V, for discrimination, as evidenced by the slope of the discriminant line in each of these plots.

3. Four-Parameter Fits.

Three fits consistent with theory were also possible at the four-parameter level: MV/AW, MV/AT, and MV/TW. These fits are again presented in descending order of misclassifications.

The MV/AW plot (figure 3, A,) contained eight misclassifications with twenty points in the zone of mixed results. This was the highest number of misclassifications observed during the correlation.

Substituting T for W provided MV/AT (figure 3, B). In this combination, the misclassifications were reduced to six. However, the zone of mixed results increased by one to a total of 21.

Three misclassifications, the fewest at the four-parameter level and the fewest at any level using only the "physical" parameters, were achieved with the MV/TW plot (figure 3, C). The ZMR value was also the lowest for the four-parameter level at 14.

4. Five-Parameter Fit.

The single five-parameter fit is shown in figure 4. Both the misclassifications at five and the ZMR at 17 were slight increases over the best four-parameter plot. However, the five-parameter plot showed better correlation than the other two four-parameter combinations and the fewest misclassifications of any plot containing the A term.

5. Relevancy of the Area Term.

At the three- and four-parameter levels in which it was possible to both include and exclude the area term, the poorest correlations (i.e., the poorest discrimination or the highest number of misclassifications) were always obtained when area was included: figures 2, A, 3, A, and 3, B, with 8, 8, and 6 misclassifications, respectively. This would suggest that the effect of area in the model should either be diminished or completely eliminated in order to achieve better correlation. However, logic and theory suggest that area, or some function of area, should be important in the dose transfer phenomenon, particularly if the model is to have generalized application; i.e., across appreciable variations in projectile impact area. In an attempt to improve the correlation by "softening" the effect of area while maintaining some capability to generalize, the model was modified by substituting diameter, a function of area, for the area. Additional support through logic can be mustered for the use of D if one considers the blunt trauma loading phenomenon against the thorax. The dose, when applied to the ribs of the thoracic cage, is distributed along the long axis of the rib whenever any portion of that rib is struck. Therefore, the load distribution and resultant response is strongly a function of the number of ribs the projectile is in contact with. It is not difficult to visualize that the number of ribs involved is limited by the diameter (or effective diameter in the case of a noncircular surface) of the impacting surface, not by its area. The plot using D instead of A (figure 5) did improve the discrimination, with the misclassifications going from five to four while the ZMR diminished from 17/30 to 11/30.

The MV/WDT model appeared to be the most likely combination of the parameters in a relevant fashion which would provide reasonable generalized blunt trauma discrimination. However, the review phase had already shown that tissue thickness, T, was not measured in most data sets. Therefore, the MV/WD model shown in figure 6 represents the maximum number of parameters common to all data sets which still permits the best correlation. It should be noted that this four-parameter model in figure 6, which uses D, provides better discrimination than the four-parameter model in figure 3, A, which uses A.

B. Determination of Relative Powers of Parameters.

As mentioned in the procedure, natural log units were used in the correlation model plots so that the slope of the discriminant line would be indicative of the exponent of the velocity parameter. In the final format (figure 6) which was considered to contain the maximum number of parameters common to all data sets in the most relevant relationship, the slope of the discriminant line was approximately two. This empirical fit then suggested that the velocity should be squared, putting dose in the form of MV^2. The compatability of the MV^2 format with physical theory added further weight to its choice as the provisional generalized correlation model for the thorax resulting from this effort. The remaining step in the analysis process was to validate the provisional model(s).

C. Validation of Models.

1. Generalized Model.

To facilitate validation, the MV^2/WD model was plotted with $\ln MV^2$ on the X axis and lnWD on the Y axis. The original 30 AMC-EA data points plus 16 additional points (tables 2 and 3), including a fifth projectile configuration, the 125/63 NCR, all from impacts against goat thoraces, were plotted by their X, Y values. Two discriminant lines, each having a slope of one, were fitted to these data points to establish three zones: a low-lethality zone, a midrange-lethality zone, and a high-lethality zone. The slope of one was necessary to maintain the exponents of the variables in their proper relationship. The intercept value for the low- to mid-lethality discriminant line is -7.61 and the intercept for the mid- to high-lethality discriminant line is -8.11. As can be seen from this plot (figure 7), the model has good discrimination capability with 0/17 deaths (0%) in the low-lethality zone, 11/22 deaths (50%) in the mid-lethality zone, and 6/7 deaths (86%) in the high-lethality zone.

Figures 8, 9, and 10 maintain the same discriminant line intercept and slope values and the same X, Y scale as figure 7, but are overlaid with three independently obtained data sets representing Land Warfare Laboratory (tables 4 and 5), Edgewood Arsenal Ad Hoc (tables 6, 7, and 8), and Lovelace Foundation effort (table 9), respectively.

Table 2. Biophysics Divsion Thoracic Impact Data
(Noncompliant Cylinder - Goat)

Data source: BIOPHYSICS DIV-AMC-EA-FY73-T (reference 2)

Animal species: GOAT   Projectile: NONCOMPLIANT CYLINDER (RING)

PLOTTED: Figures 7, 11, 12, 13, 17, 18, 19, 20, 21, 22

Animal No.	Projectile			Target		Target			Response, death	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)	Weight (mass) (W)	Tissue thickness (T)	Lung weight / Body weight (L/W)	Arterial O_2 deviation (APO_2)	Venous O_2 deviation (VPO_2)		
	gm	m/sec	mm	kg	cm	gm/kg	%	%		
19941	125	55.78	63	32.8	2.1	9.82	30.4	33.3	-	◇
19924	125	73.26	63	42.0	2.1	10.12	37.7	23.2	-	
19925	125	75.11	63	35.8	3.5	11.40	23.4	43.4	-	
19929	125	78.11	63	43.0	2.7	12.74	25.2	28.7	-	
19940	125	62.22	63	27.8	1.5	14.86			-	
19931	125	74.98	63	40.2	2.6	14.43	82.3	81.9	+	◆
19923	125	77.41	63	33.2	2.4	23.74	48.7	40.2	+	
19930	125	79.96	63	36.8	2.6	15.38	84.8	83.4	+	
19939	125	71.18	63	31.4	2.4	24.14		54.4	+	

Table 3. Biophysics Division Thoracic Impact Data
(Noncompliant Cylinder - Goat)

Data source: BIOPHYSICS DIV-AMC-EA-FY73-T (reference 2)

Animal species: GOAT   Projectile: NONCOMPLIANT CYLINDERS

PLOTTED: Figures 7, 11, 12, 13

Animal No.	Projectile			Target		Target			Response, death	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)	Weight (mass) (W)	Tissue thickness (T)	Lung weight / Body weight (L/W)	Arterial O_2 deviation (APO_2)	Venous O_2 deviation (VPO_2)		
	gm	m/sec	mm	kg	cm	gm/kg	%	%		
19872	50	78.33	40	39.5	2.2	7.44		11.8	-	□
19910	50	82.10	40	38.0	2.9	9.21		19.8	-	
19879	200	40.91	80	40.8	3.1	7.45		10.2	-	○
19916	200	51.33	80	41.6	2.6	10.65	19.8		-	
19918	200	57.30	80	35.4	1.8	11.92			-	
19917	200	61.81	80	35.6	2.4	11.32			-	
19920	200	61.04	80	34.3	1.7	21.75			+	●

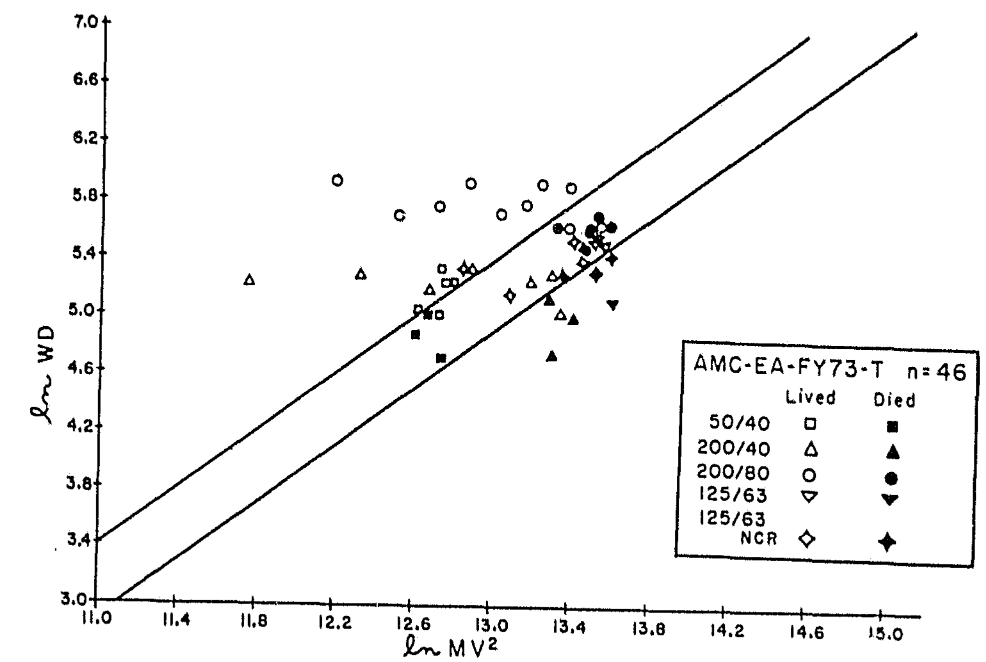

Figure 7. Generalized Model Validation Plot - AMC-EA Data

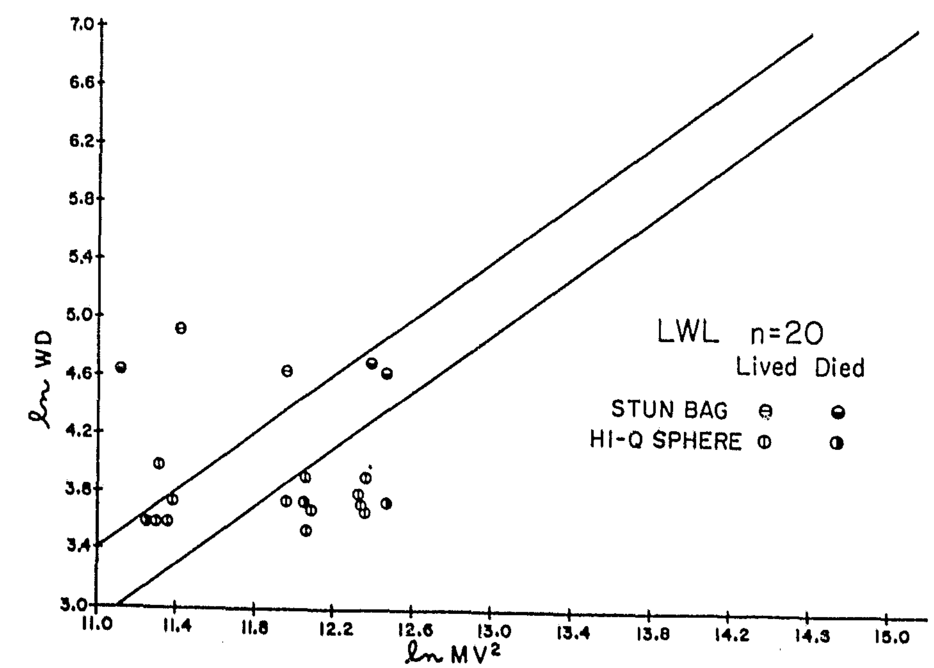

Figure 8. Generalized Model Validation Plot - LWL Data

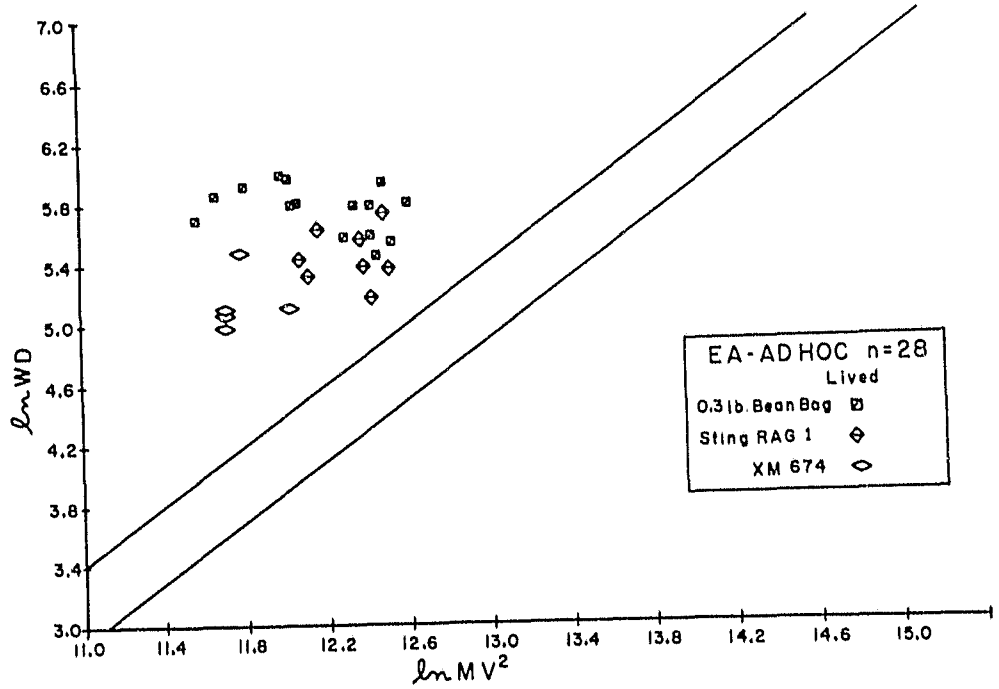

Figure 9. Generalized Model Validation Plot - EA Ad Hoc Data

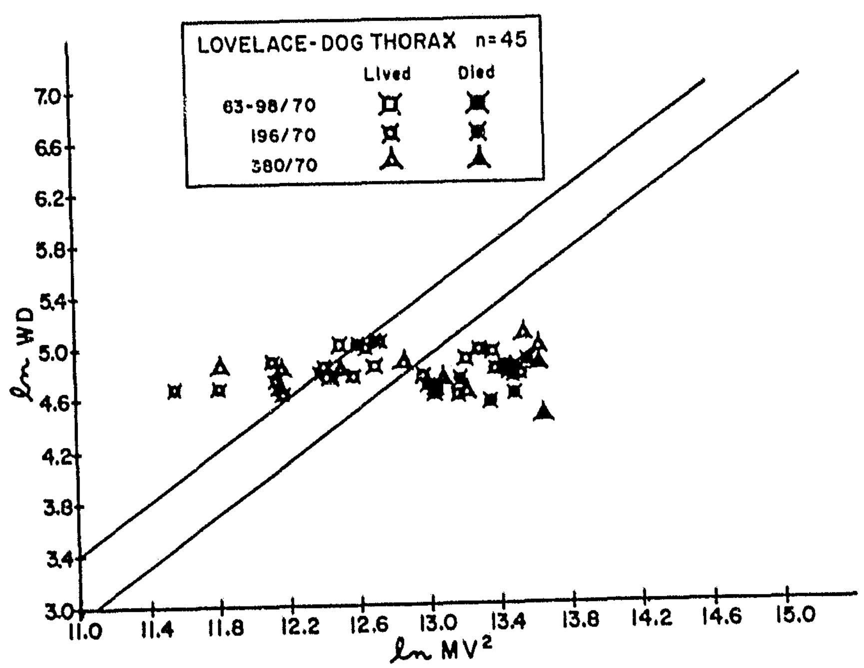

Figure 10. Generalized Model Validation Plot - Lovelace Foundation Data

Table 4. Land Warfare Laboratory Thoracic Impact Data
(Stun Bag - Swine)

Data source: LWL-AAI ER 7351 (reference 14)

Animal species: SWINE Projectile: STUN BAG

PLOTTED: Figures 8, 11, 12, 14

Animal No.	Projectile			Target weight (mass) (W)	Target Lung weight / Body weight (L/W)	Response, death	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)				
	gm	m/sec	mm	kg	gm/kg		
316	196	21.3	79	17.4	11.6	-	⊖
318	196	28.0	79	13.2	19.5	-	
314	196	18.3	79	13.1	18.4	+	⊖
315	196	34.7	79	14.1		+	
313	196	36.0	79	13.1	16.9	+	

Table 5. Land Warfare Laboratory Thoracic Impact Data
(High-Q Sphere - Swine)

Data source: LWL-CR-07B72 (reference 15)

Animal species: SWINE Projectile: HIGH-Q SPHERE

PLOTTED: Figures 8, 11, 12, 14

Animal No.	Projectile			Target weight (mass) (W)	Response, death	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)			
	gm	m/sec	mm	kg		
[illegible]	11.7	82.6	27.686	13.4	-	⦶
206	11.7	83.2	27.686	19.5	-	
208	11.7	85.0	27.686	13.4	-	
217	11.7	121.0	27.686	18.0	-	
212	11.7	121.6	27.686	12.6	-	
211	11.7	122.5	27.686	14.8	-	
215	11.7	138.7	27.686	15.9	-	
214	11.7	139.3	27.686	15.3	-	
213	11.7	140.8	27.686	18.2	-	
216	11.7	140.8	27.686	14.5	-	
207	11.7	80.8	27.686	13.4	+	◑
210	11.7	121.0	27.686	15.2	+	
13	11.7	86.2	27.686	15.35*	-	⦶
17	11.7	115.2	27.686	15.35	-	
18	11.7	148.1	27.686	15.35	+	◑

* Mean body weight of 15.35 kg is assumed.

Table 6. Biophysics Division Thoracic Impact Data
(Stun Bag - Goat)

Data source: BIOPHYSICS DIV-EA-AD HOC-EB-TR-73056 (reference 4)

Animal species: GOAT Projectile: BEAN BAG (STUN BAG)

PLOTTED: Figures 9, 11, 12

Animal No.	Projectile			Target		Response, death	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)	Weight (mass) (W)	Tissue thickness (T)		
	gm	m/sec	mm	kg	cm		
19727	132	18.3	76.2	48.4	1.8	-	⊠
19729	132	28.3	76.2	39.2	1.7	-	
19730	132	29.6	76.2	46.0	2.3	-	
19728	132	31.7	76.2	49.0	1.8	-	
19725	132	34.8	76.2	52.8	3.7	-	
19726	132	35.3	76.2	52.0	4.1	-	
19723	132	35.6	76.2	43.2	2.9	-	
19724	132	36.2	76.2	43.6	3.5	-	
19492	132	41.4	76.2	43.2		-	
19492	132	43.0	76.2	43.2		-	
19581	132	43.1	76.2	36.0		-	
19584	132	43.7	76.2	31.1		-	
19491	132	44.3	76.2	50.0		-	
19582	132	45.4	76.2	34.0		-	
19490	132	47.1	76.2	44.3		-	

Table 7. Biophysics Division Thoracic Impact Data
(XM674 Projectile - Goat)

Data source: BIOPHYSICS DIV-EA-AD HOC (reference 5)

Animal species: GOAT Projectile: XM674

PLOTTED: Figures 9, 11, 12

Animal No.	Projectile			Target		Response, death	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)	Weight (mass) (W)	Tissue thickness (T)		
	gm	m/sec	mm	kg	cm		
15283	210	24	36.5	43.6		-	◇
15285	210	24	36.5	45.0	1.5	-	
15286	210	24	36.5	39.8		-	
15281	210	25	36.5	66.0		-	
15284	210	28	36.5	45.4	1.8	-	

Table 8. Biophysics Division Thoracic Impact Data
(Sting RAG, Type 1 - Goat)

Data source: BIOPHYSICS DIV-EA-AD HOC (reference 7)

Animal species: GOAT Projectile: STING RAG (Type 1)

PLOTTED: Figures 9, 11, 12

Animal No.	Projectile			Target		Target Lung weight / Body weight (L/W)	Response, death	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)	Weight (mass) (W)	Tissue thickness (T)			
	gm	m/sec	mm	kg	cm	gm/kg		
19994	43	63.7	63	36.6	2.5	8.63	-	⊖
19957	43	64.9	63	32.8	2.9	8.90	-	
19960	43	66.7	63	44.6	2.8	7.04	-	
19959	43	73.5	63	42.0	1.8	8.38	-	
19956	43	73.9	63	35.3	2.4	9.58	-	
19954	43	75.6	63	28.4	2.3	9.19	-	
19955	43	78.2	63	50.6	2.4	9.17	-	
19958	43	78.8	63	34.4	2.6	9.30	-	

Table 9. Lovelace Foundation Thoracic Impact Data
(Noncompliant Cylinder - Dog)

Data source: LOVELACE FOUNDATION (reference 17)

Animal species: DOG Projectile: NONCOMPLIANT CYLINDER

PLOTTED: Figures 10, 11, 12

Animal No.	Projectile			Target weight (mass) (W)	Target Lung weight / Body weight (L/W)	Response, death	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)				
	gm	m/sec	mm	kg	gm/kg		
M67	63.0	72.2	70	18.1	10.06	-	⌑
M68	63.3	91.4	70	14.5	16.69	-	
M71	85.6	56.1	70	21.5	10.61	-	
M69	86.0	60.4	70	20.9	12.82	-	
M70	86.0	62.2	70	22.2	17.12	-	
M66	85.3	73.5	70	14.5	17.72	-	
M72	85.6	80.2	70	19.1	17.85	-	
M73	85.6	86.6	70	20.2	19.16	-	
M38	98.0	50.9	70	16.8	11.67	-	
M65	85.8	73.5	70	15.0	15.2	+	✖
M58	196.4	23.1	70	15.4	8.38	-	¤
M59	196.4	26.2	70	15.4	8.12	-	
M32	196.3	30.5	70	18.8	7.55	-	
M46	196.4	30.8	70	16.3	11.35	-	
M57	196.4	31.4	70	14.7	13.88	-	
M55	196.4	35.0	70	17.5	11.09	-	
M47	196.4	35.4	70	18.1	13.42	-	
M56	196.4	36.0	70	16.6	16.32	-	
M60	196.4	38.5	70	16.8	12.32	-	
M31	196.3	39.0	70	21.5	10.88	-	
M61	196.4	46.9	70	16.8	18.57	-	
M27	196.3	47.4	70	15.6	9.23	-	
M29	196.3	54.9	70	20.4	6.68	-	
M50	196.4	57.6	70	17.7	28.25	-	
M53	196.4	60.4	70	17.7	18.36	-	
M45	196.4	61.9	70	17.0	24.91	-	

Table 9. (Contd)

Data source: LOVELACE FOUNDATION (reference 17)

Animal species: DOG Projectile: NONCOMPLIANT CYLINDER

PLOTTED: Figures 10, 11, 12

Animal No.	Projectile			Target weight (mass) (W)	Target Lung weight / Body weight (L/W)	Response, death	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)				
	gm	m/sec	mm	kg	gm/kg		
M36	196.3	41.2	70	22.0	16.36	+	✖
M49	196.4	52.1	70	16.3	15.89	+	
M30	196.3	56.7	70	13.6	29.93	+	
M54	196.4	59.1	70	18.1	25.19	+	
M28	196.3	60.7	70	14.5	26.07	+	
M48	196.4	60.7	70	18.1	24.86	+	
M52	196.4	60.7	70	16.8	13.04	+	
M51	196.4	63.1	70	18.8	20.64	+	
M41	381	18.9	70	18.1	11.11	-	⅄
M40	381	22.3	70	15.4	12.27	-	
M39	381	22.5	70	18.1	10.72	-	
M62	382.8	26.5	70	17.7	9.38	-	
M63	382.8	31.7	70	18.6	17.96	-	
M43	381	35.7	70	16.3	19.94	-	
M44	381	38.1	70	14.7	21.16	-	
M33	381	44.8	70	23.1	11.47	-	
M34	381	46.9	70	20.9	21.39	-	
M64	382.8	46.6	70	18.1	16.24	+	⅄
M35	381	47.2	70	12.2	24.51	+	

Figure 8 shows 50% lethalities in the predicted mid-lethality zone. Despite this, one might question the general discrimination from the model considering the 25% lethality rate in the predicted low-lethality zone and 20% lethality in the predicted high-lethality zone. After careful examination of the raw data obtained against the thoraces of swine, possible explanations for this specific reversal in classification can be offered. The sole lethality in the low-lethality zone was listed by the experimenter as a "questionable velocity reading." The other two deaths resulting from impacts by the same-type projectile did fall in the mid-lethality zone. It is logical to assume that the questionable velocity, which is approximately half that for either of the other two lethalities, could indeed be unrealistically low and that if raised in value would move the point in question closer to or even into the mid-lethality zone. Of the eight survivors appearing to the right of the mid- to high-lethality discriminant line, one had no mass value listed for the animal, so an average mass value of 15.35 kg was assumed in order to calculate the lnWD value. This point could actually rest lower or higher on the Y axis. However, an increase of 1.5 kg to a body mass of 16.85 kg (still within the range of observed masses) would move the point from the high-lethality to the mid-lethality zone. The seven remaining survivors were impacted over the sternum rather than the ribs since the experimenters prime target for these shots was the heart, not the lung. The logical possibility of a different "dose loading" phenomenon over the sternum as opposed to that over the ribs could account for this poor correlation and suggests that, if precise discrimination is required, more than one model may be necessary for the thorax. However, insufficient data did not permit investigation of that consideration during this task.

A total of 28 data points obtained against goat thoraces with three different projectile configurations is plotted in figure 9. There were no fatalities resulting from these impacts and the model would have predicted this, as evidenced by the data points all falling into the zone of predicted low lethality.

The fourth set of independently obtained data is plotted against the model in figure 10. These data contain both survivors and fatalities resulting from thoracic impacts against dogs by three still different projectile configurations. The model successfully discriminated the low-lethality zone with 12 out of 12 animals surviving for a 0% lethality rate. However, with only one death out of nine for the points falling into the mid-lethality zone, the observed lethality rate of 11% fell below a reasonable anticipated level. The observed rate of 10 deaths out of 24 for 42% lethality would also fall below an anticipated level for the high zone. In both cases, the model made a prediction which, although not wrong from a safety standpoint, was definitely an ultraconservative estimate. Again, close examination of the data and experimental procedures provided a possible explanation for this conservative estimate. These animals had a specified survival period of only 30 minutes before being sacrificed as opposed to the 24-hour period used for the goat data from which the model was formulated. Of the 11 fatalities in this study, six (55%) died between 15 and 40 minutes, indicating that the natural lethality rate was still high in the last half of the prescribed survival period. It is conceivable, and logical, that during a 24-hour observation period, the lethality rate would have been higher and, therefore, observed and predicted values would move closer together.

To summarize the correlation resulting from the provisional four-parameter model, the data from figures 7 through 10 again using the same discriminant line intercept and slope values and the same X and Y scale, are presented in composite format in figures 11 and 12. In figure 11, individual data sets are not differentiated by symbol, merely the deaths and survivors as indicated in the legend. Good discrimination is achieved for the low-lethality zone with one fatality out of 61, 1.6%. That lethality (identified by the number 1) is the questionable velocity point previously discussed (figure 8). In the mid-lethality zone of the model, there are 15 deaths and 22 survivors for a lethality rate of 40.5%, a level compatible with the predictive expectations of the model. The individual points in this zone from the 30-minute-sacrifice data set (figure 10) are identified by a vertical line through the point symbol. There are 18 deaths out of a total of 41 points in the high-lethality zone for a lethality percentage of 43.9, a low value for a zone of predicted high lethality. However, increases in this rate would be conceivable as a result of adjustments of the sternal impact sample, the 30-minute-sacrifice sample, and the assumed body mass point (identified by the number 2) already discussed. The only unqualified survivor in the high-lethality zone is the point identified by the number 3. It is the 24-hour survivor (figure 7) in the goat data and has no basis for adjustment. This zone, therefore, would never achieve 100% lethality with the existing data; but, if the speculative adjustments mentioned fell in the right direction, the observed lethality for the high-lethality zone would be more in line with expectation and all areas would then show good correlation using the "physical" parameters.

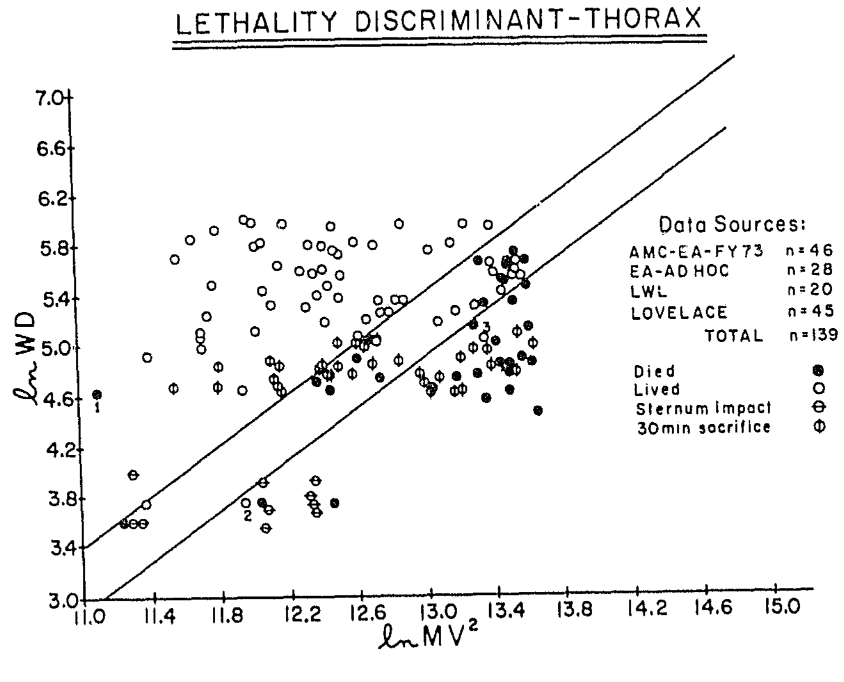

Figure 11. Generalized Four-Parameter Model with Total (n = 139) Data Sets

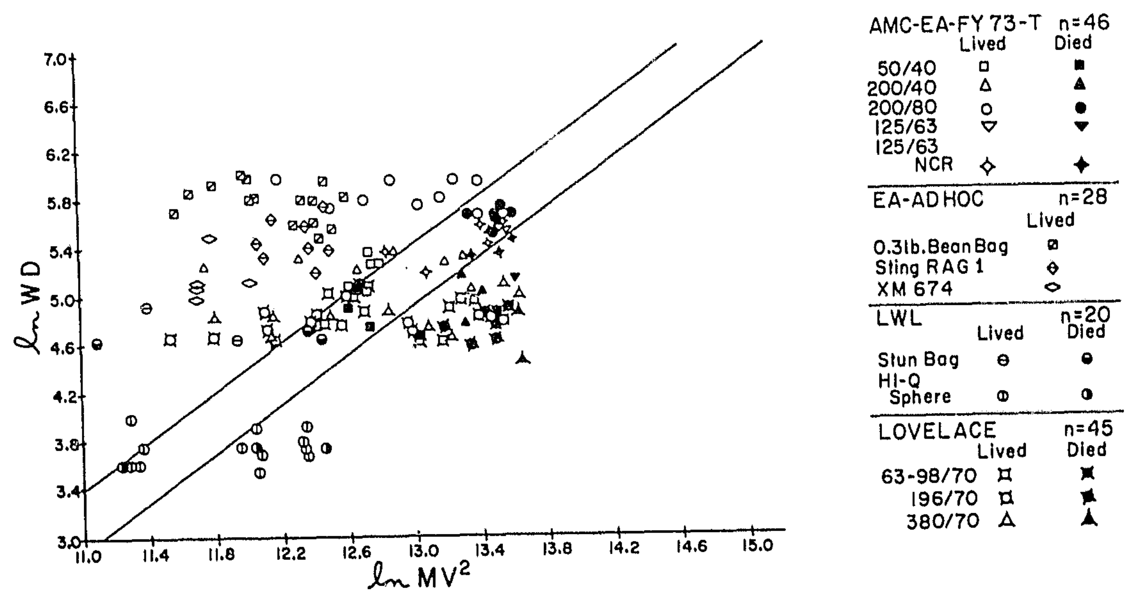

Figure 12. Generalized Four-Parameter Model with Total (n = 139) Data Sets Identified by Source

The same data sets are individually identified in figure 12, as indicated in the legend, to permit comparison relative to source, projectile, and species variations.

2. Suggested Two-Parameter ($1/2MV^2$ = 30-, 60-, and 90-ft-lb) Model.

The inadequacy in trying to establish generalized criteria for the multiparameter phenomenon of nonpenetrating-projectile-induced blunt trauma by a limited-parameter model (MV) has been demonstrated in figure 1. Figures 13 and 14 further demonstrate this. The same four-parameter format and data sets used for figures 7 and 8 were used to establish the X, Y placement of the data points in figures 13 and 14, respectively, but discrimination in figures 13 and 14 was accomplished only on the X axis; that is, live/die discrimination was attempted using only MV^2 at discrete energy levels of 30, 60, and 90 ft-lb as proposed in the literature. In figure 13, no deaths (solid symbols) occur below the 90 ft-lb level. However, survivors are still occurring in the vicinity of $\ln MV^2$ = 13.56, equivalent to 288 ft-lb. Comparison of the width of the zones of mixed results for the same data sets depicted by different format in figures 7 and 13 gives visual indication of the poorer discrimination using only the two parameters of MV^2. Inherent in using only these two parameters for generalized blunt trauma discrimination is the assumption that all other parameters known to be relevant to the phenomenon (body mass - W, projectile dimension - D, and the tissue thickness - T) remain constant. Logic, as well as the data in the literature, indicates that such is not the case.

In figure 14, the same X, Y scale is fitted with the same 20 data points as appear in figure 8. The only difference between figures 8 and 14 is that live/die discrimination in 8 is provided by four parameters (MV^2/WD) whereas 14 discrimination is based only on the X axis parameters of MV^2. Both models misclassify the lethality plotted at X = 11.2, Y = 4.6 previously described as a questionable velocity point. However, the lethality at X = 11.2, Y = 3.6 falls to the left of the 30 ft-lb discriminant line (a supposed relatively safe zone) in the two-parameter model of 14, whereas that same point is in the mid-lethality zone of the four-parameter model of figure 7.

Although neither model 8 nor 14 gave consistent discrimination of this particular data set, the inherent danger of the misclassification of the X = 11.2, Y = 3.6 lethality into a relatively safe zone through two-parameter discrimination (a nonconservative misclassification) is self-evident.

3. Provisional Generalized Model - Extrapolation.

Because of the nature of the provisional model, it is a simple matter to mathematically extend application of its predictions to man by using body mass values (W) which are realistic for man. Such an extrapolation is presented in figure 15. However, since no data were available to validate the model at this body mass range, the reader is reminded of the high risk involved in this (or any other) extrapolation and cautioned against placing any quantitative significance in figure 15. It has been presented only to demonstrate the potential application of the provisional model and the need for data against animals with body masses near to or greater than those for man, if models relating to man are to be validated.

4. Provisional Generalized Model - Liver Impact Application.

Not all impacts by nonpenetrating projectiles (including nonpenetrations of soft body armor by normally penetrating projectiles) will be limited to the thorax and its organs. Furthermore, because of the friability of abdominal organs (e.g., liver, spleen, kidney) and the potentially serious consequences given trauma (fracture) to these organs, their vulnerability given an impact must be considered in any blunt trauma evaluation. It was decided to check the four-parameter model for correlation with liver damage. The model was fitted with fracture/no-fracture data from available liver impact samples. As with the thoracic data, these individual data points are a compilation of data obtained by various exeprimenters with 10 different projectiles against three different species of animals. The response criterion was the absence or presence of a liver fracture without regard to the dimension of that fracture.

The results of this correlation may be seen in figure 16. The X, Y coordinate scale and the slope of the discriminant lines at b = 1 remain exactly the same as for the application to thoracic impacts. In order to accurately

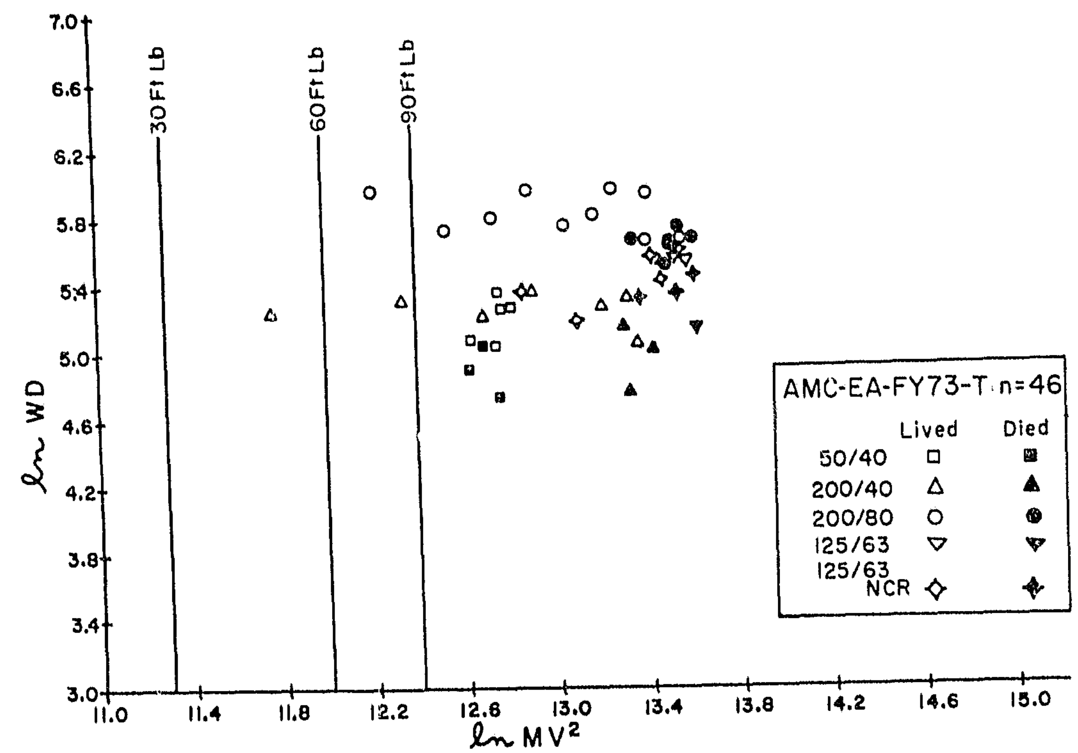

Figure 13. 30-, 60-, and 90-Foot-Pound Model - AMC-EA Data

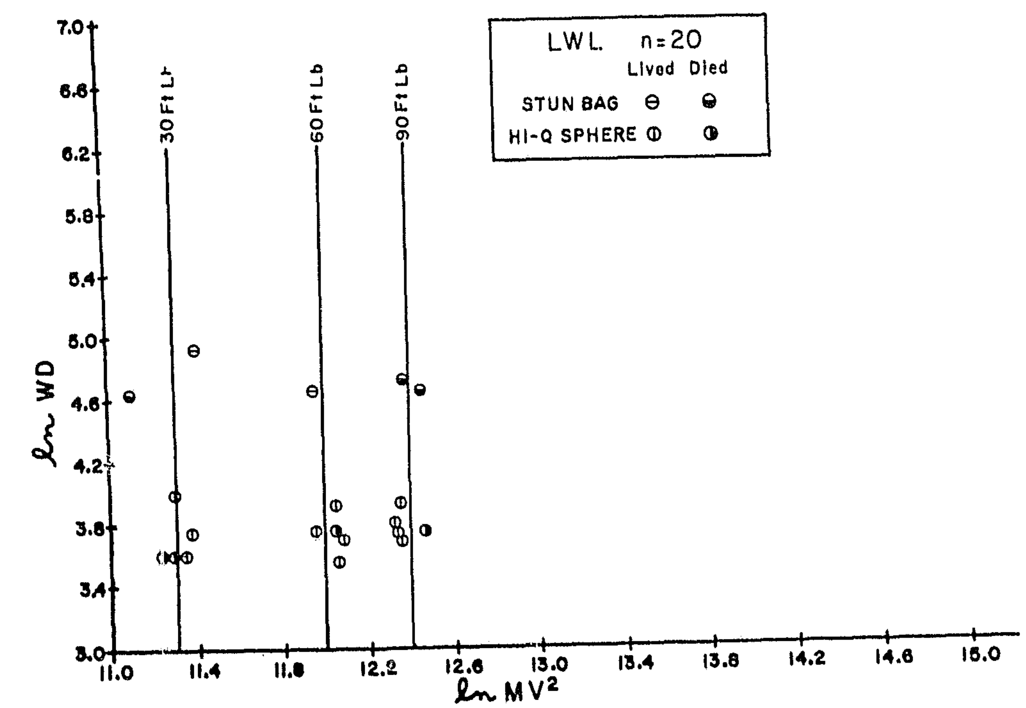

Figure 14. 30-, 60-, and 90-Foot-Pound Model - LWL Data

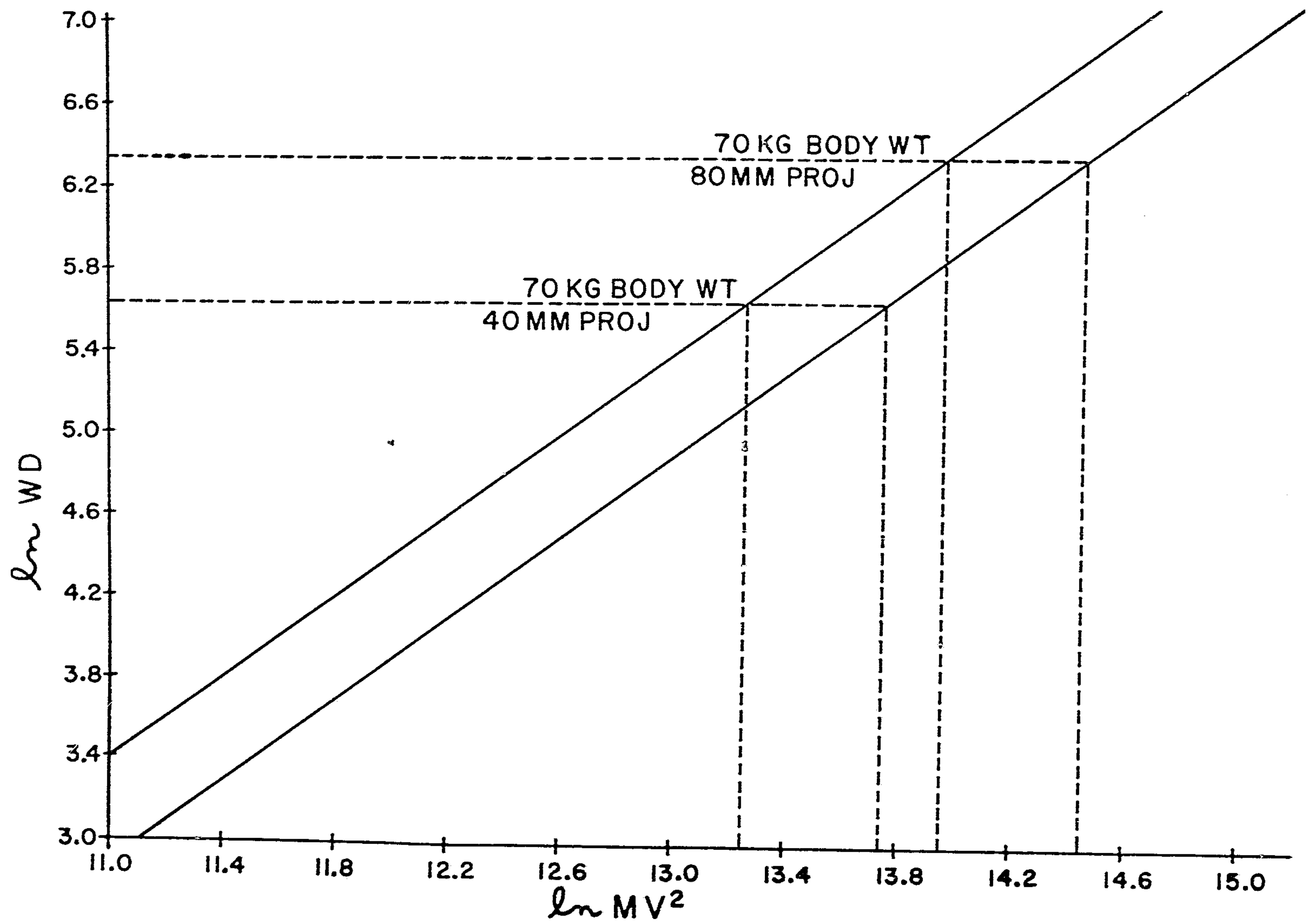

Figure 15. Model Extrapolation to 70-Kg Body Weight

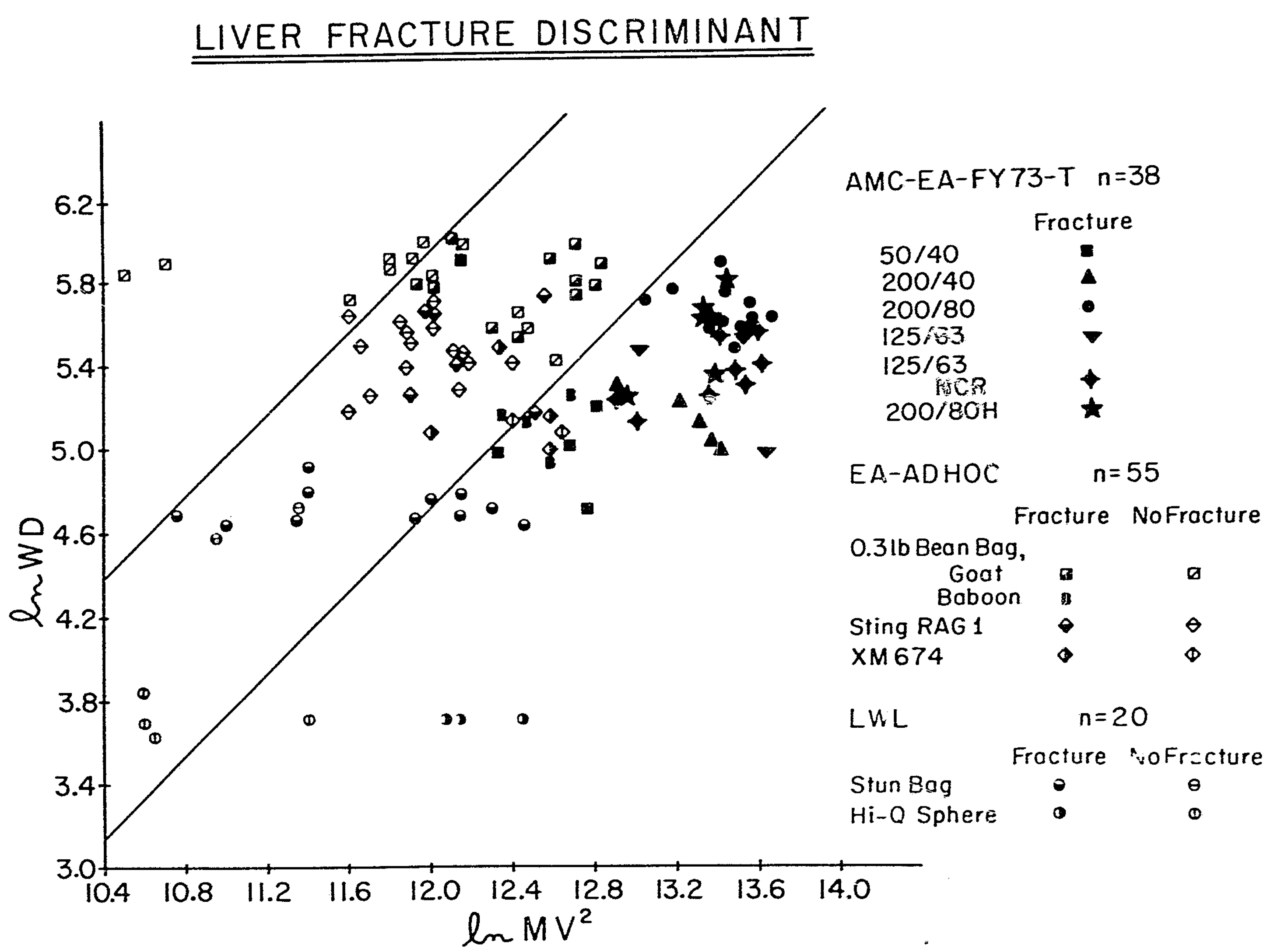

Figure 16. Provisional Generalized Blunt Trauma Model Extended to Liver Fracture/No-Fracture Application

discriminate the liver data points, however, the discriminant lines were repositioned with resultant intercept values of -6.026 and -7.28 for the low mid-response and the high mid-response discriminant lines, respectively. As can be seen in figure 16, there are no fractures out of eight exposures in the low fracture zone for a 0% fracture value. In the mid-response zone, 24 fractures were observed out of a total of 52 cases for a fracture rate of 46%. In the anticipated high-response zone, there were 51 fractures out of 53 cases for a fracture rate of 96%.

Despite the small sample size (eight) in the low-response zone and a wider zone of mixed results than was found for the thoracic application, the discrimination is reasonable - indicating a high correlation between the responses of these data sets and the physical parameters in the model MV^2/WD. The liver data are listed in tables 10 through 15.

5. Provisional Eight-Parameter Model - Soft Armor Application.

An eight-parameter model resulting from the AMC-EA basic research effort conducted by the Biophysics Division during FY73 and thought to be applicable to the current soft armor program is presented in figures 17 through 19. Each of these figures uses the same 37 data points (tables 1 and 2) and the same coordinate scale but varies in the number of parameters used for discrimination. Figure 17 uses the five parameters of the X axis for discrimination, MV^2/TWD. Figure 18 discriminates the same data by the three parameters on the Y axis, L/W, $\%APO_2$, and $\%VPO_2$, which can only be obtained by experimentation. Figure 19 uses all eight parameters for discrimination.

Comparison of these figures shows that better discrimination between positive and negative responses can be obtained by using solely the Y axis parameters (figure 18) or a combination of the X, Y axes parameters (figure 19) than can be obtained with the X axis parameters alone (figure 17). It is important to note that all of the X axis "physical" parameters may be measured or assumed prior to experimentation and although not capable of as fine a discrimination do represent a predictive capability. On the other hand, the better discrimination attributable to the "physiological" parameters of the Y axis is available only as a result of experimentally obtained data and therefore does not represent a predictive capability.

Following the observations made during the lesser parameter analyses that the projectile area term, A, appeared to add more "noise" or produce poorer discrimination when included in the "physical" parameters than did projectile diameter, D, this modification was applied to the eight-parameter model. This modification is shown in figures 20 through 22. As with the lesser parameter models, both misclassification and the zone of mixed results were diminished (improved discrimination) by substituting projectile diameter for projectile area (compare figures 17 and 20).

The provisional model for application to soft armor analysis resulting from this correlation effort can assume different format depending on the amount and kind of the input data. However, for purposes of validation, as well as convenience in the soft armor application, the format of zone of mixed results was chosen. The same X, Y parameters and scale have been employed as were used in figures 20 through 22. However, only the dashed lines which separate negative, mixed, and positive response zones have been maintained. This format is presented in figure 23. To the left of the leftmost vertical line, below the lower horizontal line and below the lower diagonal line, is the negative response zone for five-, three-, and eight-parameter formats, respectively. To the right of the rightmost vertical line, above the higher horizontal line and above the higher diagonal line, is the positive response zone, again, for five-, three-, and eight-parameter formats, respectively. The area between the two vertical lines, between the two horizontal lines, and between the two diagonal lines represents the zones of mixed results. It should be noted that the data to establish the model and the zone of mixed results lines were generated using noncompliant, nonpenetrating projectiles. These data represent impacts on goat thoraces which were not protected by armor. A limited number of data points for goats wearing soft armor were available from the early efforts in the Backface Signature Task of this program (table 16). These points have been over-laid on the zone of mixed results model in figure 23. These points represent goats covered with the various armors as indicated in the legend and struck by bullets, caliber .38 special, at nominal muzzle velocity. None of the bullets perforated the armor and, as indicated by the open symbols, all of the animals survived the effects of the blunt trauma behind the armor. The points should therefore all fall into or near the zone of predicted negative response on the live/die criterion.

Table 10. Biophysics Division Liver Impact Data
(Noncompliant Cylinder – Goat)

Data source: BIOPHYSICS DIV-AMC-EA-FY73 (reference 2)

Animal species: GOAT Projectile: NONCOMPLIANT CYLINDER

PLOTTED: Figure 16

Animal No.	Projectile			Target weight (mass) (W)	Liver fracture	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)			
	gm	m/sec	mm	kg		
19851	50	67.3	40	37.2	+	■
19907	50	79.9	40	38.4	+	
19850	50	82.9	40	28.4	+	
19911	50	85.7	40	47.2	+	
19891	200	44.8	40	51.5	+	△
19899	200	52.0	40	48.0	+	
19904	200	54.7	40	43.0	+	
19905	200	56.1	40	38.9	+	
19900	200	58.0	40	38.2	+	
19893	200	47.9	80	38.7	+	⊕
19916	200	51.3	80	41.6	+	
19915	200	55.9	80	35.9	+	
19903	200	57.2	80	46.8	+	
19918	200	57.3	80	35.4	+	
19914	200	58.3	80	41.0	+	
19919	200	59.6	80	31.0	+	
19897	200	60.9	80	34.4	+	
19920	200	61.0	80	34.3	+	
19896	200	61.6	80	38.2	+	
19917	200	61.8	80	35.6	+	
19898	200	63.3	80	36.0	+	
19922	125	62.4	63	39.0	+	▼
19926	125	77.5	63	42.2	+	
19927	125	81.2	63	26.4	+	
19941	125	55.8	63	32.8	+	◆
19940	125	62.2	63	27.8	+	
19939	125	71.2	63	31.4	+	
19924	125	73.3	63	42.0	+	
19925	125	75.1	63	35.8	+	
19923	125	77.4	63	33.2	+	
19929	125	78.1	63	43.0	+	
19930	125	80.0	63	36.8	+	
22613	200	46.3	80*	24.4	+	★
22612	200	55.3	80	32.8	+	
22611	200	55.7	80	35.6	+	
22610	200	56.1	80	35.8	+	
22615	200	56.6	80	26.8	+	
22614	200	58.3	80	42.4	+	

* Hemispherical impact surface.

Table 11. Land Warfare Laboratory Liver Impact Data
(Stun Bag - Swine)

Data source: LWL-AAI ER 7351 (reference 14)

Animal species: SWINE Projectile: STUN BAG

PLOTTED: Figure 16

Animal No.	Projectile			Target weight (mass) (W)	Liver fracture	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)			
	gm	m/sec	mm	kg		
317	196	15.5	79.375	13.8	+	◒
314	196	18.3	79.375	13.1	+	
302	196	18.3	79.375	12.3	+	
321	196	20.7	79.375	13.5	+	
306	196	20.7	79.375	13.7	-	⊖
305	196	21.0	79.375	15.6	+	◒
315	196	21.3	79.375	17.4	+	
311	196	27.7	79.375	13.6	+	
304	196	29.9	79.375	14.5	+	
319	196	31.1	79.375	15.2	+	
301	196	31.1	79.375	13.7	+	
303	196	33.5	79.375	14.3*	+	
313	196	36.0	79.375	13.1	+	

* Animal weight is not reported. A mean weight from total study of 14.3 kg is assumed.

Table 12. Land Warfare Laboratory Liver Impact Data
(High-Q Sphere - Swine)

Data source: LWL-CR-07B72 (reference 15)

Animal species: SWINE Projectile: HIGH-Q SPHERE

PLOTTED: Figure 16

Animal No.	Projectile			Target weight (mass) (W)	Liver fracture	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)			
	gm	m/sec	mm	kg		
204	11.7	58.2	27.686	17.0	-	⦶
202	11.7	58.8	27.686	14.5	-	
203	11.7	60.6	27.686	13.6	-	
2	11.7	87.2	27.686	15.1*	-	
3	11.7	123.8	27.686	15.1*	+	◑
4	11.7	124.4	27.686	15.1*	+	
5	11.7	147.2	27.686	15.1*	+	

* Animal weight is not reported. A mean weight from total study of 15.1 kg is assumed.

Table 13. Biophysics Division Liver Impact Data
(Stun Bag - Goat; Baboon)

Data source: EA-AD HOC-EB-TR-73056 (reference 4)

Animal species: GOAT; BABOON Projectile: BEAN BAG (STUN BAG)

PLOTTED: Figure 16

Animal No.	Projectile			Target weight (mass) (W)	Liver fracture	Plot symbol
	Mass (M)	Velocity (V)	Diameter (D)			
	gm	m/sec	mm	kg		
			GOAT			
19730	132	16.4	76.2	46.0	-	⧄
19727	132	18.1	76.2	48.4	-	
19729	132	28.4	76.2	39.2	-	
19721	132	31.0	76.2	47.6	-	
19722	132	31.1	76.2	47.2	-	
19728	132	32.9	76.2	49.0	-	
19724	132	33.5	76.2	43.6	+	◩
19725	132	33.7	76.2	52.8	+	
19723	132	34.6	76.2	43.2	+	
19720	132	35.9	76.2	42.4	-	⧄
19719	132	36.6	76.2	55.0	+	◩
19670	132	37.3	76.2	49.0	+	
19726	132	37.4	76.2	52.0	-	⧄
19581	132	40.5	76.2	36.0	+	◩
19585	132	41.0	76.2	38.0	-	⧄
19582	132	42.8	76.2	34.0	+	◩
19583	132	43.6	76.2	35.1	-	⧄
19491	132	46.3	76.2	50.0	+	◩
19584	132	46.9	76.2	31.1	-	⧄
19490	132	46.9	76.2	44.3	+	◩
19669	132	49.1	76.2	42	+	
19667	132	49.2	76.2	52	+	
19666	132	51.2	76.2	43	+	
19668	132	52.3	76.2	48	+	
			BABOON			
19587	132	41.0	76.20	25.6	+	◪
19588	132	43.4	76.20	19.0	+	
19586	132	46.3	76.20	22.5	+	
19589	132	48.4	76.20	23.2	+	

Table 14. Biophysics Division Liver Impact Data
(XM674 Projectile - Goat)

Data source: EA-AD HOC-EATR 4251 (reference 5)

Animal species: GOAT　　Projectile: XM674

PLOTTED: Figure 16

Animal No.	Projectile Mass (M)	Projectile Velocity (V)	Projectile Diameter (D)	Target weight (mass) (W)	Liver fracture	Plot symbol
	gm	m/sec	mm	kg		
15284	210	28	36.5	45.4	+	◆
15282	210	33	36.5	68.0	+	
15278	210	34	36.5	47.2	-	◇
15280	210	37	36.5	40.2	+	◆
15275	210	37	36.5	48.6	+	
15276	210	38	36.5	45.0	-	◇

Table 15. Biophysics Division Liver Impact Data
(Sting RAG, Type 1 - Goat)

Data source: EA-AD HOC (reference 7)

Animal species: GOAT　　Projectile: STING RAG 1

PLOTTED: Figure 16

Animal No.	Projectile Mass (M)	Projectile Velocity (V)	Projectile Diameter (D)	Target weight (mass) (W)	Liver fracture	Plot symbol
	gm	m/sec	mm	kg		
22601	43	50.0	63.5	44.8	-	◇
19997	43	51.2	63.5	29.4	-	
19999	43	52.1	63.5	39.4	-	
19998	43	52.7	63.5	30.6	-	
19980	43	57.6	63.5	42.2	-	
19974	43	57.6	63.5	41.8	-	
19981	43	57.9	63.5	35.6	-	
19969	43	58.5	63.5	39.5	-	
19982	43	59.1	63.5	30.6	+	◆
19970	43	60.6	63.5	46.4	-	◇
19976	43	61.0	63.5	46.2	+	◆
19975	43	61.6	63.5	42.8	-	◇
19971	43	63.1	63.5	45.8	+	◆
19968	43	65.8	63.5	36.8	-	◇
19984	43	65.8	63.5	31.6	-	
19967	43	65.8	63.5	36.2	+	◆
19965	43	66.4	63.5	36.8	-	◇
19966	43	67.0	63.5	36.0	-	
19983	43	74.4	63.5	36.2	-	
19972	43	78.6	63.5	28.8	+	◆
19973	43	80.8	63.5	50.2	+	

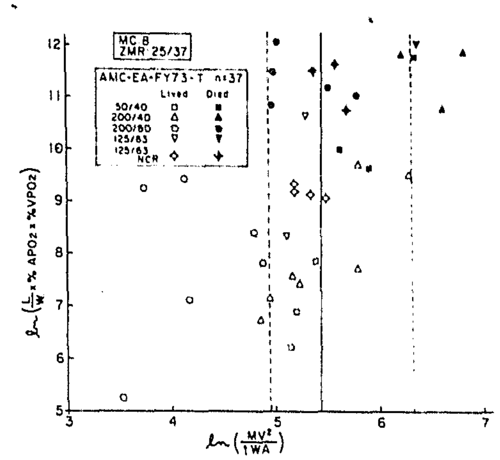

Figure 17. AMC-EA Eight-Parameter Correlation Model Using Five-Parameter (Preexperimental/Predictive) Discrimination

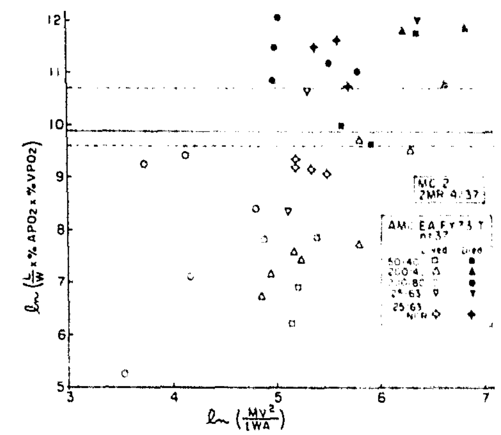

Figure 18. AMC-EA Eight-Parameter Correlation Model Using Three-Parameter (Postexperimental/Nonpredictive) Discrimination

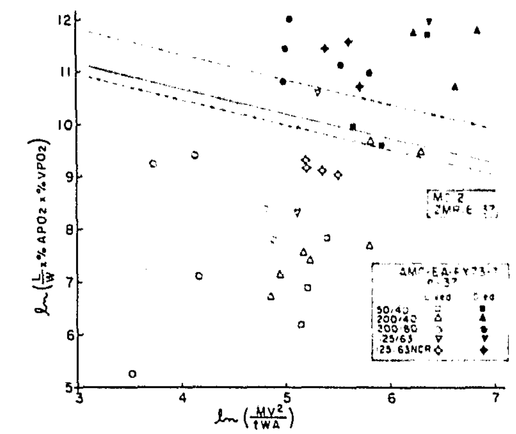

Figure 19. AMC-EA Eight-Parameter Correlation Model Using Eight-Parameter Discrimination

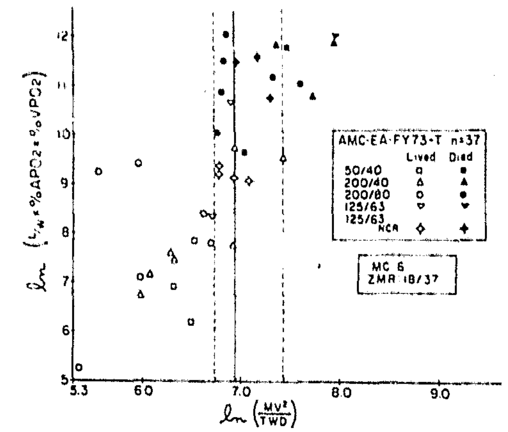

Figure 20. Modified Eight-Parameter Model Using Five-Parameter (Predictive) Discrimination

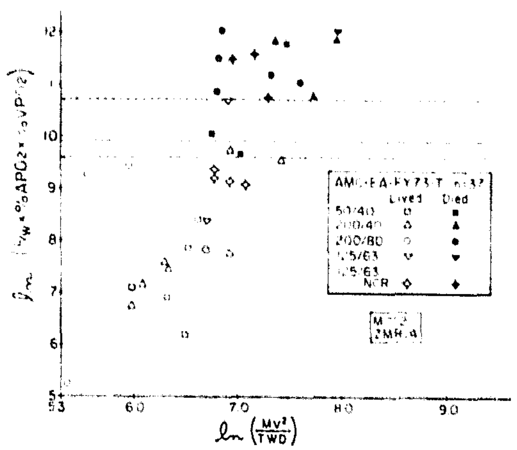

Figure 21. Modified Eight-Parameter Model Using Three-Parameter (Nonpredictive) Discrimination

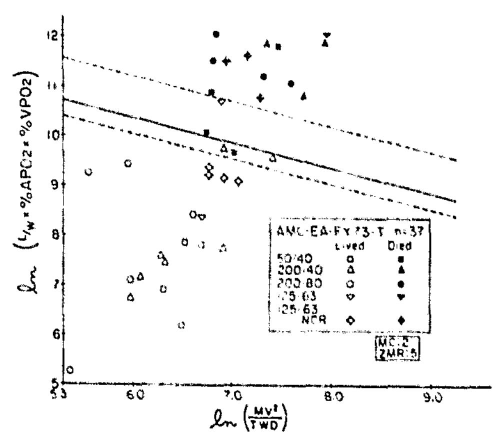

Figure 22. Modified Eight-Parameter Model Using Eight-Parameter Discrimination

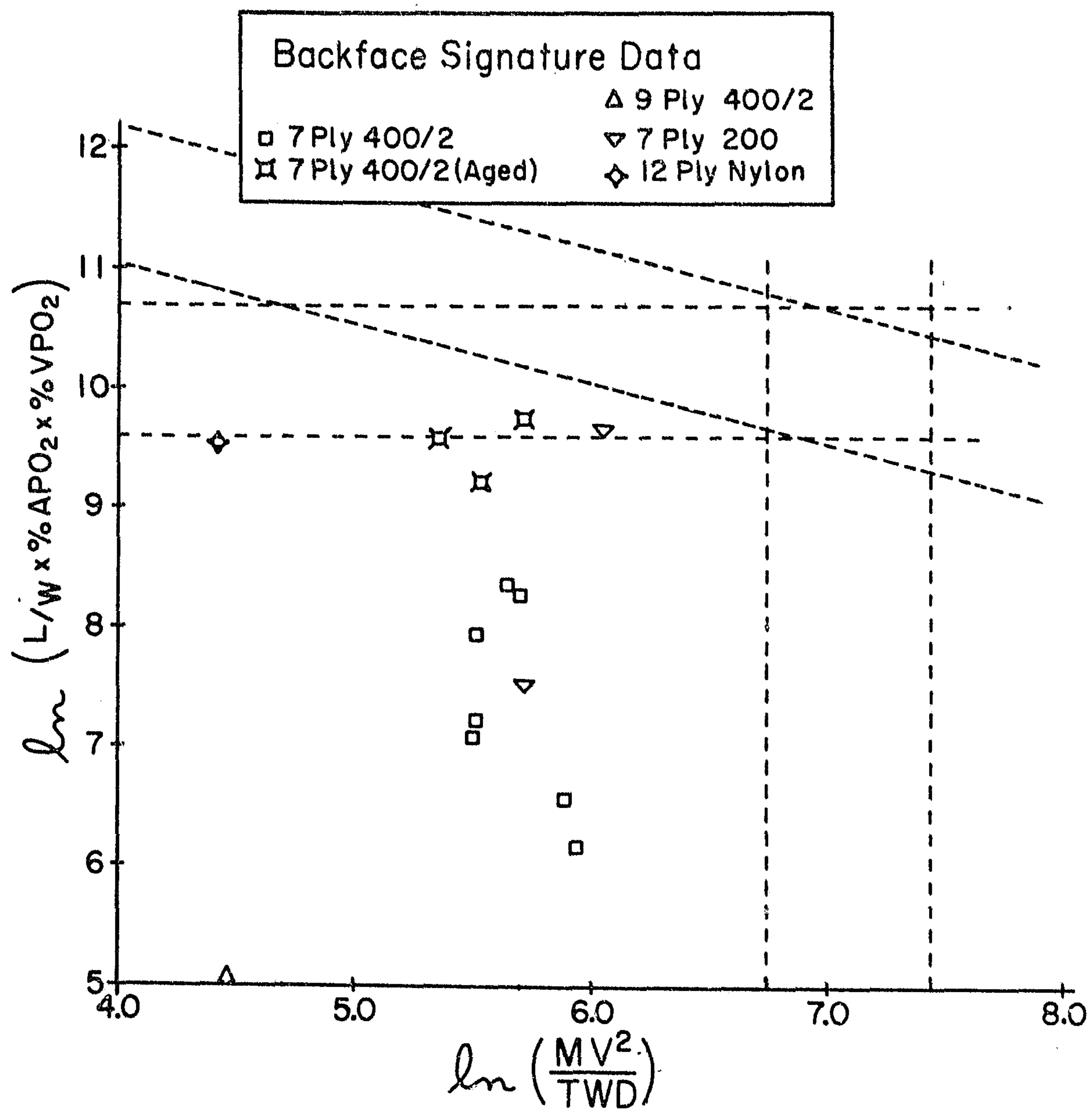

Figure 23. Eight-Parameter Provisional Model Proposed for Soft Armor Application

Table 16. Backface Signature Study Data
(.38-Cal Police Special – Armored Goats)

Data source: BIOPHYSICS DIV-FA-BACKFACE SIGNATURE STUDY (report in preparation)

Animal species: GOAT

Projectile: .38-CAL POLICE SPECIAL - VARIOUS ARMORS

PLOTTED: Figure 23

Goat No	Projectile: Mass (M)	Projectile: Velocity (V)	Projectile: Diameter (D)	Target: Weight (mass) (W)	Target: Tissue thickness (T)	Target: Lung weight / Body weight (L/W)	Target: Arterial O_2 deviation (APO_2)	Target: Venous O_2 deviation (VPO_2)	Armor type	Response, death	Plot symbol
	gm	m/sec	mm	kg	cm	gm/kg	%	%			
	Derived from backface signature										
21647	21.32	120.38	89.3	45.8	2.1	10.92	6.2	10.7	Kelvar 7-Ply, 400 2-denier	-	□
21648	21.32	120.38	89.3	51.8	2.7	11.85	8.9	27.0	Kelvar 7-Ply, 400 2-denier	-	
21649	21.32	120.38	89.3	48.4	2.4	10.91	11.9	30.3	Kevlar 7-Ply, 400 2-denier	-	
23015	21.32	120.38	89.3	41.3	2.2	6.92	2.3	30.2	Kevlar 7-Ply, 400 2-denier	-	
23016	21.32	120.38	89.3	44.5	3.1	9.75	4.7	30.2	Kevlar 7-Ply, 400 2-denier	-	
23019	21.32	120.38	89.3	47.5	2.6	7.94	11.5	46.6	Kevlar 7-Ply, 400 2-denier	-	
23020	21.32	120.38	89.3	45.4	3.1	6.10	13.1	14.7	Kevlar 7-Ply, 400 2-denier	-	
23035	21.66	120.36	90.7	45.8	3.0	8.86	23.9	49.2	Kevlar 7-Ply, 400 2-denier (aged)	-	⌑
23036	21.66	120.36	90.7	34.4	3.3	7.91	50.7	42.2	Kevlar 7-Ply, 400 2-denier (aged)	-	
23039	21.66	120.36	90.7	50.0	3.3	7.24	42.3	45.6	Kevlar 7-Ply, 400 2-denier (aged)	-	
21629	32.77	65.56	97.4	53.4	3.6	9.68	1.7	9.1	Kelvar 9-Ply, 400 2-denier	-	△
23040	14.48	182.04	83.9	48.0	2.8	9.46	25.6	65.8	Kevlar 7-Ply, 200-denier	-	▽
23041	14.48	182.04	83.9	52.1	3.6	10.44	16.2	11.0	Kevlar 7-Ply, 200-denier	-	
21625	59.66	42.78	85.1	40.4	3.8	14.18	42.0	23.4	Nylon 12-Ply	-	◇

Fourteen out of fourteen points fell into the negative-response zone (to the left of the leftmost vertical line) based on the MV^2/TWD parameter on the X axis, indicating a good correlation between observed and predicted response based on these parameters.

Twelve out of the fourteen points fell into the negative-response zone (below the lower horizontal line) based on the more sensitive Y axis discrimination, L/W X %APO_2 X %VPO_2. However, two points, one for 7-ply, 400/2 (aged) Kevlar and the other for 7-ply, 200 Kevlar, fell just outside the negative-response zone (above the lower horizontal line). In both cases, acute APO_2-VPO_2 deviation from normal values caused the positioning on the Y scale above the negative-response line. These short-term deviations not only reversed quickly but were not compatible with tissue-damage findings. Further explanation of this finding will not be attempted in this correlation effort but will be addressed in more detail in the reporting of the Backface Signature Task. However, it should be pointed out that most samples at the lower edge of the zone of mixed results would be survivors and therefore these points are completely compatible with this provisional model.

Based on the eight-parameter format, 14 out of 14 points fell into the negative-response zone (below the lower diagonal line), again indicating compatibility with the provisional model.

IV. CONCLUSIONS.

1. There is a general scarcity of empirical data of the type relevant to nonpenetrating projectile and body armor effectiveness evaluations.

2. Of those data sets which are available, none offers a complete consideration of all of the parameters thought to be important in blunt trauma assessment (e.g., dose application time and total system compliance effects).

3. In those instances where separate sources of data were uncovered for similar nonpenetrating projectiles, inconsistency in and between the test methodology and data collection techniques preclude broad and absolute data correlation between the studies.

4. Although a sufficient data base from which to form absolute generalizations (criteria) for high-velocity/low-mass-produced blunt trauma does not appear to exist, predictive and experimental models applicable to generalized blunt trauma and blunt trauma behind soft armor have been modified or developed during this effort and are presented in the body of this report. However, because of the aforementioned insufficient and inconsistent data base, model formulation and validation were restricted both in sample size and range of input parameters evaluated. For this reason, pending availability of additional data for further validation, the models presented in this report should be considered provisional.

5. Data reviewed during this effort show that serious injury and death can occur from nonpenetrating projectile impacts in animals unprotected by armor. Data from the Backface Signature and Medical Assessment Tasks of the Soft Armor Program indicate that serious injury and death can also occur from nonpenetrating projectile impacts in animals protected by armor. Therefore, any thorough evaluation of the effectiveness of soft armor should include, in addition to the obvious ability to prevent projectile penetration, the ability of the armor to prevent or significantly reduce the occurrence of blunt trauma sufficient to cause serious injury and death.

6. In view of the above, the ongoing Lightweight Body Armor Program appears to represent a reasonable effort within state-of-the-art limits, and major alterations in that program are not indicated.

V. RECOMMENDATIONS.

The following recommendations are made based on the findings of this effort.

1. Additional data base for high-velocity/low-mass-induced blunt trauma must be generated if comprehensive generalized criteria and comprehensive assessment models are to be established. Specific immediate needs relative to this recommendation are:

a. Blunt impact data should be generated against animals at least as massive as man to allow interpolation rather than extrapolation of the provisional generalized model to animals with the body mass of man.

b. Additional data against liver and/or other abdominal organs be generated to establish a lethality model data base and improve the serious injury data base for abdominal impacts.

c. Lethal armor deformation data, i. e., higher effective dose without penetration, be generated for application to and validation of the provisional soft armor application model.

d. The data generated in a, b, and c above be utilized in statistical modeling to produce probability of lethality and serious injury models for blunt trauma (see appendix C).

2. A determination of the parameters relevant to blunt trauma research should be made and updated as necessary to meet state-of-the-art requirements and thus allow a broader application of all data generated.

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APPENDIX A

CONCLUSIONS

(INTERIM)

1. There is a general scarcity of empirical data on nonpenetrating, low-mass, high-velocity impacts of the type relevant to riot control system and body armor effectiveness evaluations.

2. Of those data sets which are available, none offers a complete consideration of all of the important parameters.

3. In the two instances where separate sources of data were uncovered for the same or similar riot control projectiles, inconsistence, omission, and inaccuracy in and between the test methodology and data collection techniques preclude meaningful data correlation between the studies.

4. A sufficient data base from which to form generalizations (criteria) for blunt trauma produced by high-velocity, low-mass objects does not appear to exist. Mathematical models and relationships proposed for blunt trauma and riot control system evaluations to date are incomplete, unproven, and/or, because of state-of-the-art limitations, highly subjective.

5. In view of the above, the ongoing program appears to represent a reasonable effort within state-of-the-art limits, and major alterations in that program are not indicated.

APPENDIX B

RECOMMENDATIONS
(INTERIM)

The following recommendations are made based on the findings of this effort to date.

1. The data base for blunt trauma produced by high-velocity/low-mass objects must first be generated if generalized criteria and assessment models are to be established.

2. A standardized format for the generation and retrieval of that blunt trauma data base be established to facilitate correlations and maximize use of those data in the future.

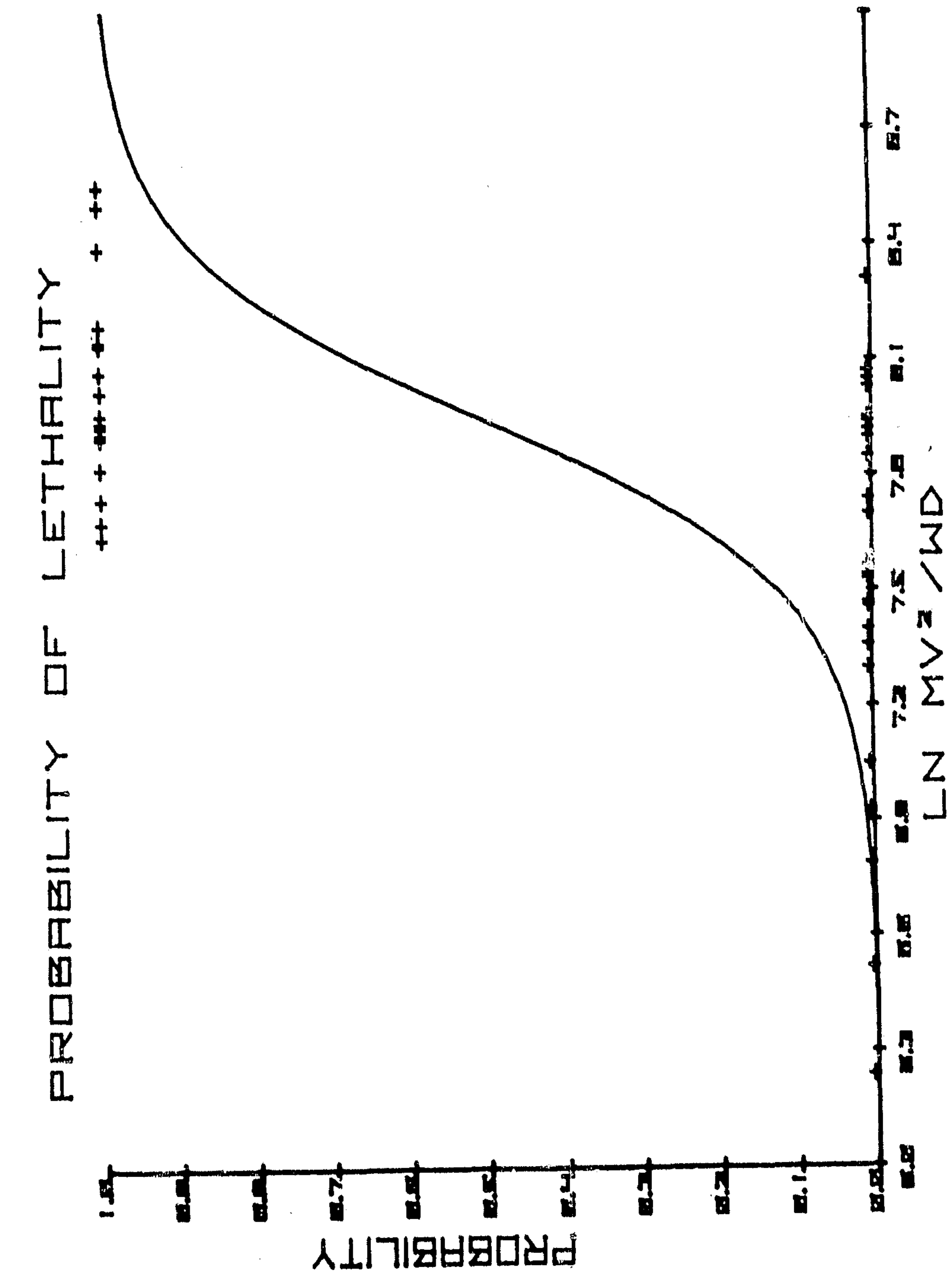
3. A determination of the parameters relevant to blunt trauma research be made and updated as necessary to meet state-of-the-art requirements and thus allow a broader application of all data generated.

4. Other than the recording of total tissue thickness over the point of impact, no changes to the on-going Lightweight Body Armor Program are indicated.

5. In the apparent absence of an available proven model to predict probability of serious injury or lethality associated with blunt trauma impacts in general and the Lightweight Body Armor Program in particular, consideration be given to a probability model of the type described in the discussion section of this report.

APPENDIX C

FIGURE



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