AD NUMBER

AD907805

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; DEC 1972. Other requests shall be referred to Army Test and Evaluation Command, Attn: AMSTE-MR, Aberdeen Proving Ground, MD.

AUTHORITY

US Army Test and Evaluation Command ltr 10 Jul 1973

[redacted]

AD-907805

AD
RDTE PROJECT NO. 1-U-6-65702-D-625-01
TECOM PROJECT NO. 9-CO-001-000-082
REPORT NO. APG-MT-4183
TEST SPONSOR US ARMY TEST AND EVALUATION COMMAND
USACDC AC NO. NOT APPLICABLE

fl.

SPECIAL STUDY OF ANTHROPOMORPHIC SIMULATORS FOR USE IN BLAST ENVIRONMENTS

FINAL REPORT

[redacted]

BY

J. COMPTON

DECEMBER 1972

[redacted]

DD 83 012

[redacted]

DISTRIBUTION LIMITED TO U. S. GOVERNMENT AGENCIES ONLY; TEST AND EVALUATION; DECEMBER 1972. OTHER REQUESTS FOR THIS DOCUMENT MUST BE REFERRED TO TECOM, ATTN: AMSTE-ME.

[redacted]

ABERDEEN PROVING GROUND

ABERDEEN PROVING GROUND, MARYLAND

RDTE PROJECT NO. 1-U-65702-D-625-01

TECOM PROJECT NO. 9-CO-001-000-082

REPORT NO. APG-MT-4183

TEST SPONSOR US ARMY TEST AND EVALUATION COMMAND

USACDC AC NO. NOT APPLICABLE

SPECIAL STUDY OF ANTHROPOMORPHIC SIMULATORS FOR USE IN BLAST ENVIRONMENTS

FINAL REPORT

BY

J. COMPTON

DECEMBER 1972

DISTRIBUTION LIMITED TO U. S. GOVERNMENT AGENCIES ONLY; TEST AND EVALUATION; DECEMBER 1972. OTHER REQUESTS FOR THIS DOCUMENT MUST BE REFERRED TO TECOM, ATTN: AMSTE-ME.

ABERDEEN PROVING GROUND
ABERDEEN PROVING GROUND, MARYLAND
21005

(Following Page Blank)

ABSTRACT

The investigation of existing Materiel Testing Directorate (MTD) capabilities involving the use of anthropomorphic simulators to acquire data pertinent to the determination of injuries to the crews of armored vehicles as a result of exposure to mine-excited shock blast was conducted from 19 April through 18 September 1972 at Aberdeen Proving Ground (APG). The objectives of this investigation were to define customer interests, the options available in anthropomorphic simulators, the availability of guidelines for correlating test results to known human effects, and the applicable instrumentation. The investigations are limited to the impact region of human tolerance levels. The graphs and charts contained in Appendix III are for reference purposes only and are not to be considered as established criteria for the evaluation of simulator test data. It is concluded that usage of the three simulators presently available be discontinued because of prohibitive design limitations and that subsequent studies be initiated within the Department of the Army to establish criteria for evaluating simulator test data relative to known human effects.

FOREWORD

This task was authorized under TECOM Project No. 9-CO-001-000-082 and was conducted under RDTE Project No. 1-U-6-65702-D-625-01.

The MTD, APG, was responsible for conducting the investigation and preparing the test report.

TABLE OF CONTENTS

SECTION 1. BODY

SECTION 2. APPENDICES

(Following Page Blank)

ABERDEEN PROVING GROUND
ABERDEEN PROVING GROUND, MARYLAND 21005

TECOM PROJECT NO. 9-CO-001-000-082

FINAL REPORT ON SPECIAL STUDY OF ANTHROPOMORPHIC SIMULATORS FOR USE IN BLAST ENVIRONMENTS

19 APRIL THROUGH 18 SEPTEMBER 1972

SECTION 1. BODY

1. BACKGROUND

Vulnerability testing of armored vehicles requires that they be exposed to hostile environments such as ballistic impacts, air bursts, and landmine explosions. In evaluating the effects of the vulnerability tests, it is essential that the maximum information pertinent to crew safety be obtained to insure each crew member's continued performance, at least to the extent that he is able to escape from a damaged or burning vehicle. Since this environment is not a type to which human beings are deliberately exposed, human simulators or cadavers are used in their stead. At present, first-generation anthropomorphic simulators (circa 1949) are used. The measurements made at the cranial and thorax cavities within them have been of limited value in determining the effects of mechanical shock, overpressure, and overtemperature on crew members. This is because of the lack of specific guidelines, in both test procedures and test plans, for interpreting the effects of the blast environment on human beings.

As a result, TECOM has approved a task in which APG will conduct a study to define:

a. Customer interest in types of human effects (exposure to short intense flame, heat, shock and impact).

b. The present capabilities and flexibility of circa-1970 anthropomorphic simulators.

c. The availability of guidelines for correlating test data with known human responses.

d. Probable new instrumentation.

The results of this task should be manifest in the development of a more meaningful test procedure and improved capabilities for evaluating the effects of hostile blast environments on personnel in armored vehicles.

The authority for testing is shown as Reference 1.

2. OBJECTIVES

The objectives are to define the following task requirements:

a. Customer interests in relation to existing test-data requirements.

b. The anthropometric and dynamic characteristics of "state-of-the-art" anthropomorphic simulators.

c. The availability of guidelines for correlating test data with known human responses.

d. Instrumentation techniques and their application to the analysis of data accumulated during tests using anthropomorphic simulators.

3. DETAILS OF INVESTIGATION

3.1 CUSTOMER INTEREST

The documentation of field-casualty experiences in armored vehicles included many instances of very serious fracture of the calcaneus (heel bone) and other bones of the foot, legs, spine, and skull; these were caused by either mine- or projectile-excited shock impacts. Such occurrences have stimulated customer interest on the effects of these shock impacts on the lower extremities, more specifically, the plantar region of the foot.

In addition, cranial, thorax, and pelvic orthogonal acceleration levels, cranial and thorax deformation, and upper-leg (femur) force and energy levels are of interest to MTD customers in determining the probability of human survival, the probability of cerebral concussions, bone fractures, or other injuries which may hinder or seriously affect the ability of a crew member to escape from a damaged or burning vehicle.

The three simulators presently available to MTD for use in obtaining mine-excited shock-blast data pertinent to the evaluation of crew survival are extremely limited in their instrumentation capabilities and dynamic response characteristics. Only orthogonal acceleration levels at the cranial and thorax center-of-mass locations can be measured; these acceleration measurements are of little value in determining anything but the probable mortality of the crew. At the time of their design (mid 1940's), there was very little reliable data on the human impact response that engineers and physical scientists could draw upon to aid in the development of the simulators. This being the case, the simulators presently in use were designed more for their anthropometric properties and, at the time of their acquisition, were the best simulators available. With the procurement of three circa-1972 simulators, MTD will have a capability for determining more meaningful results from the mine-excited shock tests and will be able to satisfy the requirements of its customers at TACOM, MUCOM, and WECOM relative to present customer interests.

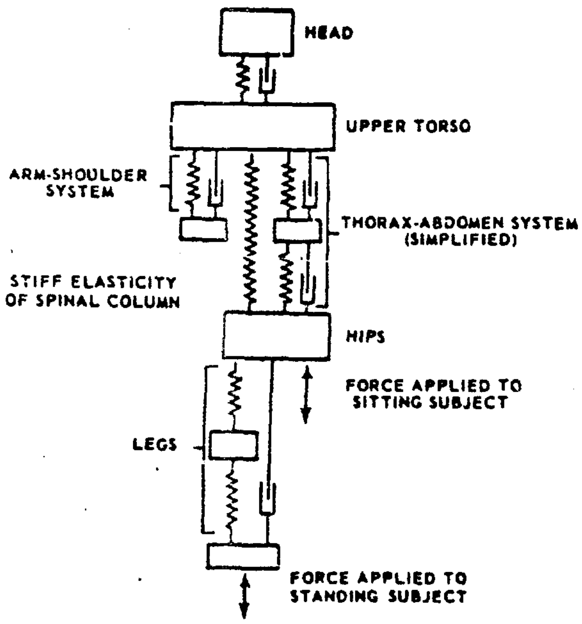
Because of MIL-STD-1472A (Human Engineering Design Criteria for Military Systems, Equipment, and Facilities) requirements that vehicle design insure operability and maintainability by at least 90% of the user population, initial customer preference to percentiles of simulators used during MTD testing were 5th, 50th, and 95th percentile adult-male automotive simulators. After an investigation revealed that only the 50th and 95th percentile male simulators were commercially available, the customer, in this case MTD, elected to obtain two 50th percentile and one 95th percentile adult-male simulators.

3.2. "STATE-OF-THE-ART" ANTHROPOMORPHIC SIMULATORS

Anthropomorphic simulators were originally used as human substitutes during the mid 1940's to test Air Force ejection-seat design for human usage during emergency conditions. Although these original simulators were primarily anthropometric in design, they served as a starting point for future simulator design. At present, anthropomorphic simulators are available over a wide range of anthropometric characteristics; i.e., size and dimensions, center-of-mass location, weight distribution, and range of motion. The automotive-test simulators currently available include the 50th percentile male, 95th percentile male, 5th percentile female, 6-year-old child, and a 3-year-old child; of these, the anthropometric characteristics of the 50th percentile male simulator are standardized and are the best documented. These anthropometric characteristics are contained in the Society of American Engineers (SAE) Standard J-963, Anthropomorphic Test Device for Dynamic Testing. The size, dimensions, weight, and range of motion characteristics for 5th, 50th, and 95th percentile simulators are listed in Table III-I.

The dynamic behavior of humans exposed to impact forces must be evaluated in terms of the complex interaction of various physiological and psychological parameters. Physical scientists have drawn upon existing human impact-response data in an effort to reduce this complexity and have devised mechanical single-degree-of-freedom analogs such as those shown in Figure 3.2-1.

From these mechanical analogs, dynamically equivalent human-response characteristics can be predicted and engineered into the anthropomorphic simulators to be used during vulnerability tests. The specifications for a 50th percentile male simulator are included in Appendix III together with a listing of the peak resonance frequency of various components of the human body (Table III-II).



This simplified model of the body as a system of masses, springs, and dampers was constructed from impedance data and other measurements of displacements of individual organs under vibration. Mechanical characteristics of body masses may be so represented for a specified frequency range.

Source: Bioastronautics Data Book (Reference 6).

Figure 3.2-1: Analog Model.

The skeletal construction of the anthropomorphic simulators consists of high-strength steel-investment castings, high-tensile manganese bronze castings for anatomical shapes, and a skull made of cast aluminum; these together with a vinyl plastisol skin and polyurenthale foam flesh, yield a simulator which approximates the major whole-body human-response characteristics.

3.3 SIMULATOR DATA EVALUATIONS

The investigations described in this report are confined to a study of the dynamic response characteristics of anthropomorphic simulators to short-duration forces where equivalent injurious human effects are mainly of a structural (skeletal) nature, rather than hydraulic (fluid) effects associated with longer duration forces. The state-of-art simulators are not capable of reflecting the effects of thermal transients or flame bursts on human beings.

The effects of human exposure to impact environments result from an interaction of the linear, quadratic, and cubic factors of motion, with inertial factors being complicated by resonant modes, elastic deformation, viscous damping, and skeletal complexity. In terms of the fundamental concepts of time and distance, the motion factors are defined as time - distance derivatives:

where

$$l = \text{distance, and } t = \text{time}$$

l/t = velocity
l/t^2 = acceleration, or velocity change with time in either rate or direction
l/t^3 = jolt, or rate of change of acceleration.

Mass set into motion has corresponding inertial derivatives:

where

$$m = \text{mass}, l = \text{distance, and } t = \text{time}$$

ml/t = momentum; ml^2/t = action
ml/t^2 = force; ml^2/t^2 = work or energy
ml/t^3 = onset; ml^2/t^3 = power.

The linear, quadratic, or cubic rates of displacement acting on a mass produce equal and opposite reactions in the corresponding inertial functions of momentum, force, and onset, which, acting through a distance, are measured as action, energy, and power.

The motion and inertial factors of impact-pulse duration, peak g force, and rate of onset all characterize, with reference to voluntary human skeletal tolerance limits, the impact environment.

The impact-pulse duration is less than 0.10 second. With reference to Figure 3.3-1, this region includes the impact and plateau regions of the generalized human tolerance curve suggested by Eiband (References 2 and 7) in 1959. The nominal peak g force is associated with the human skull-impact fracture force (600 inch-pounds) and is approximately 15 g's with an impact velocity of approximately 10 feet per second. The rate of onset for nominal human tolerance is 750 g's per second.

The numerical values of pulse duration, velocity, peak g force, and onset rate are at best subjective and are intended to represent thresholds for injurious skeletal human effects.

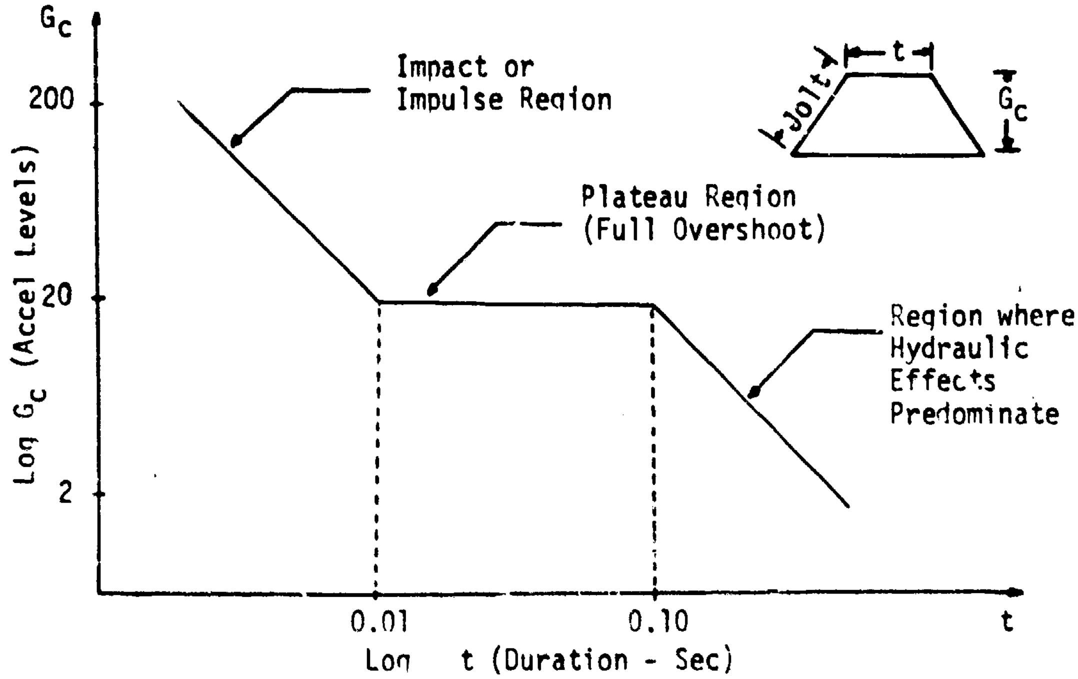


Figure 3.3-1: Definition of Acceleration Regimes.

The appraisal of data accumulated during mine-excited shock tests relative to injury of the crew must be done with great care and caution because of the effects of physiological (pulse duration, peak g force, onset rate, body orientation, force distribution, and restraint-system deformation characteristics) and psychological (age, motivation, and preparation) variables. When interpreting test results the uncertainties in attempting to extrapolate from laboratory results to actual field results must be considered.

A review of literature containing material pertaining to subjective human tolerance limits has provided sufficient information and guidance so that a meaningful and reliable analysis of test results can be accomplished.

It is not an objective of this report to establish human injury criteria but the information contained in Appendix III can be used as a source of reference for future studies specifically calling for the establishment of such criteria.

3.4 SIMULATOR INSTRUMENTATION CAPABILITIES

As was previously stated, the simulators presently on hand for use during vulnerability testing are poorly suited for their intended purpose. This is primarily caused by the materials used in their skeletal construction (steel) and the extensive use of frictional damping, which limits the natural frequencies of the individual body members (skull, thorax, and extremities) to under 300 Hz. Since the natural frequency of several major body members (skull, 700 Hz; upper legs, 550 Hz) is greater than 300 Hz, the continued use of these simulators to obtain human response data is not recommended. Further, the instrumentation capabilities of the present MTD anthropomorphic simulators include only the installation and use of triaxial linear accelerometers; the data from this instrumentation has not proven to be adequate in determining the degree of crew injury other than mortality.

Upon the receipt of present "state-of-the-art" simulators, MTD will have instrumentation capabilities which include installation cavities in the cranium, thorax, and pelvis for triaxial accelerometers and also for measuring the following:

a. Impact forces, transmitted through the upper leg through the use of load cells located in the upper-leg femur location.

b. Frontal cranium forces, through the use of the impact-indicating foams.

c. Abdominal pressures, by using transducers mounted in a synthetic abdominal sac.

d. Rib-cage impact and deflection, by using a syntactic-foam breastplate.

e. Internal stresses at patellas, neck, shoulder, and torso, through the use of internal rubber bump stops located in these areas of the simulators.

f. Calcaneus, leg, spine, and skull forces, through the use of piezoresistive strain gages.

Additional new instrumentation (i.e., piezoresistive triaxial accelerometers, femur load cells, and piezoresistive strain gages) will increase the frequency-response capabilities to 2000 Hz. Because the anthropomorphic simulators (circa 1972) do possess approximate whole-body, skeletal, human-response characteristics, the data obtained during mine-excited shock tests will be more easily analyzed to determine a realistic human response to these hostile environments.

4. ANALYSIS

Not applicable.

5. SUMMARY OF RESULTS

Customer interests ranged from the measurement capabilities of simulator instrumentation to determine the extent of probable human injury to the anthropometric qualities of the simulators to determine vehicle conformance to MIL-STD-1472A. Customers were also interested in the reliability of human-tolerance guidelines for correlating the simulator test data to actual human response (para 3.1).

The anthropometric options available on the simulators included the various percentile combinations of physical dimensions, weight distribution, center-of-mass locations, and the range of simulator-extremity motion. The dynamic response of the simulator emulates whole-body, cranial, and thorax human response to shock impacts for the type of simulators (automotive) that will be used in future MTD testing (para 3.2).

Human tolerance data, together with guidelines for correlating simulator test data to known human responses, are in Appendix III (para 3.3).

The instrumentation capabilities, presently limited to linear strain-gage accelerometers, will be improved through the use of piezoresistive accelerometers, various types of piezoresistive strain gages, and impact-indicating foams (para 3.4).

6. CONCLUSIONS

The task objective of defining certain task requirements has been accomplished.

The anthropomorphic simulators (circa-1949) currently available at Materiel Testing Directorate, should not be used for acquiring test data because of their minimal response and instrumentation capabilities.

7. RECOMMENDATIONS

It is recommended that:

a. The procurement of circa-1972 50th and 95th percentile anthropomorphic simulators, which conform to the recommendations of the Department of Transportation (DOT) Federal Motor Vehicle Safety Standard No. 208 and Society of Automotive Engineers (SAE) Standard J-963, proceed.

b. The review of human tolerance guidelines be continued.

c. A TOP/MTP presenting guidelines for analyzing data obtained with anthropomorphic simulators be prepared after the circa-1972 simulators have been acquired and used to obtain base line dynamic responses.

(Following Page Blank)

SECTION 2. APPENDICES

APPENDIX I - CORRESPONDENCE

METHODOLOGY INVESTIGATION PROPOSAL

1. TITLE: Anthropomorphic Simulators For Use In Blast Environments

2. INSTALLATION: Materiel Testing Directorate
Aberdeen Proving Ground, Md. 21005

3. PRINCIPAL INVESTIGATOR: H. T. Cline, Technical Support Division,
STEAP-MT-G, Autovon 870-3787

4. STATEMENT OF THE PROBLEM:

a. Fundamentally, armor is to protect various parts of the body against weapons. The armored vehicle then should protect the entire crew against damage. In evaluating the effects of hostile environments on vehicles, they are exposed to ballistic impacts, air bursts and land mines after which the damage is assessed. Each time an armored vehicle is exposed to such an environment, it is understandable that considerable damage results and the tests are expensive to conduct. It is essential therefore that maximum information be obtained from each test. Certain information can be gleaned from high-speed movie coverage, spalling of armor plate, and actual penetration but other information regarding the effect of mechanical shock, over pressure and temperature on crew members is difficult to assess.

b. These environments are not of a type to which human beings are deliberately exposed, thus the need for human simulators. We are currently using first generation anthropomorphic dummies (Circa 1948) and measurements made within them have not been used successfully in solving the problem. One reason is that test procedures and test plans lack specific guidelines and criteria for interpreting the environment within the vehicle's fighting compartment.

c. Preliminary investigation into current status of human simulators indicates that great changes have taken place in their design and that their skeletons and organs are better simulated for dynamic study. For example, skeletons are made of ceramic material actually used in bone transplants, transducers are incorporated to measure cranial and diaphragm pressures as well as significant data relative to the thorax, heart and other vital organs. It appears that acceleration may not be the optimum nor the only parameter to measure on human simulators. QMR, SDR and M.N. documents establish general requirements such as "provide adequate protection for the crew".

5. DESCRIPTION OF INVESTIGATION:

a. This study is visualized as having two phases; one short-term immediate phase to define the course of action, and a second phase (to be established later) where prototype hardware will be acquired and experiments conducted through piggy-back tests in the field to advance the quality of our test results. Only the first phase is discussed here.

b. APG will conduct a study to define:

(1) Customer interest in types of human effects (exposure to short, intense flame and heat; shock; impact; etc).

(2) The options available in anthropomorphic dummies.

(3) Availability of guidelines for correlation of test data with known effects on humans.

(4) Applicable instrumentation.

6. REASONS FOR CONDUCTING INVESTIGATION:

a. Present Capability.

Present capabilities are limited to the use of first generation human simulators which are basically a metal framework covered with foam rubber which has a man-like external appearance. The dummies represent 5'10" to 6' men weighing 180 to 200 lb with some joint motion so that they may assume sitting, standing or supine positions. Accelerometers can be placed in the head and chest cavities. Dynamically speaking, the sponge rubber provides only for the low frequency response (under 10 Hz) normally associated with a muscular individual. Beyond this and the fact that the gross weight and center of gravity approximate a human, the simulator is not dynamically representative of man.

b. Limitations of Present Capability.

The only real measurements obtained during these tests were values of acceleration. No criteria are provided in test plans which could be used to evaluate these values. The most complete information on human damage potential prepared especially for electro/mechanical personnel is found in Vol 3 of the Shock and Vibration Handbook, edited by Harris and Crede. In this volume, criteria are established as to the impulse a body restrained by seat belt, chest belt, head restraint and arm restraint, can withstand without damage. Unfortunately these criteria are useless because crew members of armored vehicles do not use restraints of any form. In addition, acceleration values measured in the head and chest cavity have little value in determining the probability of concussions, leg fractures or other injuries as measures of crew member continued performance or ability to escape from a damaged or burning vehicle.

c. Anticipated Improvements Resulting from the Research Investigation.

Results of both phases of this task should manifest themselves in a meaningful test operating procedure and in improved tools for evaluating the effects of hostile environments on crew members in armored vehicles. The results will provide others a basis for specifying detailed requirements and criteria for protecting against crew injury.

d. Pertinence to TECOM Mission.

All new armored vehicles are required to undergo vulnerability tests within the present TECOM mission.

7. IMPACT IF NOT FUNDED OR DELAYED:

a. If not conducted: MTD will lack proper background information for procuring optimum hardware under IMP Task A-1-7 as well as criteria for evaluating the dynamics of human simulators in vehicle vulnerability tests.

b. If delayed: This information will not be available for preparing procurement packages for Task A-1-7 as scheduled in the IMP.

8. PROJECTS TO BENEFIT FROM INVESTIGATION:

In general, all new vehicles which are subjected to vulnerability tests. Examples of such vehicles are:

ARMOR	1EG 965-000-005	FY72
MICV, XM765	NA	FY73
SCOUT, XM800	NA	FY73

9. RESOURCES:

a. Financial

	Dollars in Thousands			
	FY 72		FY 73	
	in-house	out-of-house	in-house	out-of-house
Personnel Compensation				
Permanent Full-Time	0.6			
Part-Time	6.4			
Travel	.8			
Contractual Support				
Consultants & Other Svcs				
Materials & Supplies				
Equipment				
G&A Costs	1.6			
Sub-totals	9.4	0.0	0.0	0.0
FY Totals	9.4		0.0	

b. Explanation of Cost Categories

(1) - (6) Not required.

(7) G&A Costs. This includes cost of supporting activities provided by APG (i.e., post); it does not include operating overhead incurred by MTD.

c. Obligation Plan

	FQ 3	4	1	2	TOTAL
Obligation Rate FY 72 & 73 (Thousands)	4.0	3.4	2.0		9.4

Anthropomorphic Simulators For Use In Blast Environments - Cont'd

d. In-house Personnel

	Number	Man-hours, FY 72 - FY 73 Required	Available	Total Man-hours Required
Physical Scientist GS-1301	1	30	30	30
Mech Engr GS-0830	1	240	240	240
Editing & Typing		24	24	24
		294	294	294

10. INVESTIGATION SCHEDULE:

	FY 72: J A S O N D J F M A M J	FY 73: J A S O N D J F M A M J
In-house	- - - - (M A M J)	- - R (J A S)
Contract		
Consultants		

Symbols: - - - - Active investigation work (all categories)

. . . . Contract monitoring

A - Award of Contract

R - Final report due at HQ, TECOM

11. ASSOCIATION WITH IMP: This task provides the basis for selecting hardware under IMP Task A-1-7.

12. ASSOCIATION WITH MTP PROGRAM: No immediate revisions to MTP will result from this phase of the work. It is possible that some revisions will result from future phases, specifically MTP-2-2-617A.

SAUL TARAGIN
Chief, Methodology and
Instrumentation Division
Materiel Testing Directorate

(Following Page Blank)

APPENDIX II - REFERENCES

1. Letter, TECOM, AMSTE-ME, Anthropomorphic Simulators For Use in Blast Environments, 24 March 1972.

2. Eiband, M. A., Human Tolerance to Rapidly Applied Acceleration - A Summary of the Literature, NASA Memo 5-19-59E, June 1959.

3. Cline, H. T., MTD, STEAP-MT-G, DF on Human Simulators, 9 November 1971.

4. MIL-STD-1472A, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, 15 May 1970.

5. Harris and Crede, Shock and Vibration Handbook, Volume 3, McGraw - Hill, Library of Congress Catalog Card Number: 60-16636, 1961.

6. Webb, Paul, Bioastronautics Data Book, NASA SP-3006, 1964.

7. Stanley Aviation Company, A Study of the Dynamic Model Technique in the Analysis of Human Tolerance to Acceleration, NASA TN D-2645, March 1965.

8. National Academy of Sciences, Impact Acceleration Stress, A symposium held at Brooks Air Force Base, November 27 to 29, 1961, with a comp ensive chronological bibliography. Publication 977, National Academy of Sciences, National Research Council, Washington 25, D. C., 1962.

9. Fraser, T. M., Human Response to Sustained Acceleration, NASA SP-10[illegible], Prepared by Lovelace Foundation for Medical Education and Research, 1966.

10. Haber, Heinz, Proceedings of a Symposium on Frontiers of Man-Controlled Flight. Presented at Los Angeles, California, April 3, 1953, The Institute of Transportation and Traffic Engineering, 1953.

11. SAE Handbook 1972, Society of Automotive Engineers, Inc., 1972.

12. DOT, Federal Motor Vehicle Safety Standard Number 208, April 29, 1971.

(Following Page Blank)

APPENDIX III - DATA

Guidelines for Correlating Test Data to Known Human Effects

Federal Motor Vehicle Safety Standard No. 208 establishes quantitative criteria for occupant injury of automotive vehicles, as determined by the use of anthropomorphic test devices. The intent of the injury criterion is to set limits on the acceleration exposure of those members of the simulator cited which reflect the available biomechanical data in terms that can be measured by a simulator:

a. Head-Injury Criterion. The resultant acceleration at the center of gravity of the head during impact shall be such that when the average acceleration (expressed in g's) during any time interval is raised to the 2.5 power and multiplied by the length of the interval in seconds, the product shall not exceed 1000 g's per second. In mathematical terms, the resultant acceleration at the center of gravity of the head shall be such that the expression:

$$\left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a\,dt \right]^{2.5} (t_2 - t_1) \leq 1000 \text{ g/sec}$$

where

a is the resultant acceleration expressed as a multiple of g (the acceleration gravity constant), and t_1 and t_2 are any two points during impact, shall not exceed 1000 g's per second.

b. Upper-Thorax Injury Criterion. A deceleration g value shall not exceed a value of 60 g's except for a cumulative period of not more than 3 milliseconds.

c. Upper-Leg Injury Criterion. Femur axial force shall not exceed 1400 pounds.

In addition, this standard specifies weight and dimension requirements for vehicle occupants, as shown in Table III-I.

Table III-I. Standards

Parameters	50th Percentile, 6-Year-Old Child	5th Percentile, Adult Female	50th Percentile, Adult Male	95th Percentile, Adult Male
Weight, pounds	47.3	102	164	215
Erect sitting height, inches	25.4	30.9	35.7	38
Hip breadth (sitting), inches	8.4	12.8	14.5	16.4
Hip circumference (sitting), inches	23.9	36.4	42.0	47.2
Waist circumference (sitting), inches	20.8	23.6	33.0	42.5
Chest depth, inches		7.5	9.0	10.5
Chest circumference, inches				
Nipple		30.5	37.7	44.5
Upper		29.8	37.7	44.5
Lower		28.6	37.7	44.5

The individual data-channel frequency-response requirements of this standard conform to the SAE Recommended Practice J-211, with channel classes as follows:

a. Head acceleration, 1000 Hz.

b. Upper-thorax acceleration, 180 Hz.

c. Upper-leg force, 600 Hz.

The peak resonant (natural-frequency) measurements of the human body (Reference 6) are shown in Table III-II.

Table III-II. Resonance Measurements

Characteristics	Peak Resonance, Hz
Transverse, supine	1
Whole body, unit mass	2
Longitudinal, supine	3-3.5
Vertical, sitting	4
Vertical, standing	5
Longitudinal, abdomen	6
Longitudinal, anterior chest	7
Longitudinal, abdomen	8
Longitudinal, anterior chest	9
Longitudinal, anterior chest	10
Longitudinal, anterior chest	11
Vertical, standing	12
Vertical, seated, head	18
Vertical, standing, head	20
Vertical, standing, head	30
Vertical, seated, eyeballs	60
Vertical, seated, eyeballs	90
Jaw versus head	100
Skull	300
Skull	400
Skull	600
Skull	900

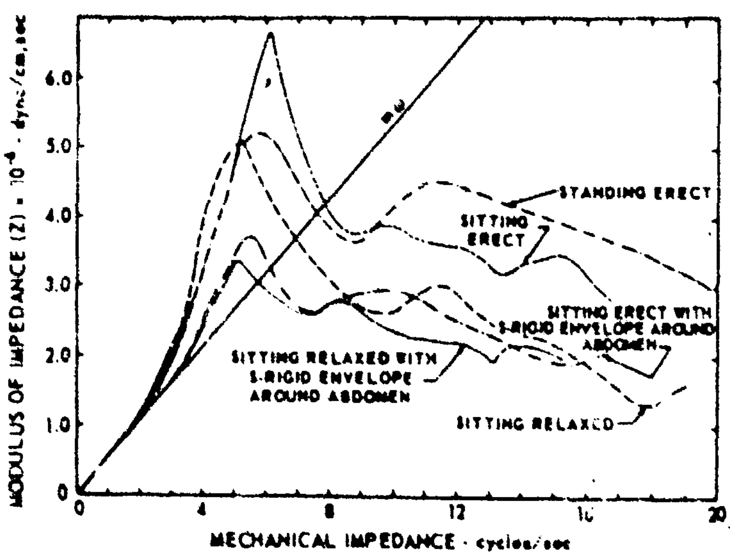
For Supplemental Information, the following graphs and charts serve as guidelines for correlating test data to known human effects:

Physical Properties of Human Tissue

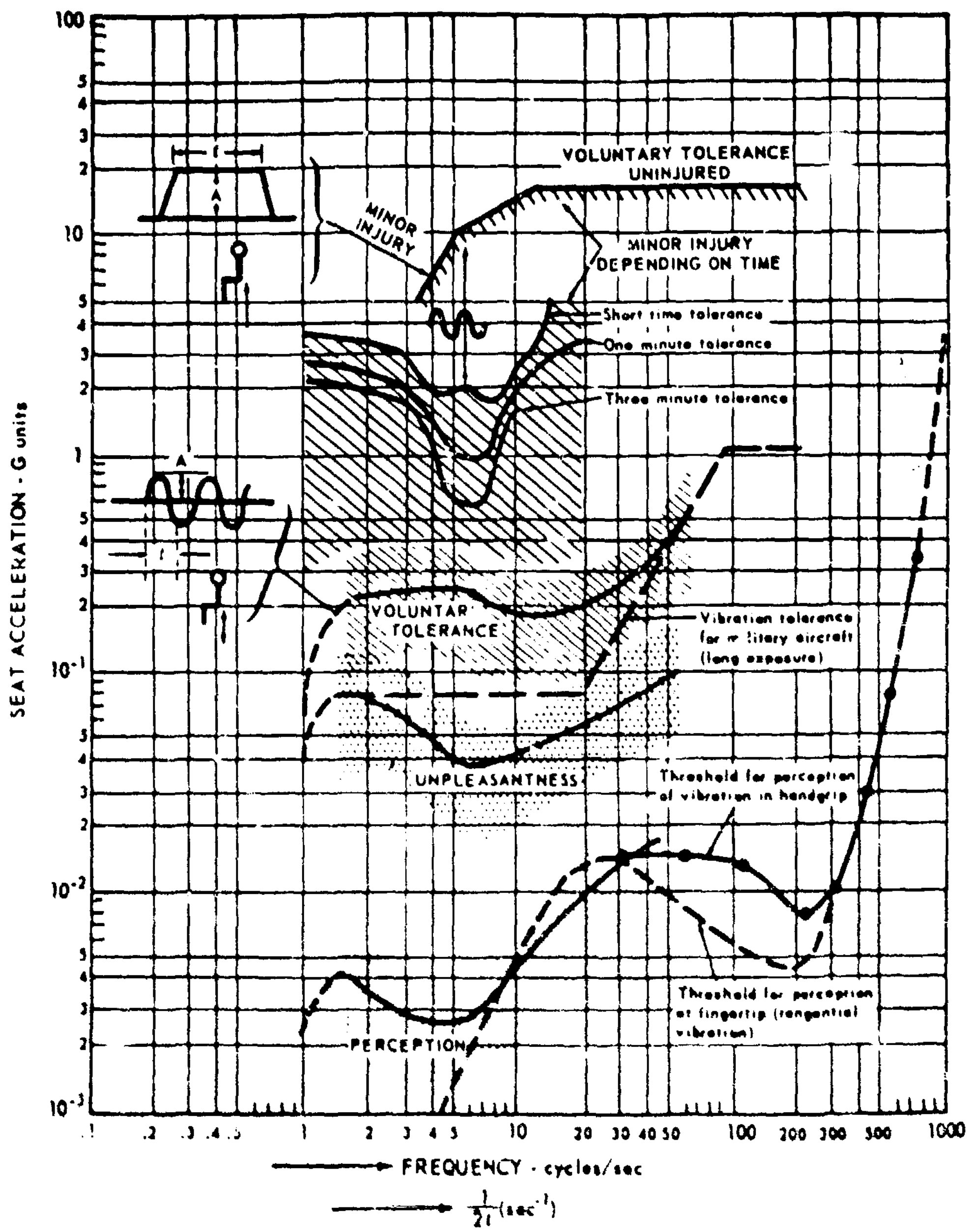
	Tissue, Soft	Bone, Compact	
		Fresh	Embalmed, dry
Density, gm/cm^3	1-1.2	1.93 - 1.98	1.87
Young's Modulus, $dyne/cm^2$	7.5×10^4	2.26×10^{11}	1.84×10^{11}
Volume compressibility,* $dyne/cm^2$	2.6×10^{10}	-	1.3×10^{11}
Shear elasticity,* $dyne/cm^2$	2.5×10^4	-	7.1×10^{10}
Shear viscosity,* $dyne\ sec/cm^2$	1.5×10^2	-	-
Sound velocity, cm/sec	$1.5\text{-}1.6 \times 10^5$	3.36×10^5	-
Acoustic impedance, $dyne\ sec/cm^3$	1.7×10^5	6×10^5	6×10^5
Tensile strength, $dyne/cm^2$	-	9.75×10^8	1.05×10^9
Shearing strength, $dyne/cm^2$, parallel	-	4.9×10^8	-
perpendicular	-	1.16×10^9	5.55×10^8

*Lamé elastic moduli

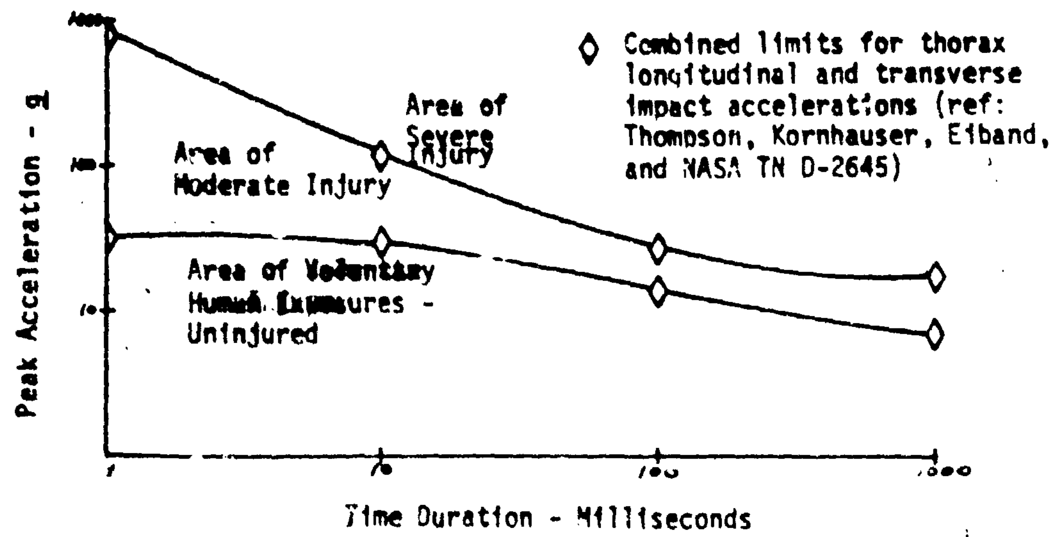
This table lists some mechanical properties of human bone, which in the body structure behaves mechanically more or less like a solid, and soft tissue, which behaves like an elastomer. Strength data for these tissues are not yet available. (Ref 6).



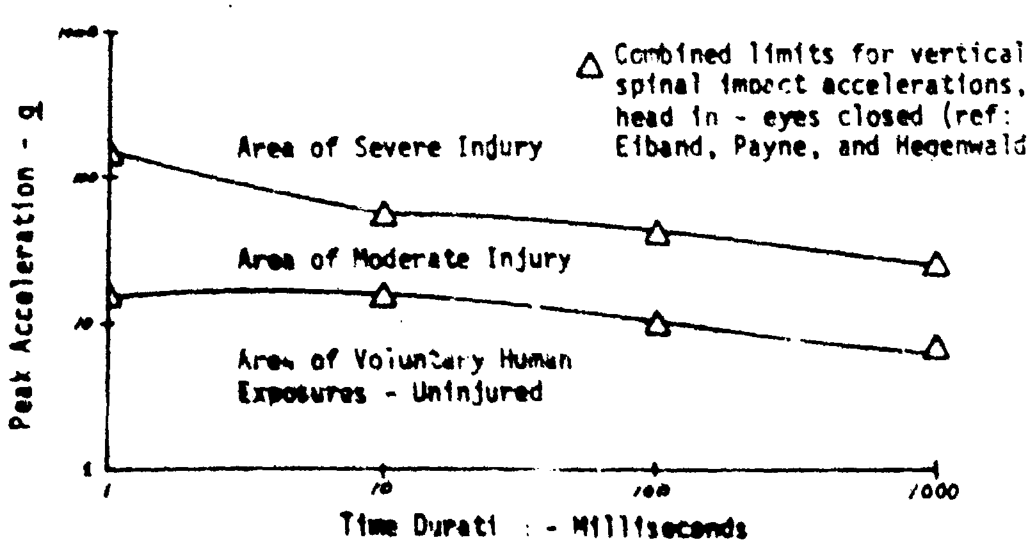
This shows the mechanical impedance of a standing and sitting human subject vibrating in the direction of his longitudinal axis. The various curves show the effect of changing posture and of enclosing the abdomen with a semi-rigid nylon girdle reinforced with stays. The impedance reflects the mechanical energy transmitted to the body. The impedance (mω) of a mass corresponding to this subject's weight is also shown. (Ref 6).



This illustrates schematically a number of tolerance criteria for vibration. The four shaded zones represent: threshold for perception; the unpleasant area of vibration; the limits of voluntary exposure, unprotected, for 5-20 minutes; and the voluntary tolerance limits for subjects with lap belt and shoulder harness for three minutes, one minute, and less than one minute. Above this, minor injuries occur, depending on time. At the top of the chart is plotted the voluntary tolerance curve for impact, which may be considered to be half-cycle vibration of large magnitude. The conventional way of measuring durations (t) and amplitudes (A) is shown in the small diagrams at the left.(Ref 6).



Human Tolerance Level to Thorax Transverse and Longitudinal - Impact Accel.



Human Tolerance Levels to Vertical Spinal - Impact Accelerations

A review of experimental experiences with impacts produced by short track deceleration devices has shown that there are numerous physiological changes following impacts in the transverse direction when the peak forces range from 15 to 25 g, and onsets range from 400 to 1000 g/sec. These are transient changes, and occur in subjects who are entirely uninjured in the mechanical sense of bone fracture or detectable tearing of tissues and organs. The physiological changes are summarized in the following table (Ref 6).

Effect	Notes
Shock	Blood pressure 90/60 mm Hg routinely seen 15-30 sec after impacts producing 15-20 ±g peaks, where onset rate was 500 g/sec. Lower pressures observed after greater impacts.
Bradycardia	Slight slowing of heart rate (bradycardial) following 15 g peak impacts facing forward, and greater slowing in backward facing impacts. The effect was related to activity of the vagus nerve, since atropine blocked the bradycardia. At greater peak accelerations, greater slowing occurred.
Transient neurological changes	Subjects appeared to be stunned for 10-15 seconds at 20 g peak accelerations (onset at 400 and 800 g/sec), and abnormal slow wave patterns were seen on the electroencephalogram for several minutes following peak impacts at 25 +g, 1000 g/sec onset. Other changes included increased muscle tone, euphoria, loquacity, hand tremor, decreased coordination, and gross involuntary movements in head, arms, and trunk. Increased deep tendon reflexes were commonly present after ±15 g and after a peak impact of 25 g reflexes were absent for several seconds, then hyperactive for about a minute.
Changes in blood platelets	One hour after impacts with +20 g peaks and onsets of 400 or 800 g/sec, blood platelets were found to be reduced. A week later the platelet count was higher than the control value.
Psychological changes	Psychological evaluation with the Kahn symbol arrangement test showed changes which increased +g impacts from 10 to 25 g peak accelerations.
General stress reactions	Changes were seen in the indicators of adrenal gland activity, and various changes occurred in chemical constituents of the blood.

2 February 1973

TECHNICAL REQUIREMENTS FOR ANTHROPOMORPHIC SIMULATORS

1. General

This is a purchase description of the basic requirements for anthropomorphic simulators used during shock and vibration tests. The dynamic and physical characteristics of the simulators will emulate those of an adult male humanoid as closely as possible (state of the art) in size, shape, mass, and kinematics. The simulators will conform to the recommendations of SAE J963, Anthropomorphic Test Device for Dynamic Testing and Dept of Transportation (DOT) Federal Motor Vehicle Safety Standard No. 208, unless otherwise stated.

2. Size

Two simulators will have 50th percentile size and weight characteristics; one simulator will have 95th percentile size and weight characteristics. The exterior contours shall conform to these dimensions as well as presenting a normal humanoid physical appearance.

3. Motion

The three simulators shall have a range of component kinematic patterns similar to those of the 50th percentile adult male humanoid described in SAE J963. The head, torso, arm, pelvic, and leg components of the simulators shall respond with humanoid characteristics during various impact conditions.

4. Component or Segment Requirements

4.1 Head

The head shall consist of composite structures that are geometrically similar to the human skull. The basic cranial structure shall have an accessible internal ballast and instrumentation cavity and a pliable external covering with appropriate facial contours.

4.2 Torso

The connecting and supporting structures shall allow the simulators (50th and 95th percentiles) to maintain a sitting posture similar to a human occupant of an automotive vehicle. A ball-and-socket lumbar spine and straight-form pelvis with foam-filled abdominal sac adaptation kit will be required for the 50th percentile simulators only to facilitate the use of these simulators for applications where a standing or supine simulator is required.

4.2.1 Shoulder Sections

The shoulder structures shall be geometrically and functionally similar to the human shoulder.

4.2.2 Thorax

The thorax (chest) of the 50th percentile simulators shall have a dynamic impact load-deflection spring rate as recommended in SAE J963 and an instrumentation cavity in the spinal column of the rib cage accessible from the thorax assembly. The 95th percentile simulator shall have an impact load-deflection spring rate comparable to that of a 95th percentile adult male humanoid with an instrumentation cavity in the spinal column of the rib cage accessible from the thorax assembly.

4.2.3 Abdominal Section

The simulated abdominal structure shall be soft and pliable.

4.2.4 Pelvic Section

The pelvic structure shall be geometrically and functionally similar to the human pelvic with an instrumentation cavity provided in the sacral region of the pelvis.

5. Durability

To withstand repetitive testing the simulator shall be constructed of durable, high strength materials which shall result in a minimum of repair and replacement parts.

6. External Covering

The skin and flesh of the simulators shall be soft, pliable, tear resistant and elastic. The covering may be discontinuous as required for unrestricted motion.

7. Instrumentation

There shall be provisions for internal placement of instrumentation in the head, thorax, and pelvic sections. All instrument cavities shall be readily accessible and the head and thorax cavities shall contain removable ballast to establish initially specified masses and centers of gravity.

APPENDIX IV - DISTRIBUTION LIST

TECOM Project No. 9-CO-001-000-082

Addressee	Final Report
Commander US Army Test and Evaluation Command Aberdeen Proving Ground, Maryland 21005 ATTN: AMSTE-ME	3
Commander White Sands Missile Range New Mexico 88002 ATTN: STEWS-TE-P	3
Commander US Army Tank-Automotive Center Warren, Michigan 48090 ATTN: AMSTE-BB	3
Commander US Army Weapons Command Rock Island Arsenal, Illinois 61201 ATTN: AMSWE-RD	3
Commander US Army Munitions Command Dover, New Jersey 07801 ATTN: AMSMU-RE-R	3
Commander Yuma Proving Ground Yuma Proving Ground, Arizona 85364 ATTN: STEYP-MMI	3
Commander Aberdeen Proving Ground Aberdeen Proving Ground, Maryland 21005 ATTN: STEAP-MT-G	4
STEAP-MT-M	1
STEAP-TL	2
STEAP-MT-E	1
STEAP-MT-U	2
STEAP-MT-X	1

Addressee	Final Report
Commander Hq, Defense Documentation Center for Scientific and Technical Information Cameron Station Alexandria, Virginia 22314 ATTN: Documentation Service Center	2

Secondary distribution is controlled by US Army Test and Evaluation Command, ATTN: AMSTE-ME.