NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

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ANTHROPOMORPHIC TEST DUMMY

Volume I - Program Summary-Background and Results

Contract No. DOT-HS-299-3-569

October 1974

Final Report

PREPARED FOR:

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16. Abstract

This report in three volumes summarizes the design development and performance of an anthropomorphic test dummy. The report covers work done in response to DOT contract DOT-HS-299-3-569 and related General Motors in-house programs.

Volume I is a program summary with background and results.

Volume II covers the design development and performance of the Contract Dummy in detail.

Volume III is a design data package containing prints, parts lists, material specifications, film documentation, etc.

The many improved features of the Contract Dummy are described. The marked improvement of repeatability and reproducibility of the Contract Dummy are documented. The anthropometric and biomechanical basis of the design is described. Improvements of durability, maintainability, ease and cost of manufacture are treated. Improved system and component test procedures, equipment, and test results are presented.

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VOLUME I

PROGRAM SUMMARY - BACKGROUND AND RESULTS

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SECTION 1

INTRODUCTION

There is a critical need in the safety community for an anthropomorphic test dummy that will provide meaningful human injury assessments in simulated automobile crashes. A collateral need is for the development of repeatable testing procedures and for dummy features that enhance the accuracy of the initial test setup.

In response to this need, NHTSA issued, in July 1972, a Request for Purchase (RFP) for an Anthropomorphic Test Device (dummy) and a Data Package. General Motors offered a counter proposal in response to this RFP and was subsequently awarded a contract. Two of the resulting test dummies (one of which is shown in Figure 1-1) have been delivered along with detailed manufacturing drawings and this Final Report, which consists of three volumes. This volume gives a summary of the dummy design and performance, while Volumes II and III present the detailed program information.

The goals of this program in order of priority are summarized as follows:

- Repeatability and reproducibility of assembled dummy performance.
- Development of repeatable testing procedures.
- Ease and accuracy of dummy setup to initial test position.
- Anthropometric and biomechanical fidelity.
- Durability and maintainability.
- Quality of instrumentation.
- Cost of manufacturing.

This priority was used to resolve conflicts arising in meeting the respective goals. In particular, conflicts arising between repeatability and biomechanical fidelity were resolved in favor of the former. This position was taken because biomechanical fidelity cannot be documented unless satisfactory repeatability is achieved.

This volume first gives a brief overview of design features of the delivered dummies and then describes the documentation tests. Then, the repeatability and reproducibility of these dummies are discussed, followed by a section on the related biomechanics and anthropometry. Finally, the program conclusions and recommendations are presented.

SECTION 2

CONTRACT DUMMY FEATURES

In the past, dummies have been designed to the erect seating position of SAE J963. However, dummies are used in the "automotive seated position" rather than this erect position. The Contract Dummy has been designed for the automotive seated position but can be made to assume the erect position for measurement purposes (see Figure 2-1). This change is consistent with the goals presented earlier (i.e., improved setup repeatability and fidelity). This dummy departs from previous practice in that it can be disassembled for measurement of segment weight and center-of-gravity locations rather than sectioned or sawn as implied by SAE J963. The disassembly procedure corresponds closely with an anatomically based segmenting scheme, and the inertial properties specified for the dummy subassemblies are based on available anthropometric data interpreted with reference to this segmenting scheme. This approach allows subassembly weight and c.g. location to be controlled more accurately, and it allows the user to check these properties whenever it is desired. Also, the Contract Dummies have new locations for both the head and chest accelerometer packages. In the head, the accelerometers are located at the c.g. of the head alone (without the 2/3 of the neck as called for in J963). Accelerometers in the chest are located at the c.g. of the "essentially rigid thorax" rather than at the c.g. of the shoulders and 1/3 neck, as formerly used. These changes are consistent with the goals listed in the previous section.

Analytical models of the dummy in a crash environment were employed to study the sensitivity of the dummy response to changes in joint resistances, link lengths, and inertial properties. This information was then used to aid the selection of design tolerances for the dummy components.

A further design goal was durability and ease of maintenance. Up to twenty tests on a single prototype have been conducted without serious malfunction. Commonization of parts (e.g., elimination of right- and left-hand components) should assist maintainability. Parts that are well documented with drawings and material specifications should provide for efficient manufacture of this test device. All parts except the vinyl head skin and molded polyacrylate neck and lumbar spine are being manufactured by outside vendors. It is expected that the remaining parts could be manufactured by outside sources in the near future.

Notable features of various subsystems of the dummy are treated below.

A. HEAD

The skull of the Contract Dummy head (Figure 2-2) features more humanlike geometry and is a precision aluminum casting which is easy to manufacture and has uniform wall thickness and symmetry.

The thickness of the vinyl skin has been specified and closely controlled to assure biomechanical fidelity and repeatable head response in hard surface impact. The skin fits well to the skull contour, and retainers are used to prevent the skin from moving relative to the skull.

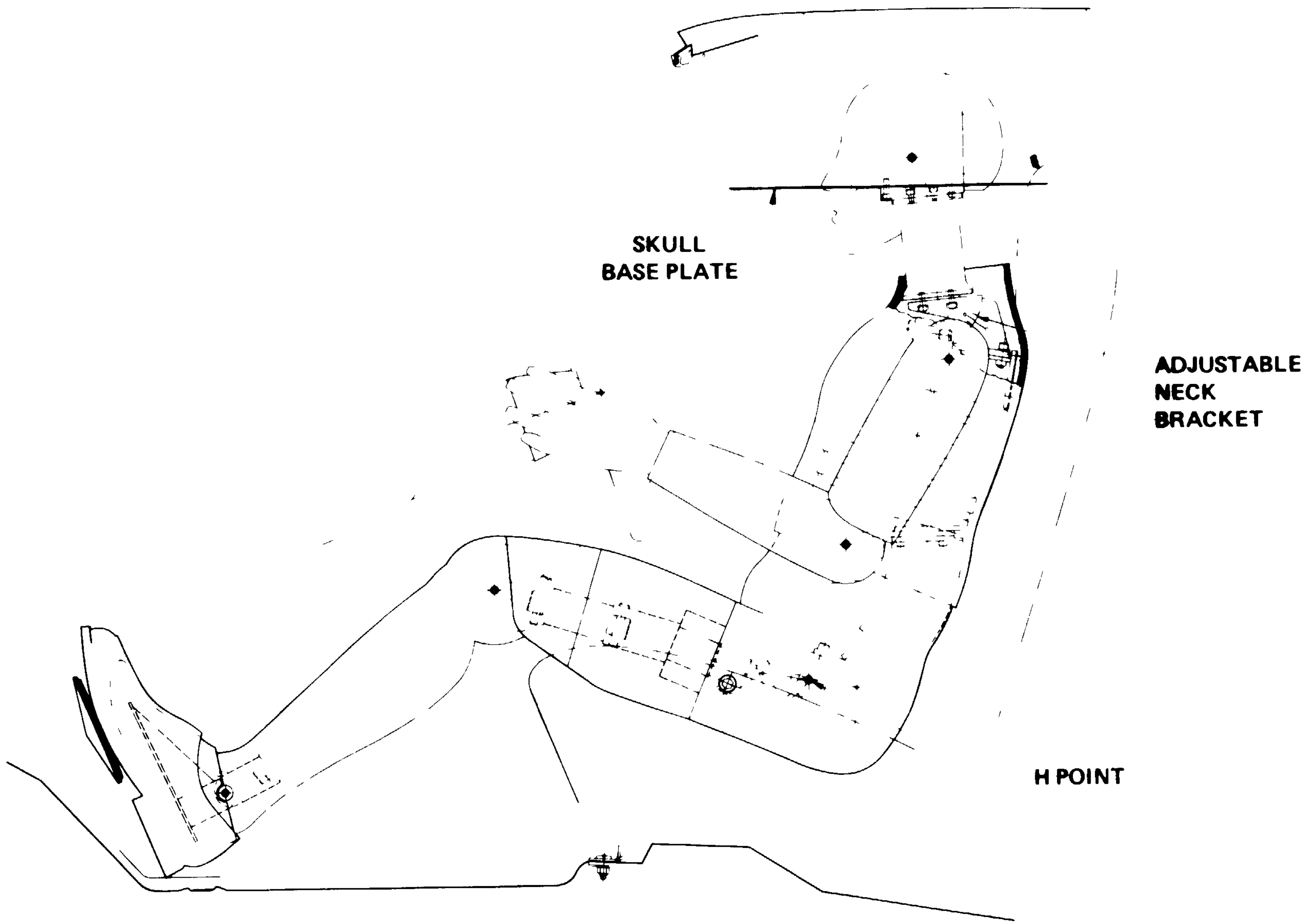

Figure 2-1 Automotive Seated Position

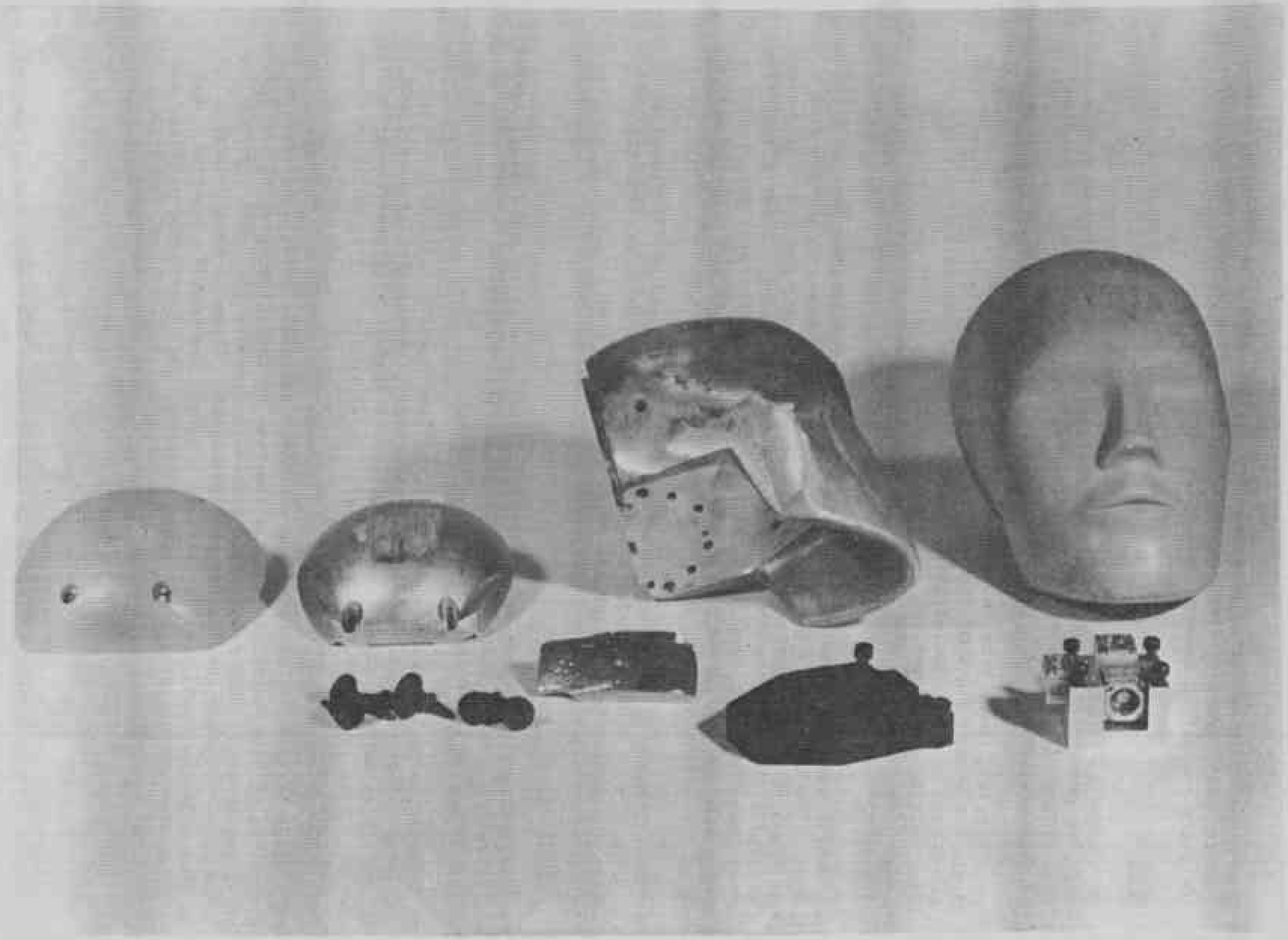

Figure 2-2. Contract Dummy Head Assembly

The head assembly is ballasted to attain th design weight, center-of-gravity location and mass moment of inertia about a lateral axis through the c.g. An adaptor plate simplifies neck-to-head attachment.

B. NECK

The neck proper (Figure 2-3) is composed of a polyacrylate elastomer which has good damping properties. This material provides repeatable response and is durable. Integrally molded end plates provide the attachment to the head and to the neck bracket.

The neck bracket, which provides the neck-to-spine attachment, can be adjusted to maintain the base plane of the head horizontal for current vehicle seat back angles. Of cast aluminum for weight control and ease of manufacture, it has a positive locking adjustment.

C. SHOULDERS

The shoulder assembly (Figure 2-4) forms an articulated linkage between spine and arms. The elevation/depression clavicular link motion is controlled by a rubber block in conjunction with a Delrin pivot. Anterior-posterior excursions are controlled by a cast urethane member for self-centering. Upper arm flexion involves joint bushings, and cushioned rubber stops limit travel and prevent metal-to-metal contact. The cast aluminum clavicular link and clavicle are designed for weight control, durability and the maximum expected loads.

The whole assembly is smoothly contoured to provide a good belt-to-shoulder interface. A neck flange assures a repeatable shoulder belt location and prevents incidental belt damage and torso jacket tearing.

D. THORAX

The thorax assembly (Figures 2-5 and 2-6) consists of a spine and ribcage covered by a removable chest jacket. The whole assembly is ballasted for accurate weight and c.g. location control.

The thoracic spine, of welded steel construction, has the following structural functions. It provides a neck bracket attachment, the clavicular link pivot, and the rib attachment support and location. A lumbar spine attachment is also provided. Finally, it houses the triaxial accelerometer instrumentation block for the chest.

The ribcage assembly is designed for maximum practicable dynamic deflection. It consists of steel ribs attached to the rear of the spine, with helper leaves for stress control. The ribs are contoured to simulate the human form and are backed up by polyethylene foam damper assemblies. These dampers eliminate spurious vibrations and provide vertical rigidity and buckling control. An aluminum sternum completes the ribcage assembly, and it provides rigidity and durability.

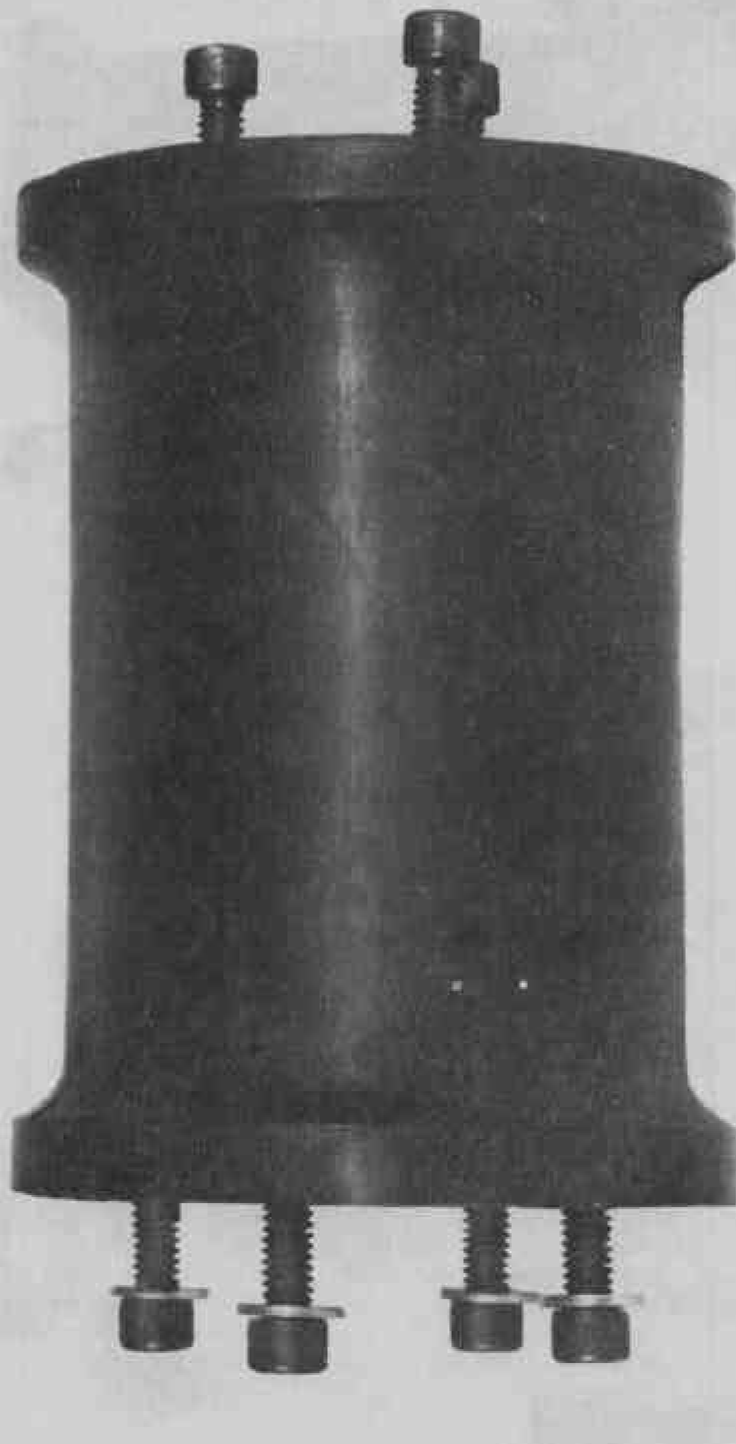

Figure 2-3. Molded Neck Assembly

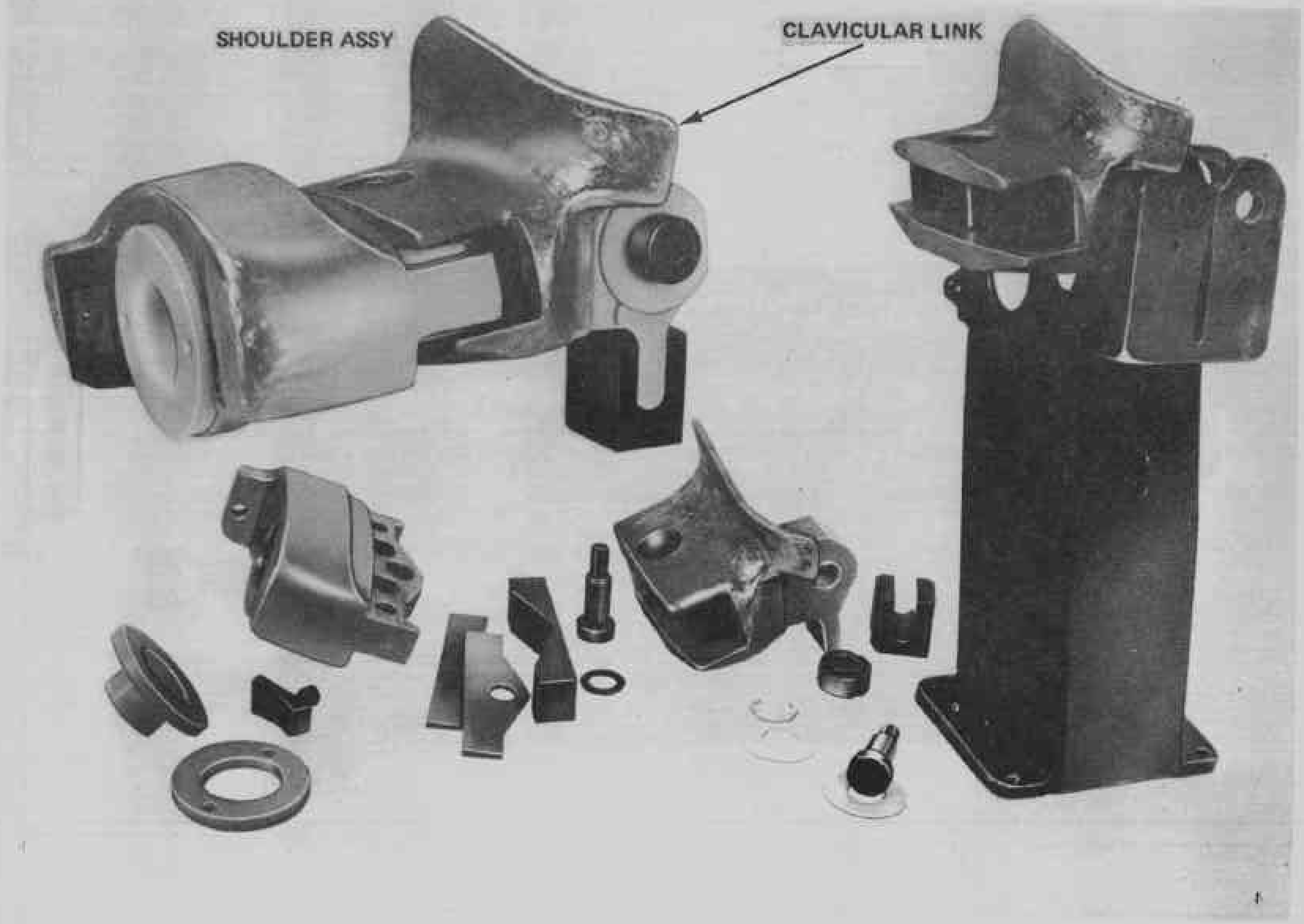

Figure 2-4. Shoulder and Clavicular Link

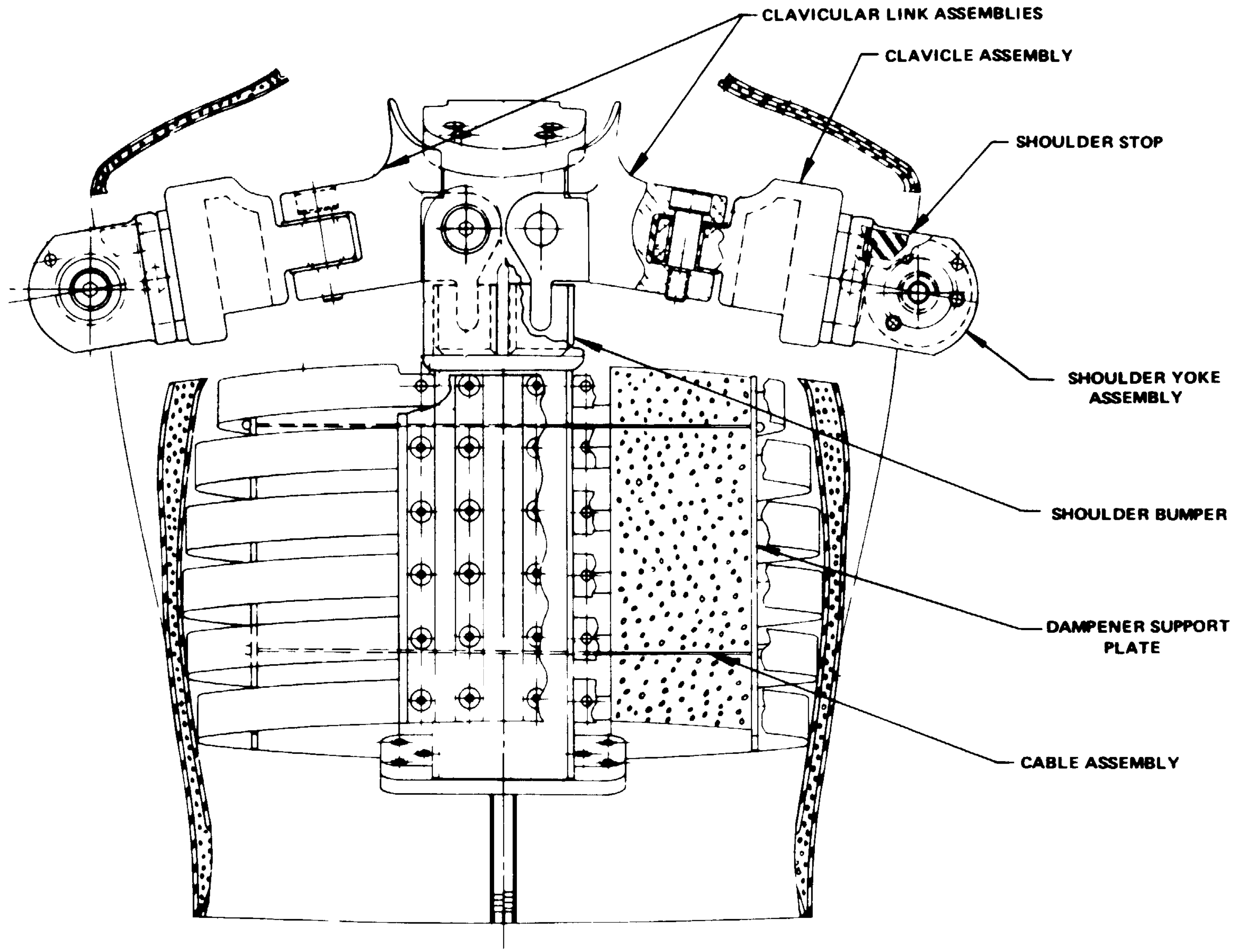

Figure 2-5. Front View of Upper Torso Assembly

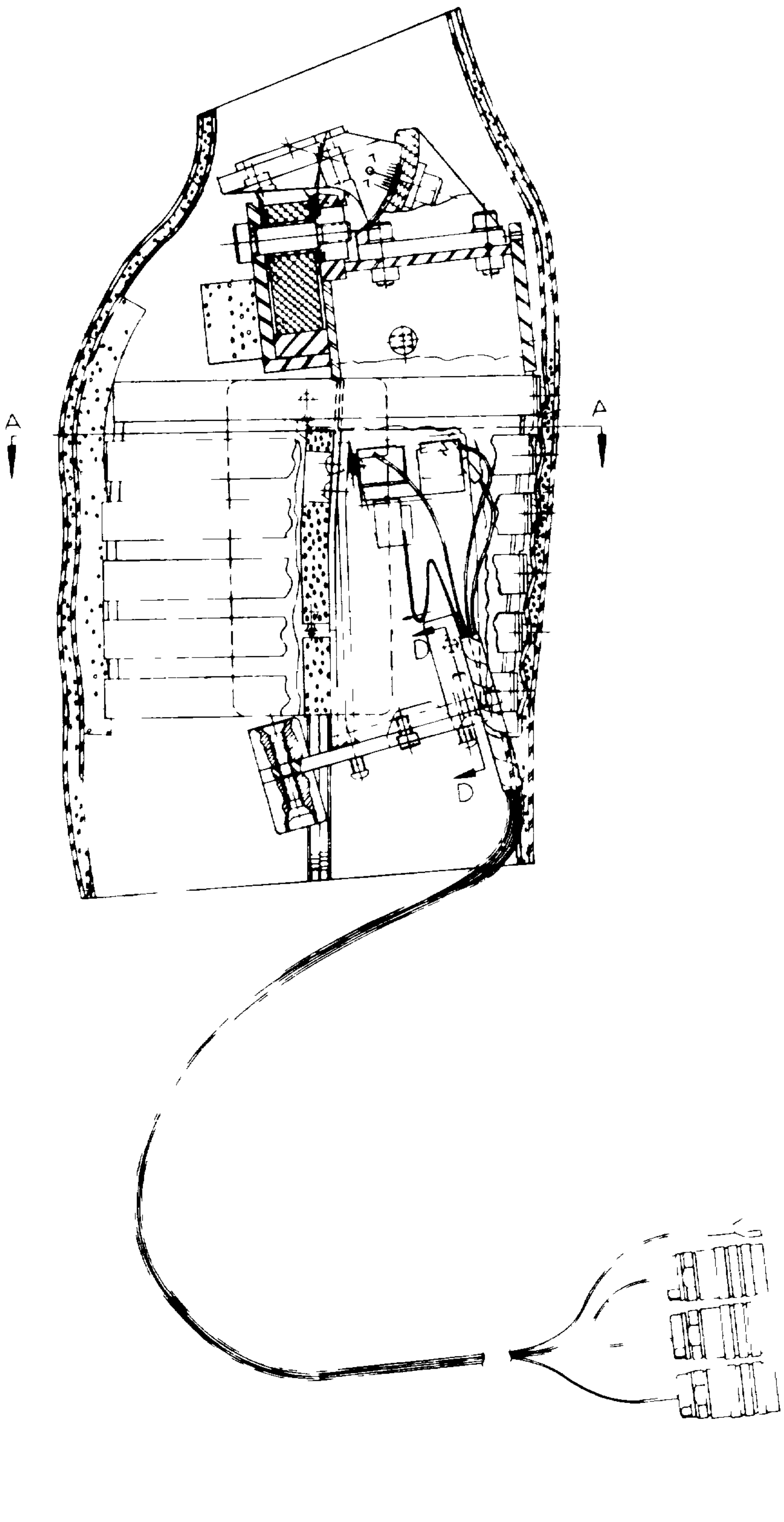

Figure 2-6. Side View of Upper Torso Assembly

E. LUMBAR SPINE

The lumbar spine is a molded, curved polyacrylate rubber member similar to the neck. The curved contour provides the more humanlike, in-car seating position. Molded-in end plates provide attachment means to the thoracic spine and pelvis. Dual cable stabilizers assure lateral seating control, yet still permit fore and aft flexibility.

F. JOINTS

The knee (Figure 2-7) consists of a cast aluminum knee cap with a steel clevis. The knee joint is typical of the new joints designed for the Contract Dummy. Adjustable from 1 g to 3 g preloading, it maintains its setting over several tests, and constant torque is held at varying joint angle or velocity. The joint operates on a clutch principle. The clutch force is provided by a urethane spring held by a floating nut against Delrin pressure plates. The pivot bolt in the joint is isolated from rotational forces. The number of operating parts of this joint have been reduced from 49 to 7 compared to a current, commercially available dummy.

Other joints incorporating this new design are the elbow and arm/shoulder joints. Flesh contours have been modified to eliminate interference with joint motion.

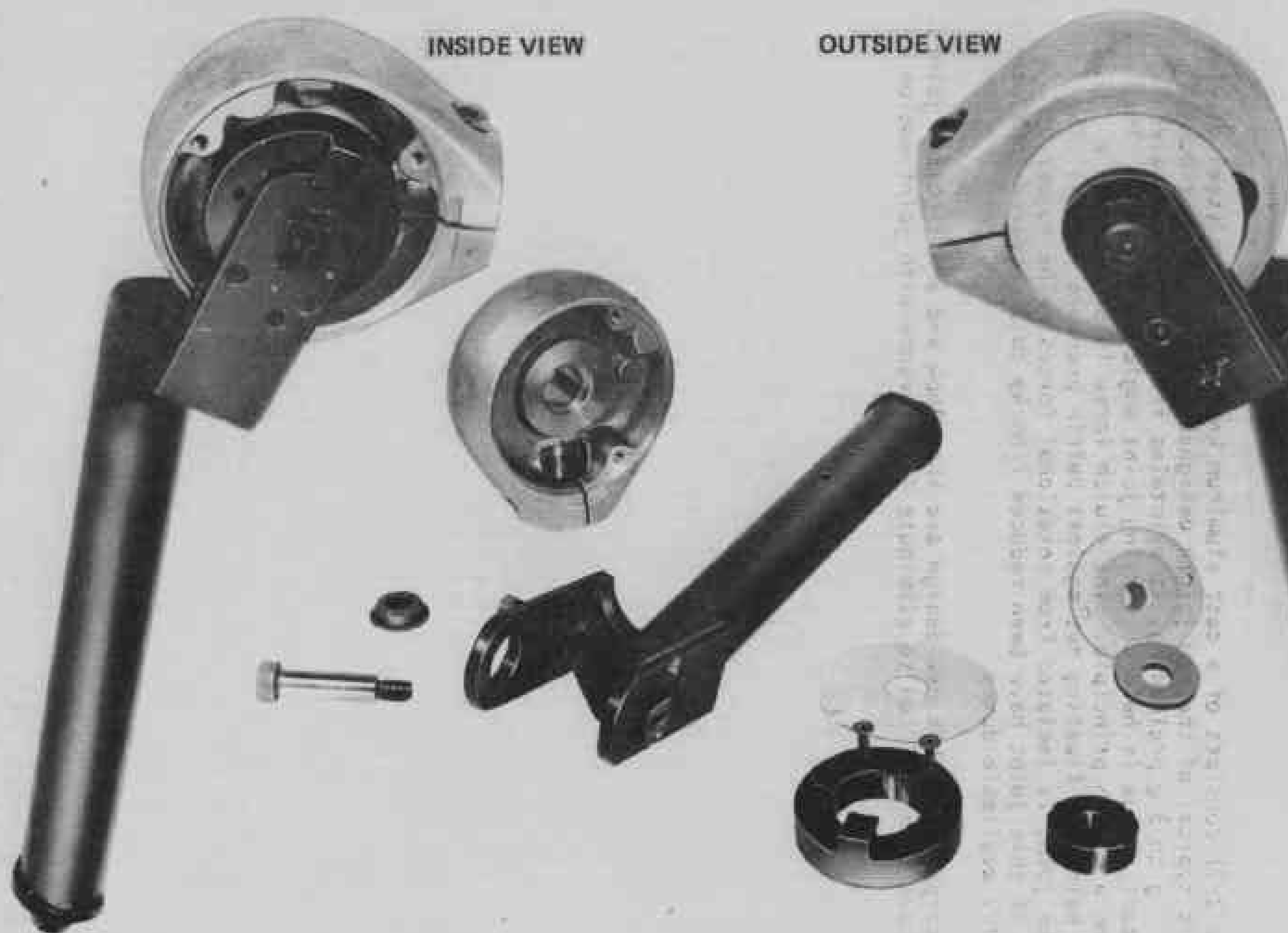

Figure 2-7. Knee Joint Assembly

SECTION 3

TEST DEVELOPMENT AND DUMMY PERFORMANCE DOCUMENTATION

A. BACKGROUND

The end result of a dummy design is testing in simulated automotive crash environments using many restraint system designs. These, of course, are system tests. How does a dummy designer choose which of the many combinations of restraint systems, automotive interior environments, setup and test procedures, and acceleration pulses will be used as the primary development system test for the dummy? Ideally, the system test environment and conditions for the dummy should be the same as those in which biomechanical data were collected. Unfortunately, this cannot be done because the biomechanical performance for any restraint system has not been documented.

Another approach would be to pick several representative tests (e.g., a three-point belt test, an air bag test, etc.) and assess the dummy's repeatability (similarity of results on repeated runs with a single dummy) and reproducibility (similarity of results when different dummies of the same design are used) for each environment. However, this was not considered a practical solution for this contract because extensive development would be needed on each type of test to eliminate the effects of test or test hardware variation from indicated dummy performance.

The approach taken under this contract was to take one type of test and develop it to try to remove all extraneous variables. The restraint condition chosen was the three-point, lap-shoulder belt system typical of present-day automotive restraint systems. This system was chosen for several reasons:

- It is representative of three-point belt systems in current cars.
- Field accident data are available on this type of restraint system, providing some knowledge of its effectiveness.
- External sources of variability are easy to control.
- Major components (neck, chest, pelvis, and limbs) of the dummy are exercised.

B. TEST DESCRIPTION

To ascertain the performance of the dummy alone with as little influence as possible from external variables, a"hard-seat" fixture was designed for the HYGE impact sled. Uniform, rigid, seating surfaces allowed the variability associated with typical automotive seats to be eliminated and aided in precise control of the dummy's initial seated position. A positioning template was used to locate the dummy's head, chest and H-point for each test. The fixture is shown in Figure 3-1. The applied acceleration pulse, the seating geometry, and the belt anchorage locations were selected as being representative of a 30 mph barrier collision of a current compact car. Detailed descriptions of these points may be found in Volume II.

C. PERFORMANCE DOCUMENTATION

Using the test described above, the delivered dummies have been subjected to the "hard-seat" environment. The results of these Contract-required tests on the delivered dummies, D5 and D6, are shown in Table 3-1. Graphical presentations of the time histories of the average sled acceleration, measured sled velocity, head acceleration (resultant and components), chest acceleration (resultant and components), femur loads, lap, shoulder and tongue belt loads, and fixture acceleration (resultant and components) are presented in Appendix 3-A.

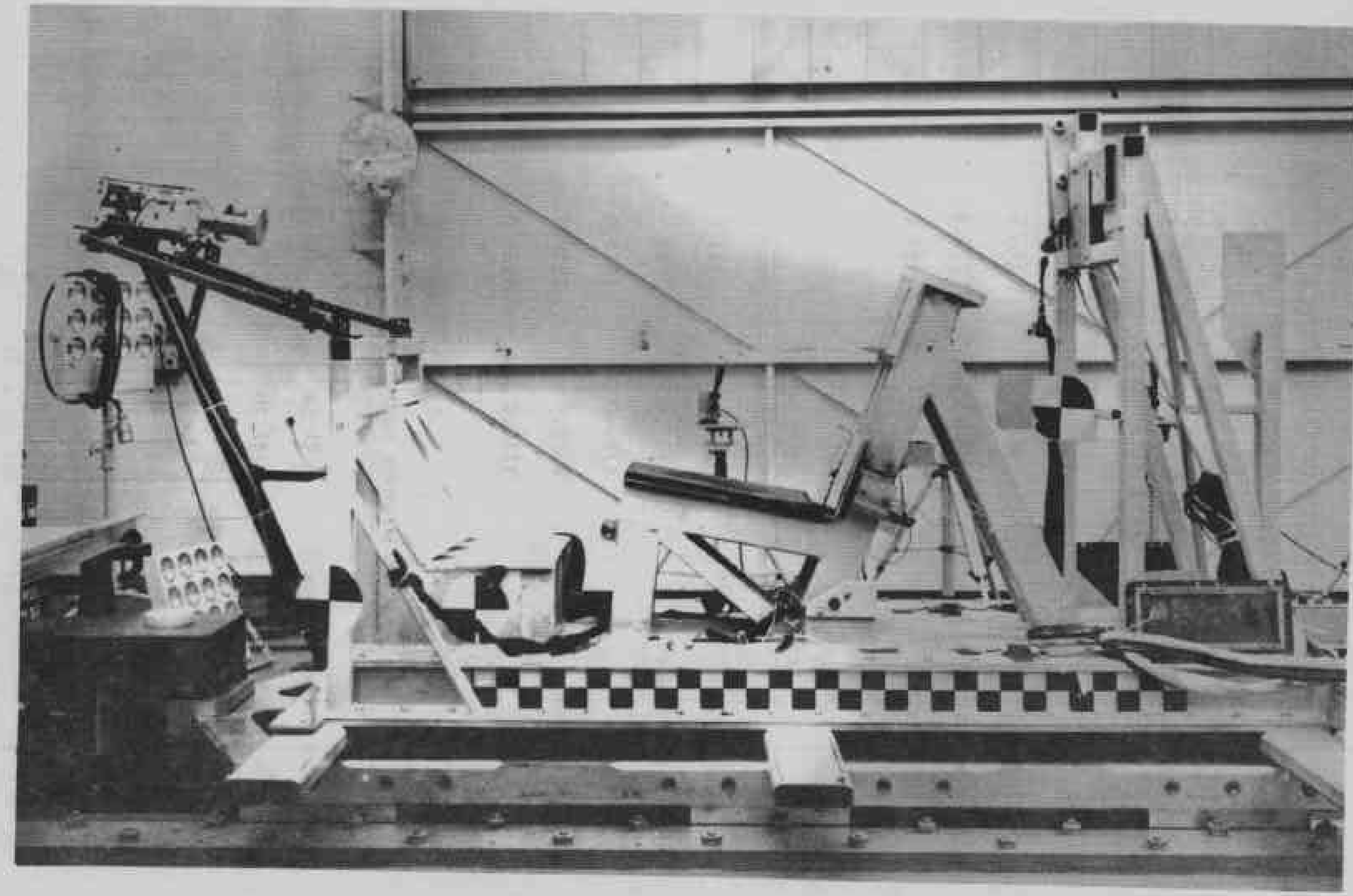

Figure 3-1. Hard Seat Test Fixture

TABLE 3-1

PERFORMANCE DOCUMENTATION RESULTS

NHTSA CONTRACT DUMMIES

HEAD AND CHEST RESPONSES

	DUMMY D5	DUMMY D6
HIC	581.0	530.0
Head SI	880.5	776.3
Chest SI	436.5	433.8

FEMUR AND BELT LOADS (Lb)

Left Femur	283.4	311.0
Right Femur	301.4	340.1
Lap	1725.0	1550.0
Shoulder	2475.0	2500.0
Tongue	3725.0	3525.0

SLED AND FIXTURE PARAMETERS

Sled Velocity (mph)	34.54	34.49
Fixture SI	232.20	231.00

SECTION 4

REPEATABILITY AND REPRODUCIBILITY (R & R)

Repeatability as used in our program means the similarity of test results when a single dummy is given several repeat tests. Reproducibility is the similarity of test responses when more than one dummy is subjected to the same test conditions. Repeatability depends not only on each dummy component performing the same in test after test, but also depends on the control of the test setup, data recording, and many other variables which are external to the dummy. Reproducibility depends upon repeatability and also upon the degree to which the dummies in question are manufactured alike. Reproducibility of a dummy design cannot be truly evaluated on prototype hardware. Furthermore, the small sample size limits the statistical significance of the results.

With the test environment described in the previous section, as many extraneous variables as possible have been eliminated so that the test results should be primarily a measure of the dummy R & R. However, it is first necessary to decide how R & R will be measured.

A. MEASUREMENT TECHNIQUES

During the course of the project several variables were explored as repeatability measures of dummy performance. These included the following:

- Resultant acceleration level exceeded for three milliseconds
- Mean of resultant acceleration over the entire event
- Severity Index
- HIC-1
- Root-Integrated-Mean-Square-Difference (RIMSD)*

While the RIMSD appeared to be the most sensitive indicator of repeatability, the severity index was chosen as the measure because it gave almost as sensitive an indication of repeatability and was much easier to compute and was available in our standard data processing package. Also it is an integrated quantity using data from the whole response event, and magnifies local differences in the acceleration traces due to 2.5 power weighting of the calculation. To put input parameters on a common basis with the dummy response, severity index was also calculated for the sled and fixture acceleration, and it was used as a repeatability measure.

A typical system test sequence consisted of six repeat tests, from which mean and standard deviation for each response recorded were calculated. The coefficients of variation, defined as a ratio of the standard deviation to the mean, were the principal measures of repeatability for each set of dummy tests. The mean, standard deviation, and coefficients of variation of the pooled data from tests involving different dummies were used to assess reproducibility.

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* This is a statistical technique for comparing the similarity of two curves and can be utilized in a "goodness of fit" test. It can be computed for any recorded variable and is calculated over the entire time history.

B. GOALS

Hard-seat results on early prototype dummies showed coefficients of variation as high as ten percent for head and chest S.I. This level of repeatability was also typical of commercially available test dummies. It was concluded that a reasonable goal for the Contract Dummy would be a coefficient of variation of less than five percent for each response measured.

C. DUMMY PERFORMANCE

Two separate repeatability and reproducibility test series were conducted using the hard-seat fixture and experimental methodology described earlier. First, a series of 18 tests were conducted that established the R & R baseline for the Contract Dummy essentially as it was documented in the Preliminary Data Package (i.e., Design No. 1). A second set of 16 tests run (eight each) on dummies D2 and D3 established the R & R for the final design (i.e., Design No. 2). Design No. 1 had repeatability and reproducibility of less than eight percent for head and chest SI's. These tests indicated that, while repeatability was improved, the desired goal of less than five percent had not been attained.

Efforts to improve the repeatability of the Contract Dummy concentrated on the redesign of the shoulder structure and joints. Two dummies were modified with new parts (Design No. 2), and the second series of hard-seat tests were conducted to determine if repeatability had been improved. Results of the tests of these two designs are illustrated in Figures 4-1 and 4-2. Note that mean level differences in the figures are attributable to test device arm placement (see Volume II for discussion). Detailed response levels are included in Appendix 4-A in graphic and tabular form.

In summary it can be concluded that the delivered Contract Dummy can be expected to give repeatable responses better than five percent in a hard seat, three-point belt restraint system test. This conclusion is postulated on the assumption of well-controlled setup and test procedures. No conclusion can be drawn on reproducibility because of the small sample size.

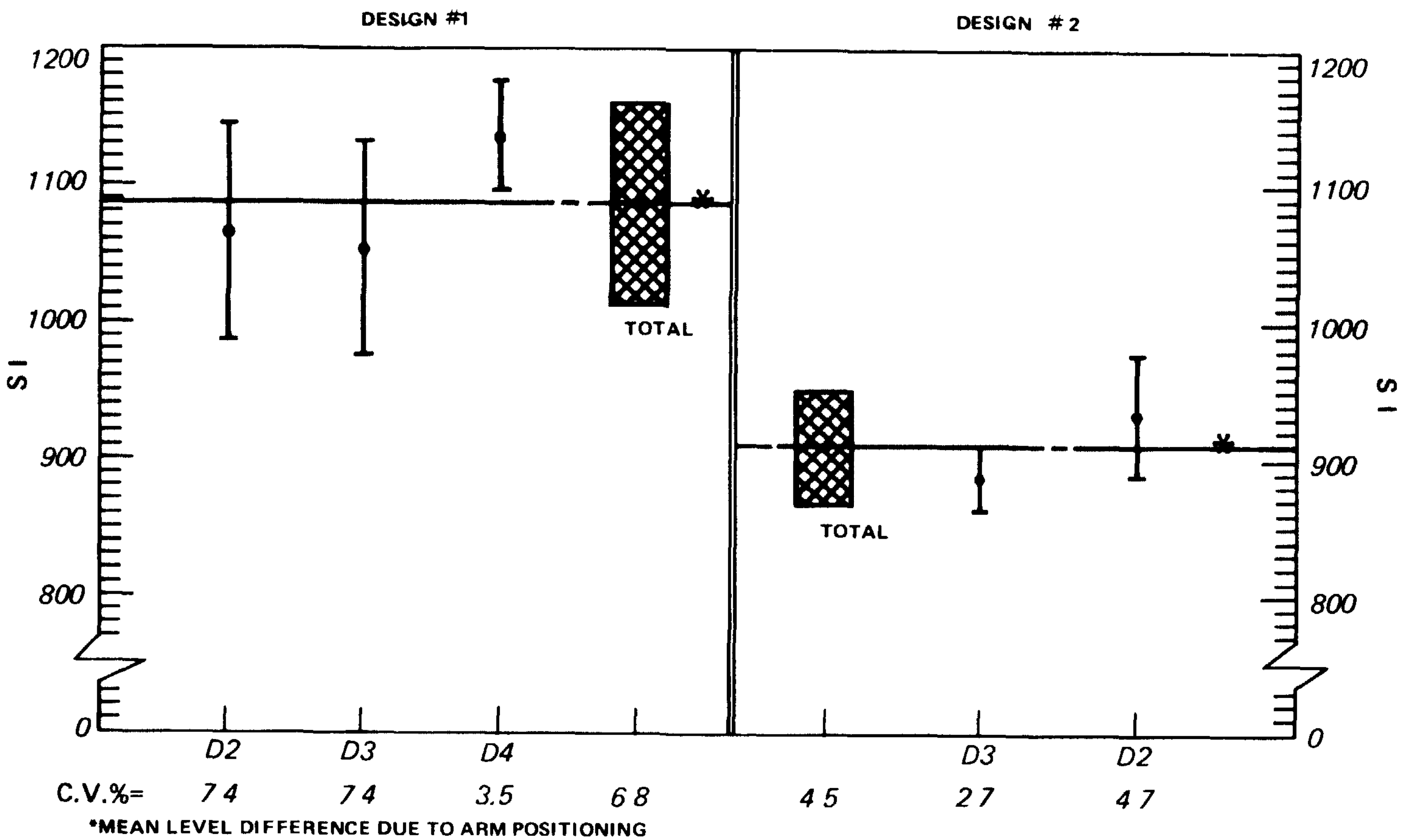


Figure 4-1. Head Severity Index - Design I, Design II

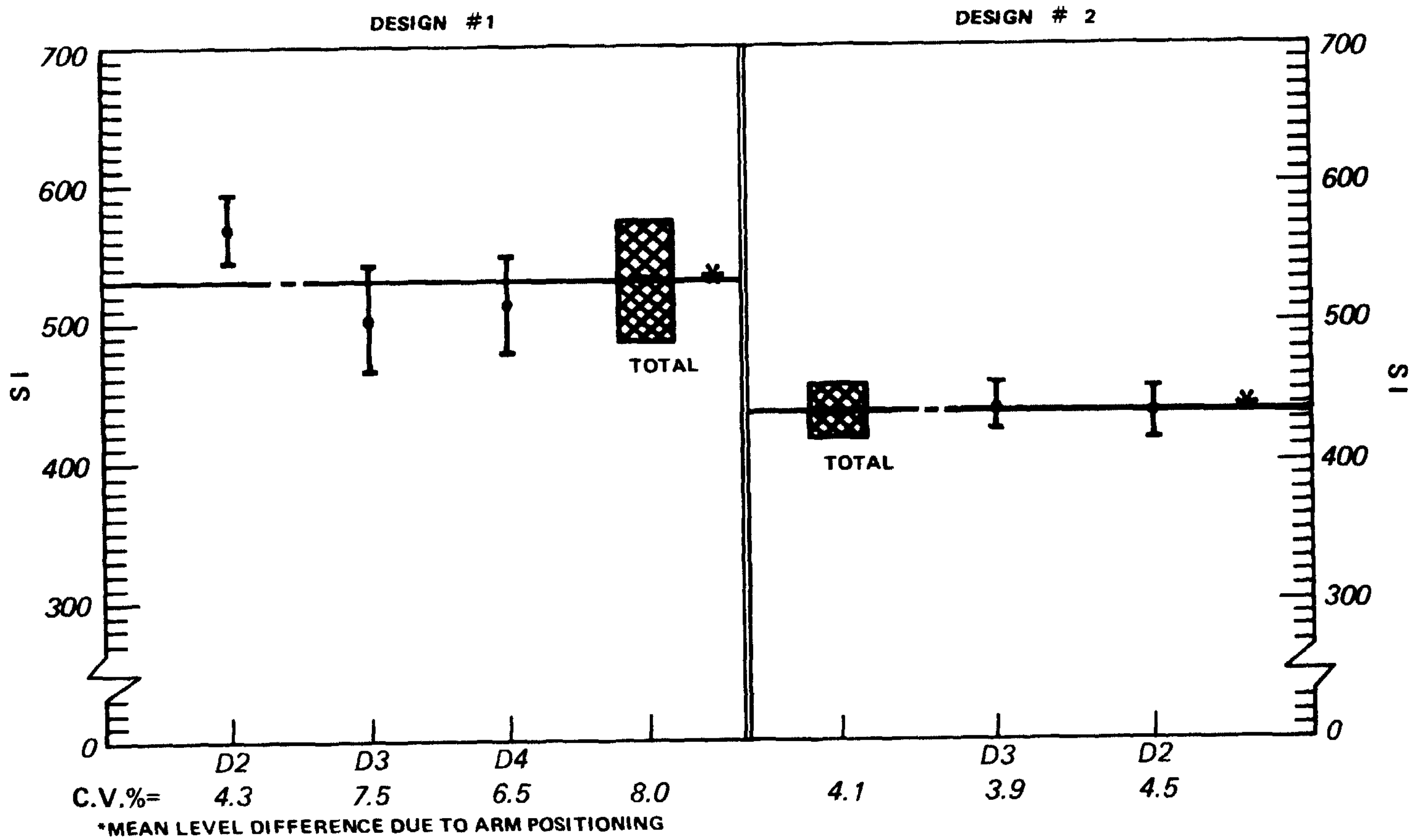


Figure 4-2. Chest Severity Index - Design I, Design II

SECTION 5

ANTHROPOMETRY AND BIOMECHANICS

In automotive crash testing, human-injury assessments are usually based on analyses of dummy head acceleration, chest acceleration, and femur load. If these injury assessments are to be valid, then the responses measured in the dummy must be the same as would be measured in the human under the same circumstances. Assuring the equivalence of human and dummy response for injury assessment requires the following:

- Knowledge of human response and the factors affecting that response.
- Characterization of human response into dummy specifications and performance requirements.
- Design and development of dummy systems to comply with these requirements.

In the General Motors program, limited requirements have been specified as necessary for similarity of dummy and human response, but they are not sufficient to assure this similarity. In Volume II, these requirements are presented and discussed in detail.

A. ANTHROPOMETRY

Anthropometry is the basis for humanlike crash-dummy design geometry. The erect seated position has been used for most of the seated anthropometric measurements and is the position for which dummy geometric and inertial characteristics are described. The external body dimensions specified in SAE Recommended Practice J963 are representative of the 50th percentile American adult male and have been used in the General Motors program (Table 5-1 and Figures 5-1 and 5-2). In an effort to more completely and realistically define the geometric and inertial properties of the Contract Dummy, the placement of important joint pivots have been defined (Table 5-2 and Figure 5-3). Section planes between the dummy head, neck, and upper and lower torso have been specified; and requirements for the weight and center-of-gravity locations for these segments have been presented (Table 5-3 and Figure 5-4). Additional specifications for the head include anatomically based coordinate directions and the mass moment of inertia about a lateral axis through the head center of gravity. Anthropometric data have been used in the Contract Dummy design to assure that when the dummy is placed in an automotive-type seat, the torso is realistically positioned, and the head is correctly located relative to the hip structure.

TABLE 5-1 EXTERIOR BODY DIMENSIONS

DIMENSIONAL SYMBOL	DESCRIPTION	DESIGN* VALUE (INCHES)	SAE J963 (INCHES)
I	Shoulder - Elbow Length	14.4	14.1±0.3
J	Elbow Rest Height (Erect)	9.5	9.5±0.5
L	Popliteal Height	17.3	17.3±0.2
M	Knee Height (Sitting)	21.4	21.4±0.3
N	Buttock Popliteal Length	18.45	19.5±0.3
O	Chest Depth	8.8	9.0±0.4
P	Buttock Knee Length	23.2	23.3±0.3
Q	Thigh Clearance	5.9	5.7±0.3
R	Elbow - Finger Tip Length	18.3	18.7±0.5
S	Foot Length	10.4	10.5±0.2
T	Head Length	7.7	7.7±0.2
U	Sitting Height (Erect)	35.7	35.7±0.5
V	Shoulder Breadth	18.3	17.9±0.4
W	Foot Breadth	4.0	3.8±0.3
X	Head Circumference	22.7	22.5±0.5
Y	Chest Circumference	38.0	37.7±1.0
Z	Waist Circumference (Sitting)	34.0	33.0±1.0
AA	Head Breadth	6.0	6.1±0.2
AE	Occiput to Z-Axis	1.3	-

* Referenced to the Erect Seated Position

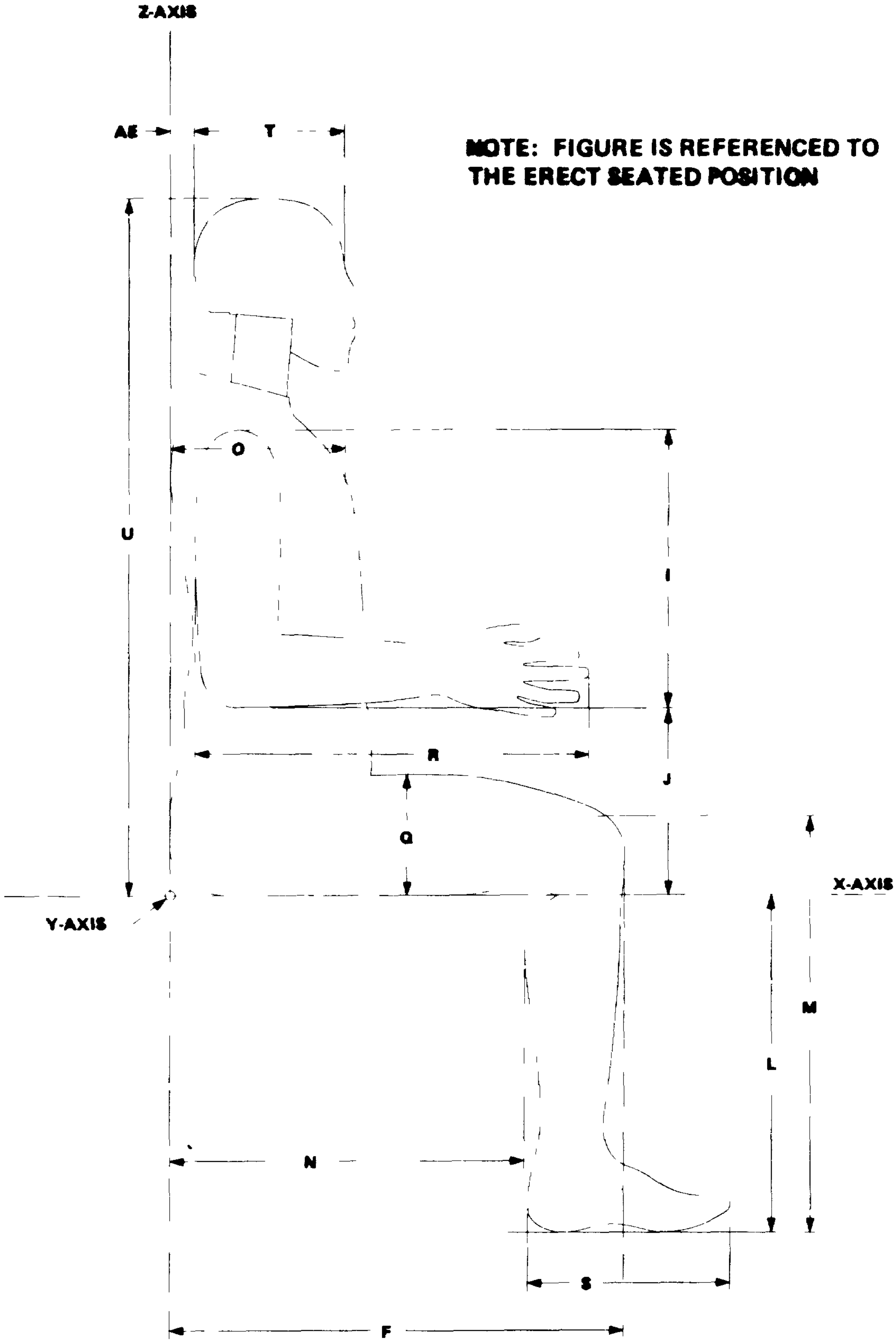


Figure 5-1. Exterior Body Dimensions — Side

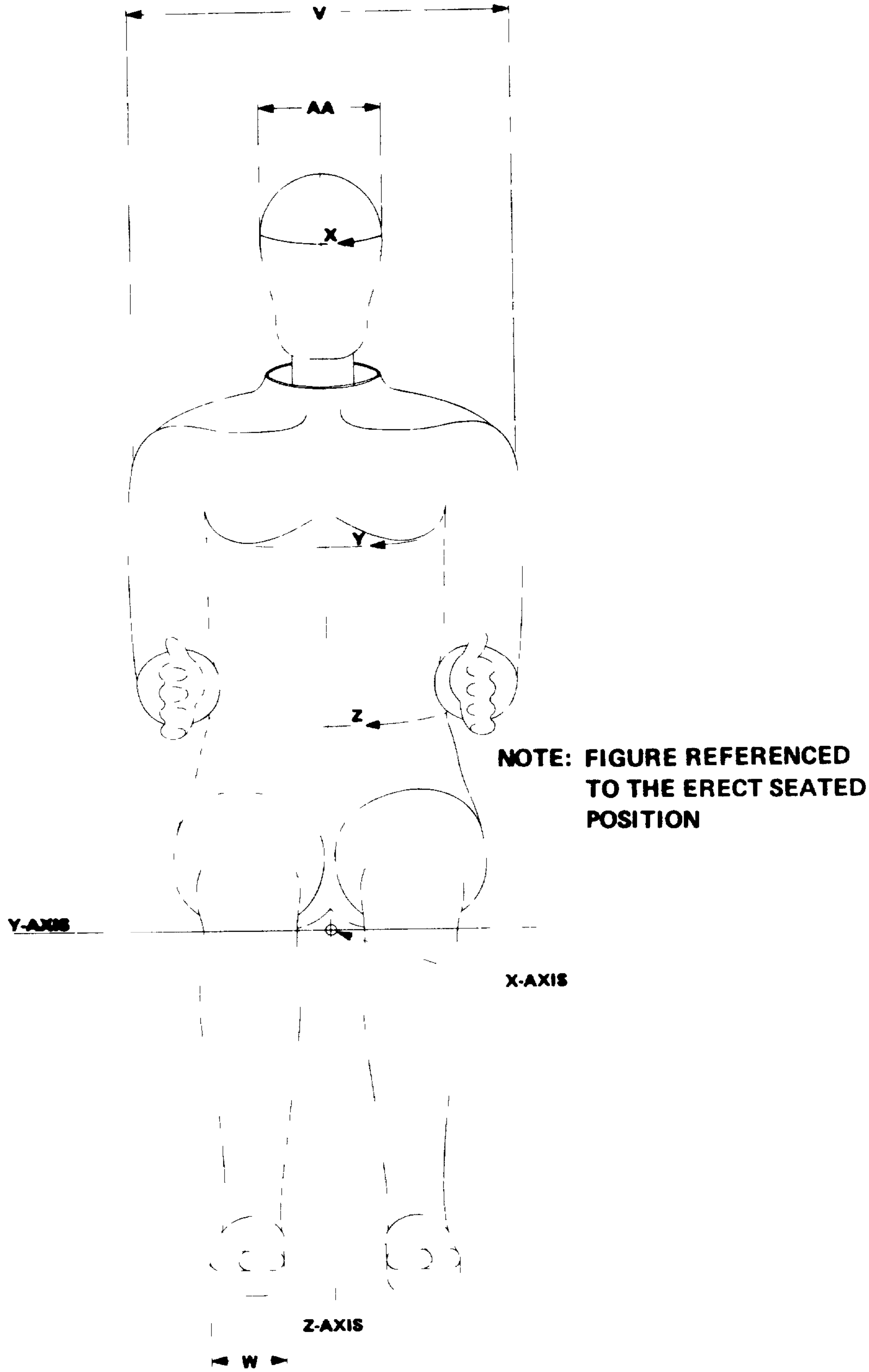


Figure 5-2. Exterior Body Dimensions: Front

TABLE 5-2 BODY PIVOT AND FLEXIBLE COMPONENT LOCATIONS

DIMENSIONAL SYMBOL	DESCRIPTION	NOMINAL* DESIGN VALUE (INCHES)
A	Shoulder Pivot to X-Axis	21.9
B	Shoulder Pivot to Z Axis	3.5
C	Shoulder Pivot to Elbow Pivot	10.3
D	Elbow Pivot to Wrist Pivot	9.8
E	Lumbar Lower Centerline Point to X-Axis	7.7
E^1	Lumbar Vertical Height	5.6
F	Lumbar Lower Centerline Point to Z-Axis	2.9
F^1	Lumbar Horizontal Offset	0.5
G	H-Point to X-Axis	4.0
H	H-Point to Z-Axis	5.0
J	H-Point to Knee Pivot	15.7
K	Knee Pivot to Ankle Pivot (Horiz.)	16.3
L	H-Point to Neck Lower Centerline Point	20.8
M	Neck Lower Centerline Point to Z-Axis	4.5
P	Upper Neck Centerline Point to Z-Axis	4.9
Q	Neck Vertical Height	4.9
R	H-Point to Knee Pivot (Vertical)	1.9

* Referenced to the Erect Seated Position

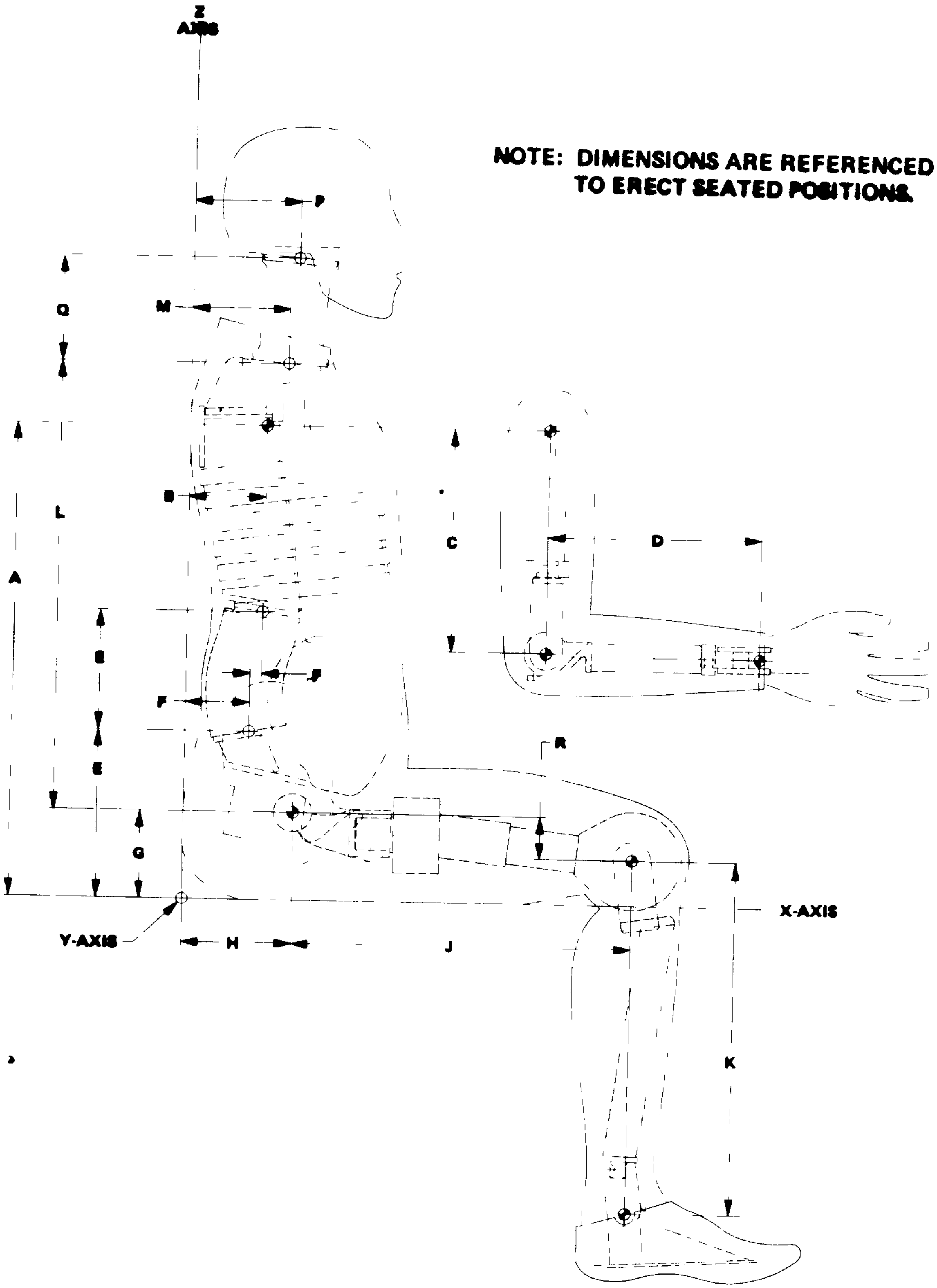


Figure 5-3. Pivot Points and Flexible Component Locations

TABLE 5-3 WEIGHTS OF SUBASSEMBLIES

(SECTIONED AS PER FIGURE 5-4)

Segment	Anthropometric Goal[1] (Lb)	X Dummy[2] Design Value (Lb)	Delivered Dummies[3] #5 (Lb)	#6 (Lb)
Head	10.0	10.00 ± 0.05	10.03	10.04
Neck	3.1	2.70 ± 0.05	2.68	2.69
Upper Body	38.2	36.1 ± 0.4	36.0	36.1
Lower Body	50.8	40.3 ± 0.4	40.3	40.1
Upper Arms (Both)	8.5	8.5 ± 0.2	8.3	8.5
Lower Arms & Hands (Both)	7.5	9.9 ± 0.2	9.9	9.9
Upper Legs (Both)	26.8	36.0 ± 0.4	35.6	35.9
Lower Legs & Feet (Both)	19.0	20.0 ± 0.4	19.9	19.6
TOTAL	163.9	163.5[4]	162.7	162.8

[1] Refer to Volume II.

[2] Differs from column 1 because all anthropometric goals could not be met without redesign/remanufacturing.

[3] Tolerance on measurement is ±1.0%

[4] Sum of component tolerances is ± 2.1 Lb.

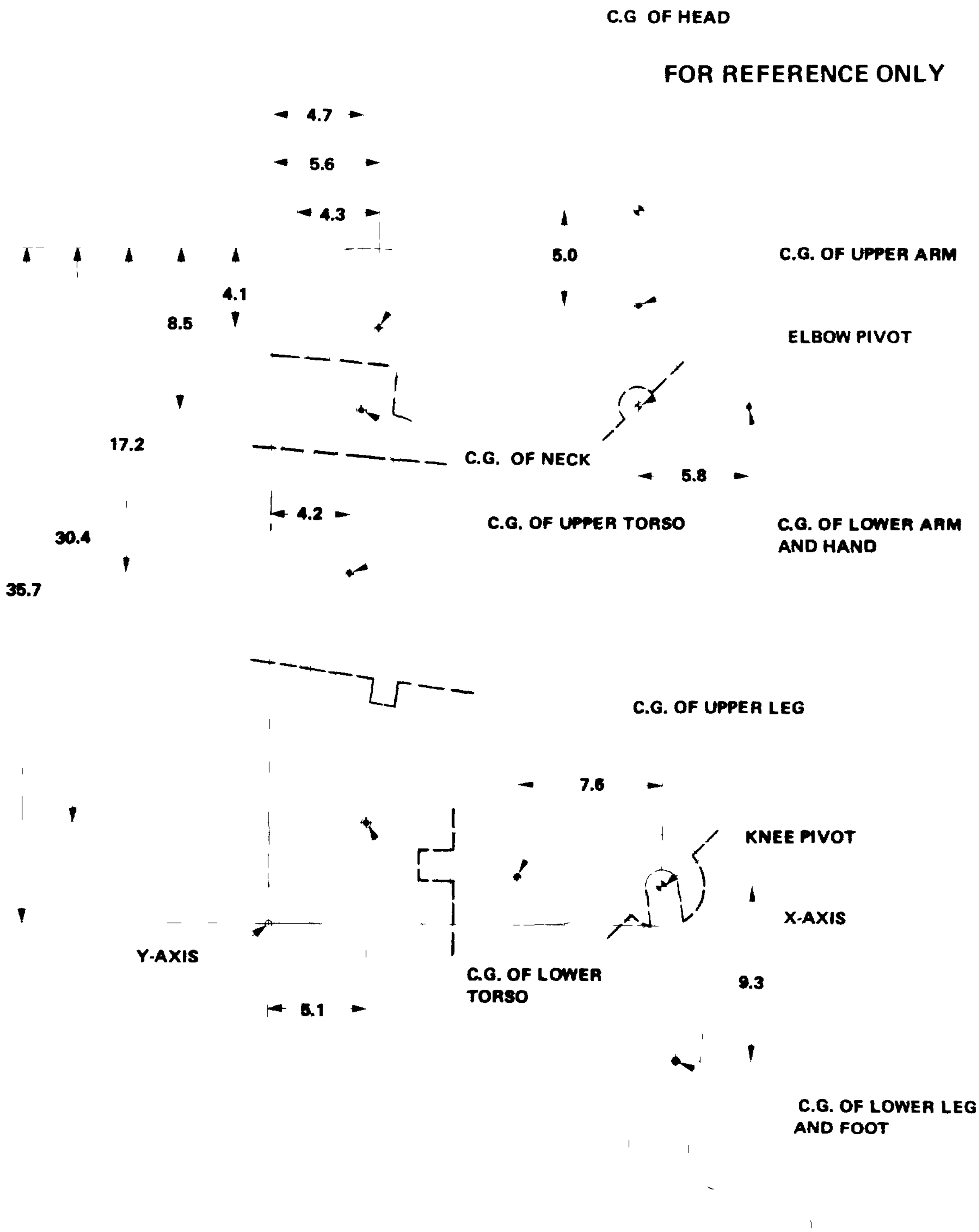


Figure 5-4 Dummy Segmenting for Weight and C.G. Locations

B. BIOMECHANICS

At this time, no biomechanical data exist as a basis for the specification of humanlike response requirements for the dummy as a system. With regard to the subsystem performance, few requirements based on limited biomechanical data have been specified as performance goals for use during the Contract Dummy development. The following paragraphs review these goals and generally describe the Contract Dummy's compliance (Consult Volume II for more detail).

1. Head

The Contract calls for a drop test response of 120-150g peak resultant acceleration for a 6 inch drop onto a steel plate and 200 to 250g for a 12 inch drop. Since the start of the Contract, a review of the biomechanical data suggests that a performance of 225 to 275g for a 14.8 inch drop height would be more appropriate. The Contract Dummy head complies with all of these requirements.

2. Neck

Neck biofidelity is to be judged by the flexion and extension corridors of Mertz, et al (Ref. Bibliography, Item 1) given in the Contract.

The Contract Dummy neck performance lies within the flexion corridor but does meet the peak torque or area ratio requirements. However, in extension, the neck performance does not comply.

3. Chest

The thoracic impact corridors by Kroell, as cited in Ref. Bibliography, Item 2, were the biomechanical goals during chest development. The Contract Dummy chest response approaches, but does not comply with the corridors.

4. Knees

Biomechanical requirements for static knee penetration into a deformable material were used to evaluate the knee structure. These requirements were not met by the Contract Dummy. For a given penetration the femur loads slightly exceed the maximum specified load.

The requirements used for the development of the Contract Dummy were based on currently available knowledge of human impact response and the factors affecting that response. These requirements are a set of conditions necessary for similarity of dummy and human response, but they are not sufficient to assure humanlike response to general impact conditions even at the subsystem level. The inability to definitively specify a set of requirements sufficient to assure that the Contract Dummy is humanlike, in terms of the responses which are the basis for human injury assessment, is due primarily to a lack of appropriate human impact response data.

SECTION 6

CONCLUSIONS

This Contract effort has produced a test dummy that:

- Gives improved repeatability through
  - Shoulder design which improves shoulder belt interface.
  - Joint design which gives more uniform resisting torque.
  - Lumbar spine design which allows a natural automotive seated position without preloading of flexible parts for improved setup.
- Offers potential reproducibility gains with
  - Data package that represents a milestone in depth of design documentation for manufacturing of identical dummies.
  - Dummy segmentation techniques which allow better control of inertial properties.
  - Subassembly weights that are controlled (rather than total weight) for more accurate weight distribution.
- Has improved durability and ease of use and maintenance because
  - Joints no longer require setting between each test.
  - Separate left- and right-hand parts have been eliminated in many places for smaller parts inventory.
- Has improved biofidelity because
  - Skull and head contours are based on a study of human shapes.
  - Head impact performance is based on a drop test which is correlated with cadaver testing.
  - More humanlike automotive seated positioning is used.
  - Neck and chest were designed towards biomechanical corridors.

This program has identified improved system and component tests for dummy development and evaluation such as:

> The "hard-seat" fixture and positioning template for a test environment with a minimum of external variables.
>
> A neck subsystem R & R test which attempts to relate to the total system test.

However, before undertaking this program, General Motors made it patently clear that a major part of a successful dummy program was missing; namely, correlation of real-life injury criteria with performance data derived from a test dummy built to the Contract specifications in the RFP or as modified in our Proposal. In view of the absence of quantitative human-injury criteria that are correlated with anthropomorphic dummy and product performance, General Motors does not believe that the specifications in the Contract executed define a satisfactory compliance test device.

There is no assurance that the measurements made with the dummies which are delivered can be correlated to human injury tolerance levels. Furthermore, there is no assurance that changes in the responses of the dummy due to variations in test environments can be correlated to human response sensitivity. Both of these requirements must be met before the degree of protection afforded by a restraint can be truly evaluated.

General Motors cannot assure that, even with test devices built to the more definitive specifications contained in the Data Package (Volume III), comparable results can be obtained among different testing agencies. During our testing, even though rigorous control was exercised, variance in test results did occur which could not be attributed to the test dummy.

The test dummy developed in response to this Contract does not meet the requirements of the test device set forth in Regulation 572 for use with FMVSS 208, since the performance requirements are different.

SECTION 7

RECOMMENDATIONS

General Motors recommends that NHTSA not specify this Contract Dummy for use in the determination of injury criteria in any occupant protection standard that would apply to all types of restraint systems. It is our concern that since complete biomechanical fidelity has not been achieved with this dummy, its use would generate misleading test results.

It is recommended that when the performance of various test dummy designs are compared, they be evaluated under the same set of controlled test conditions. Further it is recommended that the type, location, and calibration procedure of all instrumentation be specified.

Continuing effort in the simulation of human impact response should be concentrated in the following areas of biomechanics, anthropometrics, and test dummy hardware:

A. BIOMECHANICS

Human response and cadaver data should be obtained for various types of system tests (e.g., three-point belt systems, air cushions, and padded interiors). This would provide a basis for validating dummy responses in controlled, simulated collision environments.

Sensitivity studies should be conducted to determine how changes in impact environments affect human response. These data would serve as a basis for comparing dummy and human response sensitivities.

- To aid in dummy component development, biomechanical tests should be conducted with the objective of isolating the response characteristics of a given body segment.
- Biomechanical performance data on human joint resistance should be gathered and incorporated into performance specifications for dummy joints.
- The dynamic deformation and friction characteristics of human soft tissue should be documented and incorporated into dummy specifications.

B. ANTHROPOMETRICS

- Accurate determination of the human body segment masses, moments of inertia, c.g. locations, pivot locations, and segment mobility is required.

The external contours of the test dummy need to be defined as rigorously as was done for the head of the Contract Dummy.

A formalized procedure for crash dummy positioning in automotive seats based on human anthropometric data should be developed.

C. TEST DUMMY HARDWARE

- Repeatability and reproducibility tests for dummy components should be developed which have a meaningful relationship with that component's response in systems tests.
- The sensitivity of dummy system and component responses to such factors as temperature, time between tests, and number of tests should be investigated.

Further development work should be pursued on the various dummy subassembly designs as the above information becomes available.

APPENDIX 3-A

PERFORMANCE DOCUMENTATION

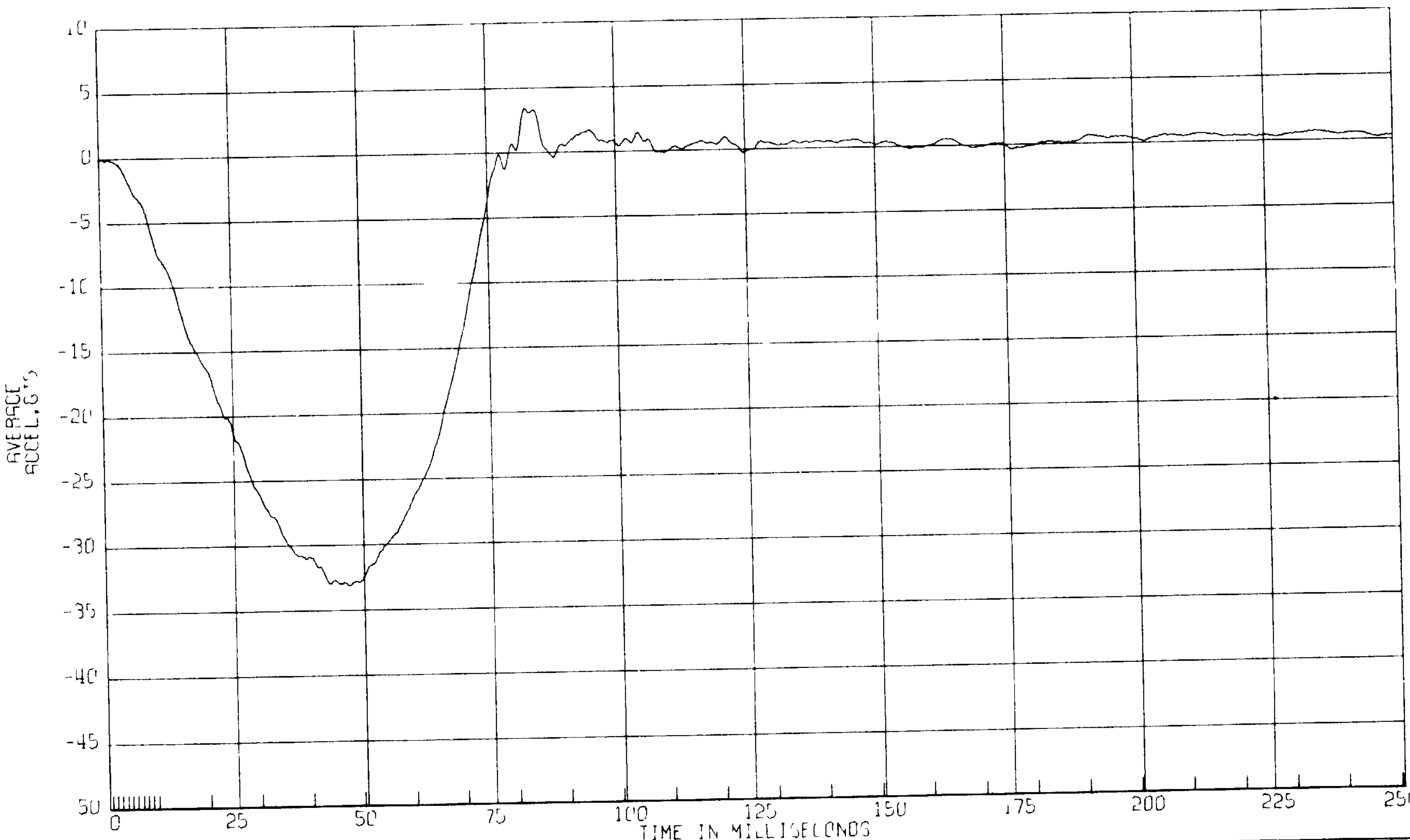
S3905 HARD SEAT HALF SINE
30-200-051
PERFORMANCE VALIDATION
A-D DATA SAE CLASS 60

NHTSA CONTRACT DUMMY NUMBER 05

AVERAGE SLED ACCELERATION

FIGURE
REPORT PG

11-15-73



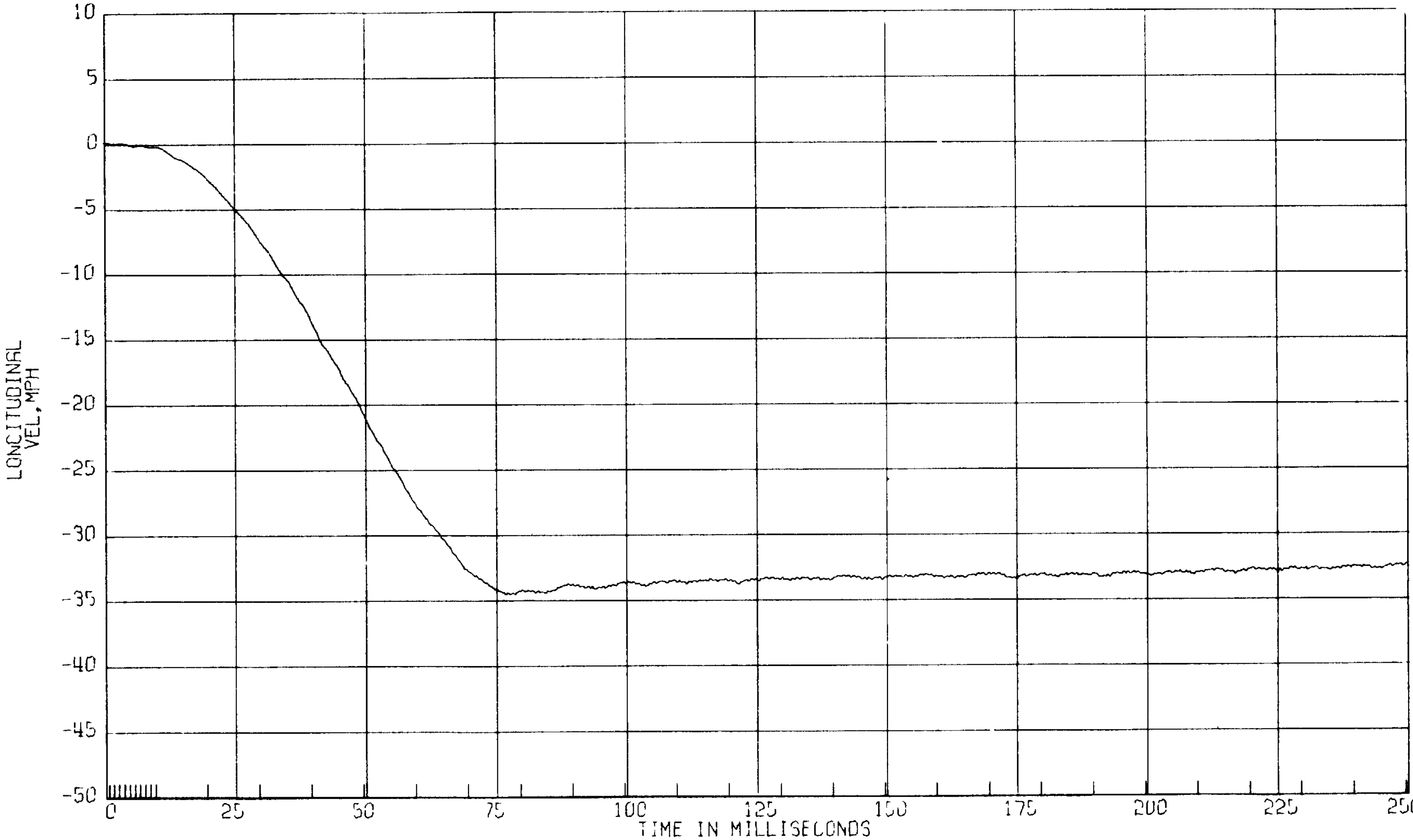
S3905 HARD SEAT HALF SINE
90-200-051
PERFORMANCE VALIDATION
A-D DATA SAE CLASS 60

NHTSA CONTRACT DUMMY NUMBER 05

MEASURED SLED VELOCITY

FIGURE
REPORT PC-

11-15-73



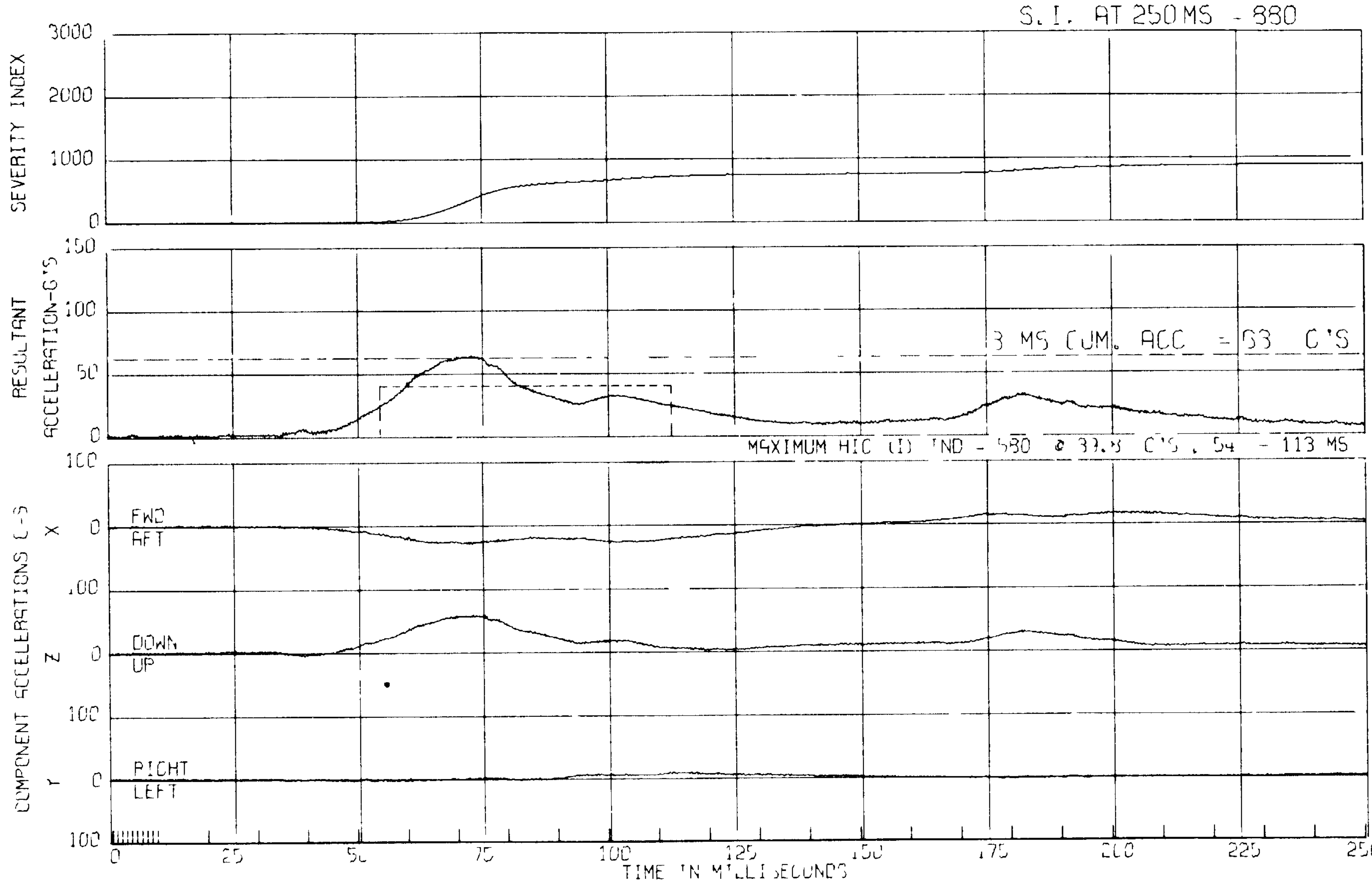
S3905 HARD SEAT HALF SINE
90-200-051
PERFORMANCE VALIDATION
A-D DATA

NHTSA CONTRACT DUMMY NUMBER 05

HEAD ACCELERATION

FIGURE
REPORT PG-

11-15-73



S3905 HARD SEAT HALF SINE
9U-200-051
PERFORMANCE VALIDATION
A-D DATA SAE CLASS 180

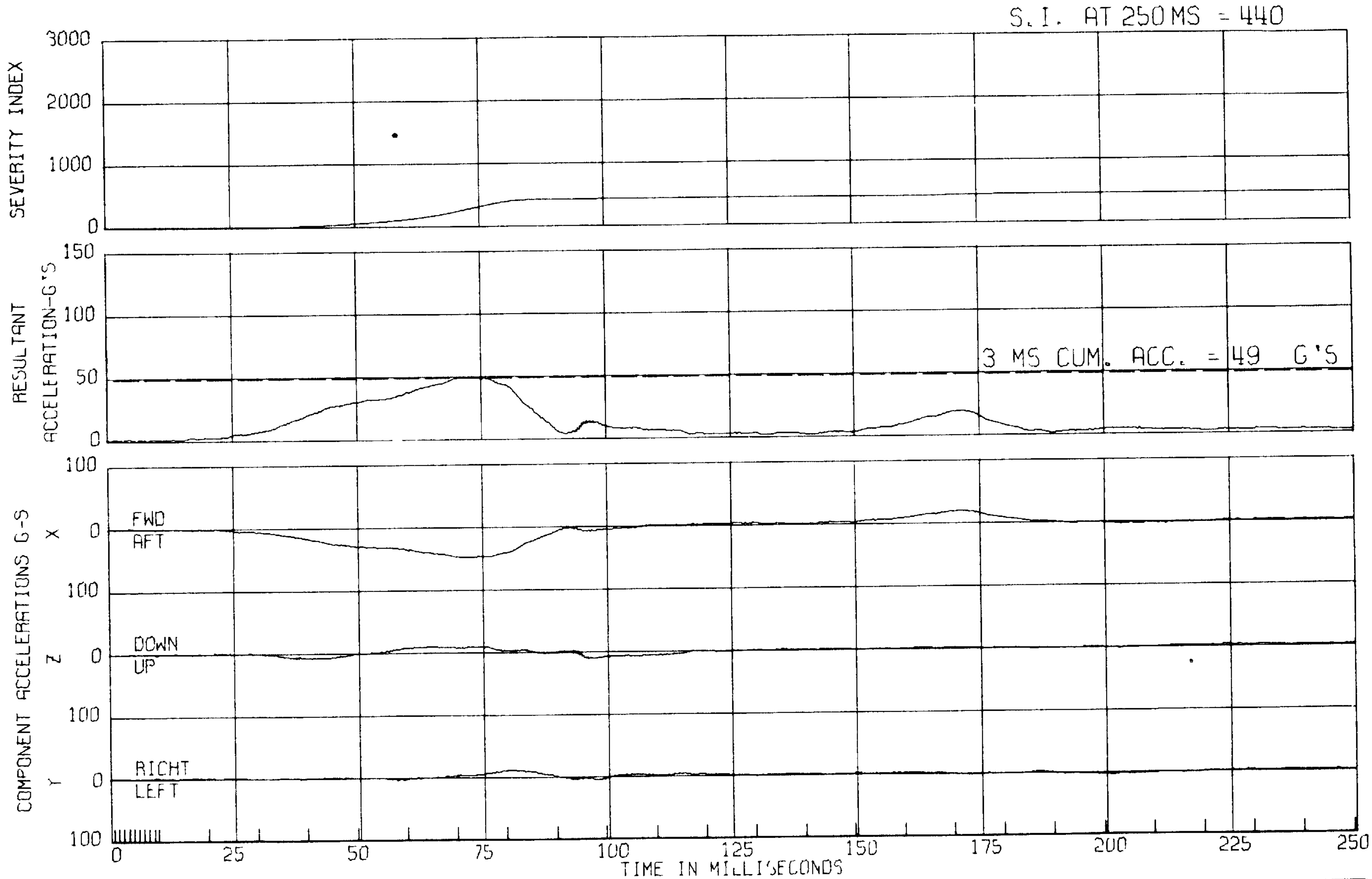
NHTSA CONTRACT DUMMY NUMBER D5

CONTRACT CHEST

CONTRACT CHEST ACCELERATION

FIGURE
REPORT PG-

11-15-73



4

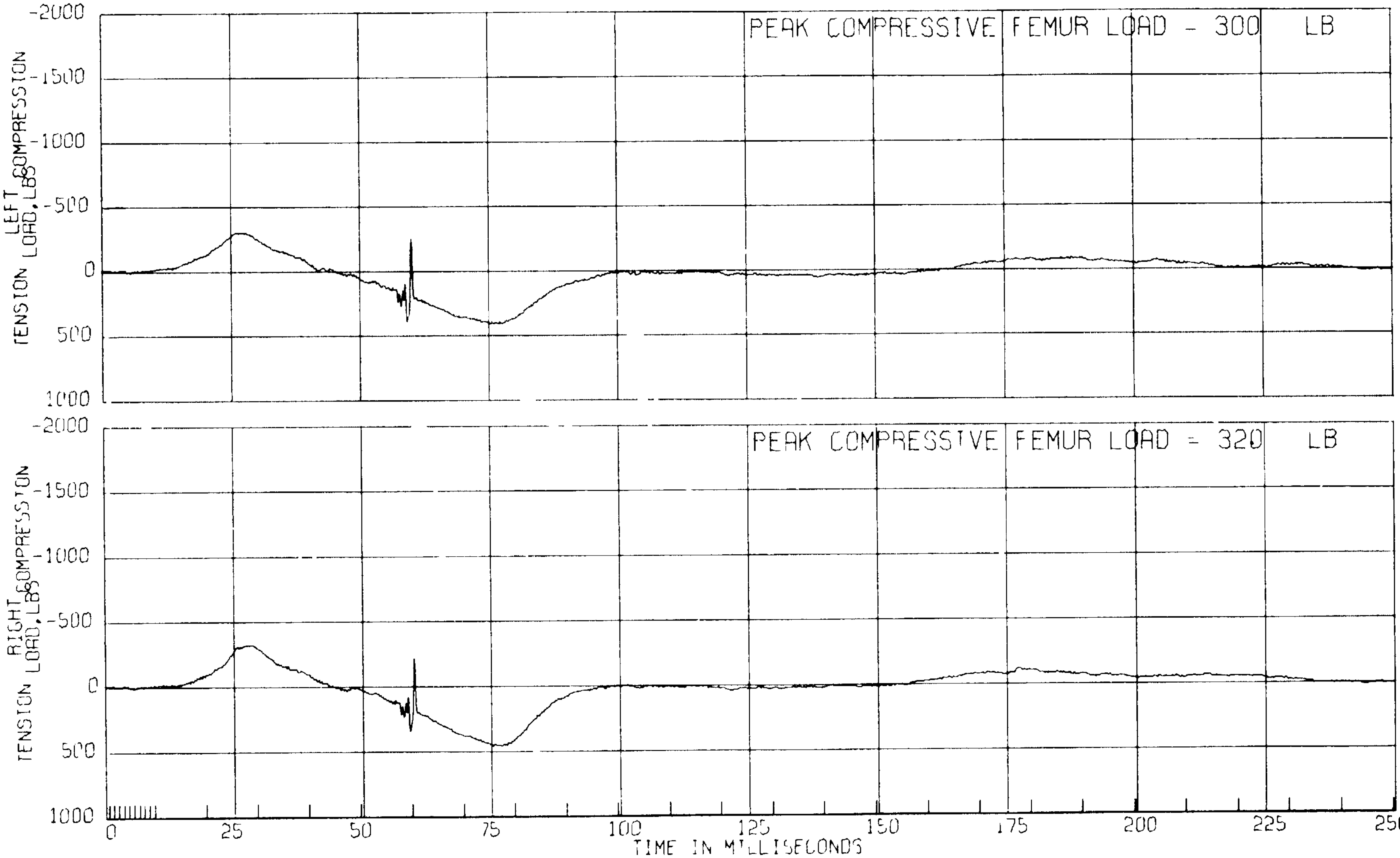
53905 HARD SEAT HALF SINE
90-200-051
PERFORMANCE VALIDATION
A-D DATA SAE CLASS 600

NHTSA CONTRACT DUMMY NUMBER 05

FEMUR LOADS

FIGURE
REPORT PG-

11-15-73



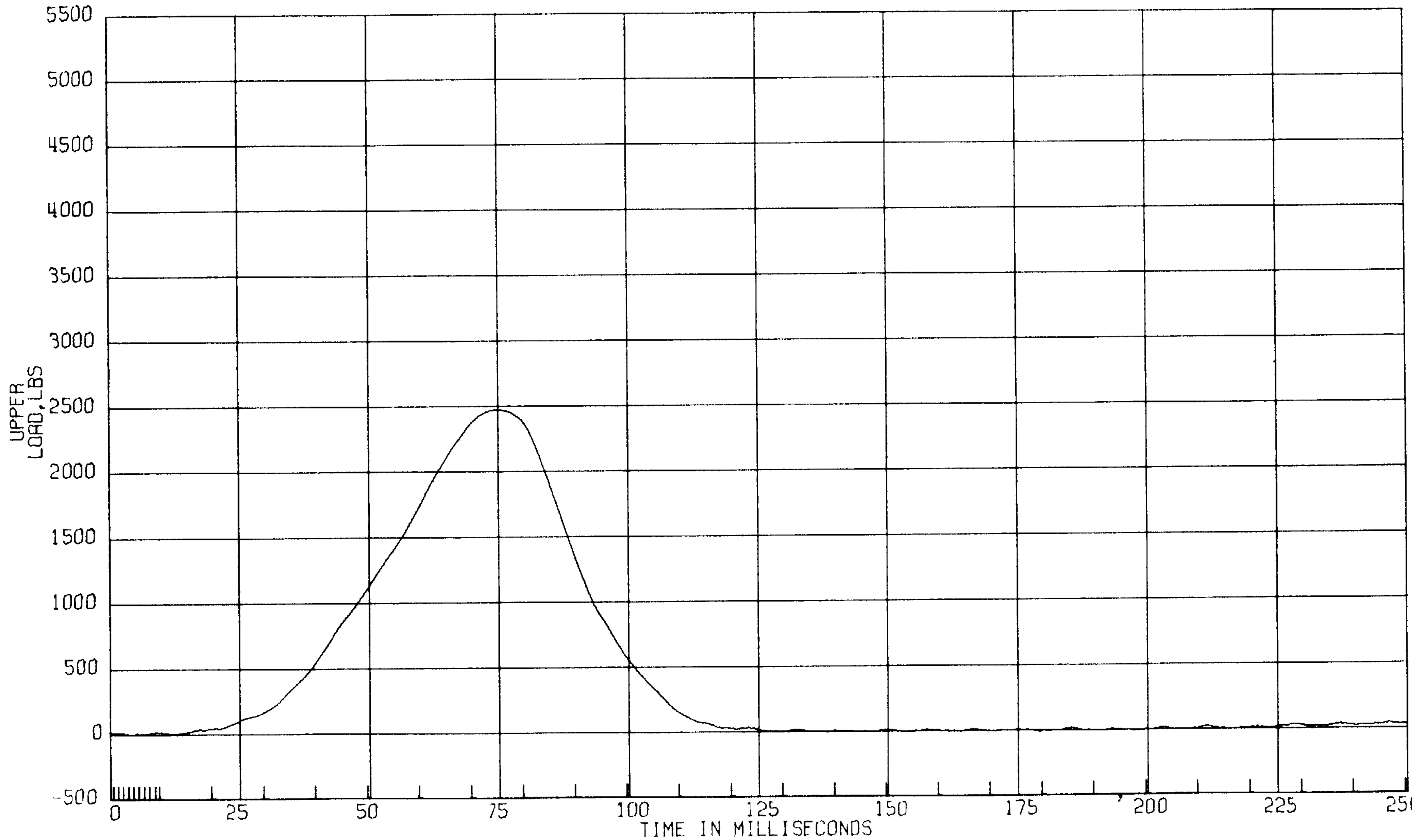
S3905 HARD SEAT HALF SINE
90-200-051
PERFORMANCE VALIDATION
A-D DATA SAE CLASS 60

NHTSA CONTRACT DUMMY NUMBER 05

SHOULDER BELT LOAD

FIGURE
REPORT PG-

11-15-73



7

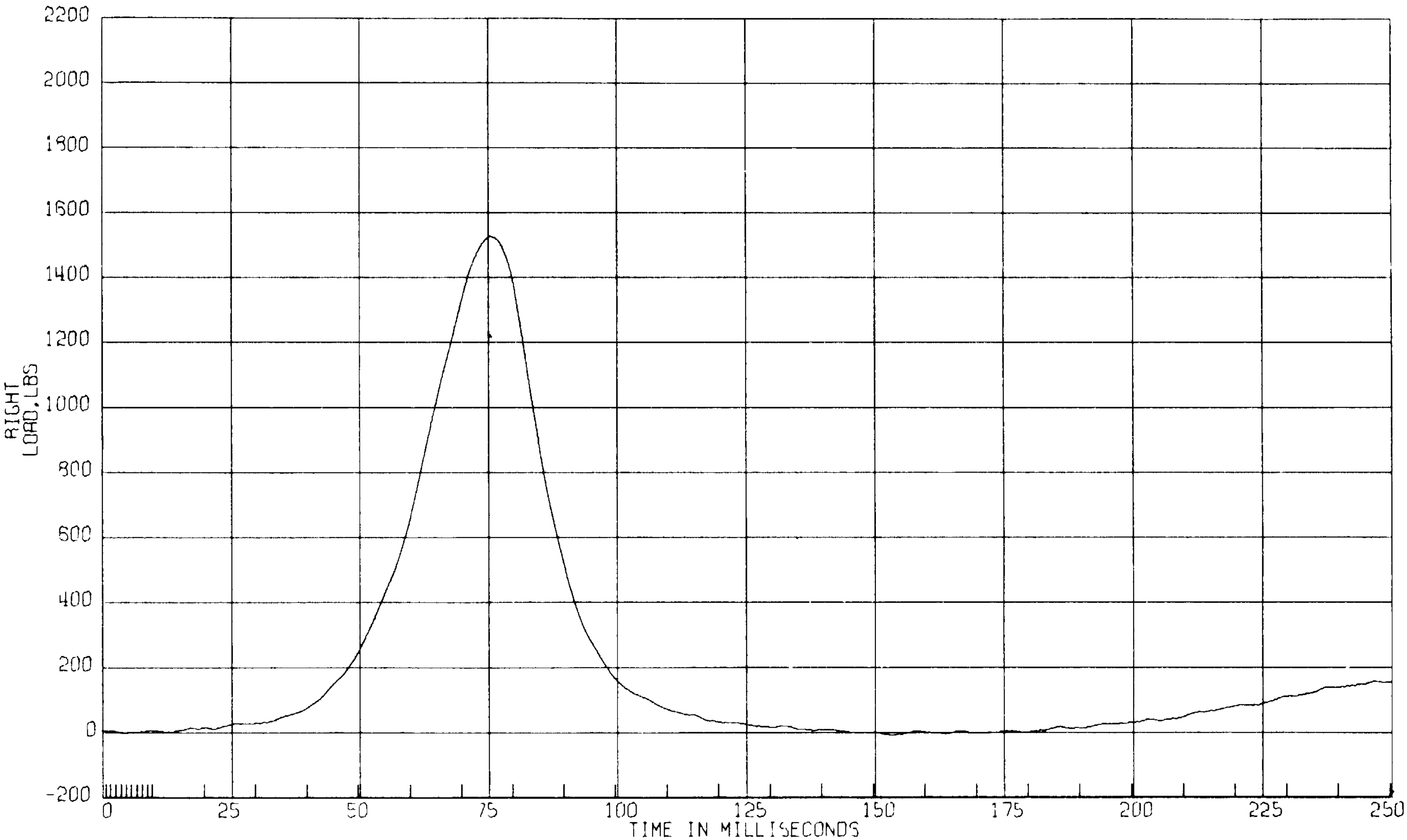
S3905 HARD SEAT HALF SINE
90-200-051
PERFORMANCE VALIDATION
A-D DATA SAE CLASS 60

NHTSA CONTRACT DUMMY NUMBER 05

LAP BELT LOAD

FIGURE
REPORT PG-

11-15-73



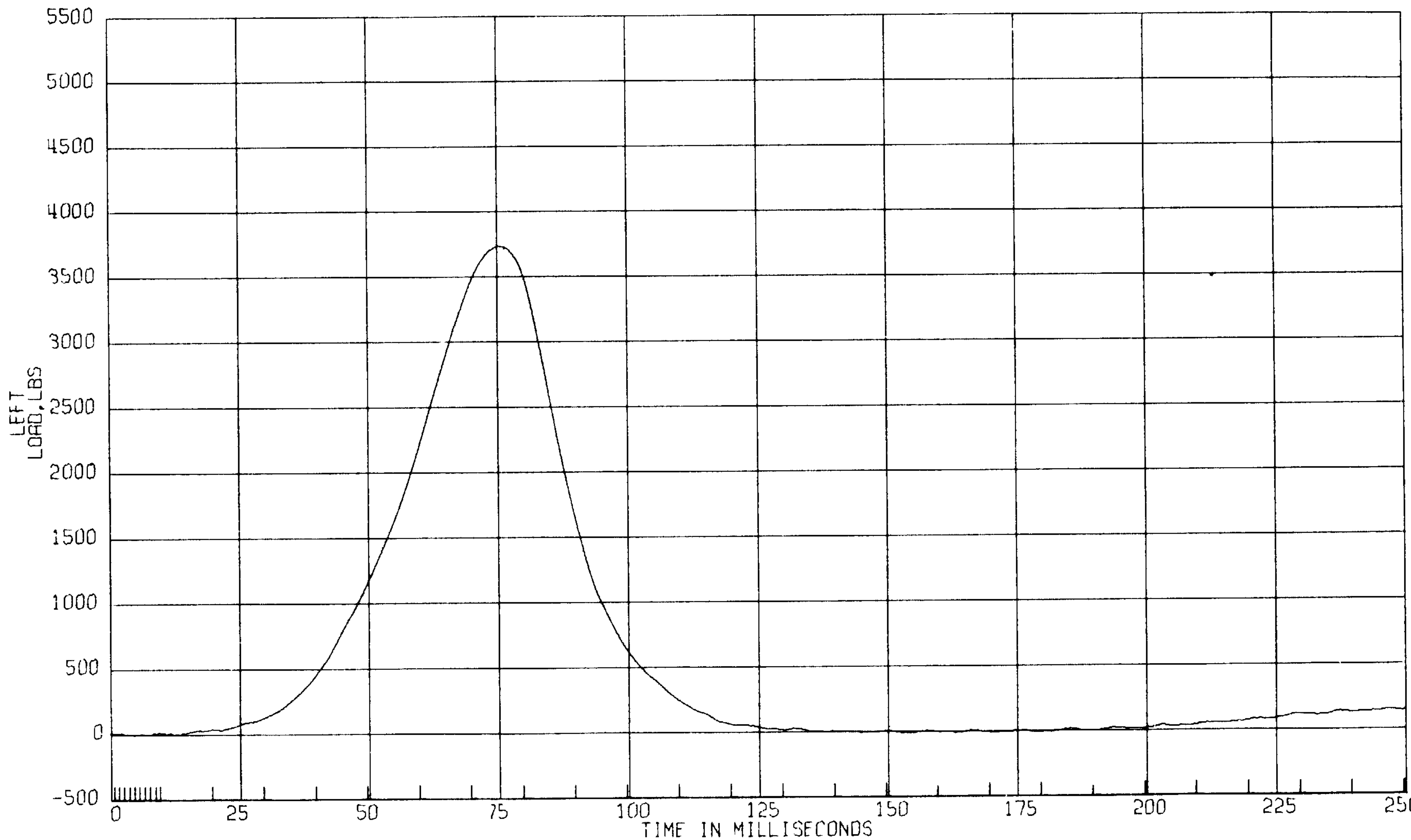
S3905 HARD SEAT HALF SINE
90-200-051
PERFORMANCE VALIDATION
A-D DATA SAE CLASS 60

NHTSA CONTRACT DUMMY NUMBER 05

TONGUE BELT LOAD

FIGURE
REPORT PG-

11-15-73



53305 HARD SEAT HALF SINE
90-200-051
PERFORMANCE VALIDATION,
A-D DATA SAE CLASS 60

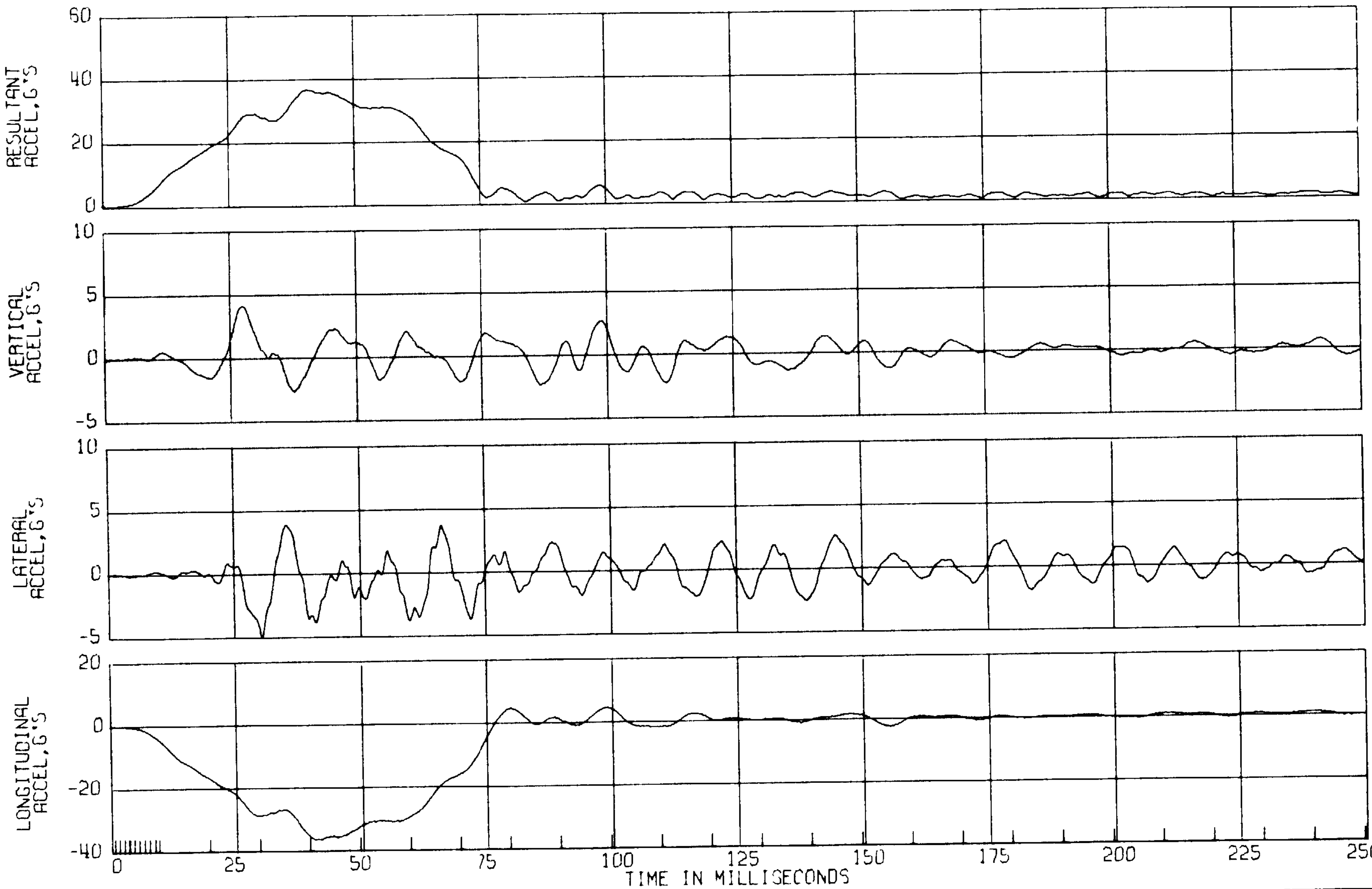
NHTSA CONTRACT DUMMY NUMBER 05

FIXTURE

FIXTURE ACCELERATION

FIGURE
REPORT PC-

11-15-73



APPENDIX 4-A

DUMMY REPEATABILITY

AND

REPRODUCIBILITY

REPEATABILITY AND REPRODUCIBILITY

GM CONTRACT DUMMY DESIGN 1

HEAD AND CHEST RESPONSES

DUMMY NO.	D2			D3			D4			D2, D3, D4		
	$\overline{X}$	S	C.V.	$\overline{X}$	S	C.V.	$\overline{X}$	S	C.V.	$\overline{X}$	S	C.V.
HIC	702	57	8.2	690	48	7.0	737	27	3.7	709	48	6.7
HEAD SI	1068	79	7.4	1055	78	7.4	1136	40	3.5	1086	73	6.8
CHEST SI	571	25	4.3	505	38	7.5	517	34	6.5	531	43	8.0

FEMUR AND BELT LOADS

DUMMY NO.	D2			D3			D4			D2, D3, D4		
	$\overline{X}$	S	C.V.	$\overline{X}$	S	C.V.	$\overline{X}$	S	C.V.	$\overline{X}$	S	C.V.
LEFT FEMUR	207.7	8.8	4.2	206.7	14.6	7.1	241.5	13.7	5.7	218.6	20.4	9.4
RIGHT FEMUR	182.9	18.7	5.9	204.5	16.5	8.1	201.6	23.8	11.8	196.4	19.4	9.9
LAP	1465.5	67.6	4.6	1479.3	37.8	2.6	1557.	84.7	5.4	1470.6	62.6	4.3
SHOULDER	2869.5	89.3	3.1	2826.2	88.0	3.1	2937.5	76.0	2.6	2877.7	97.4	3.2
TORSO	3483.0	63.2	1.8	3429.7	63.5	1.9	3523.2	86.2	2.4	3478.6	77.8	2.2

SLED AND FIXTURE PARAMETERS

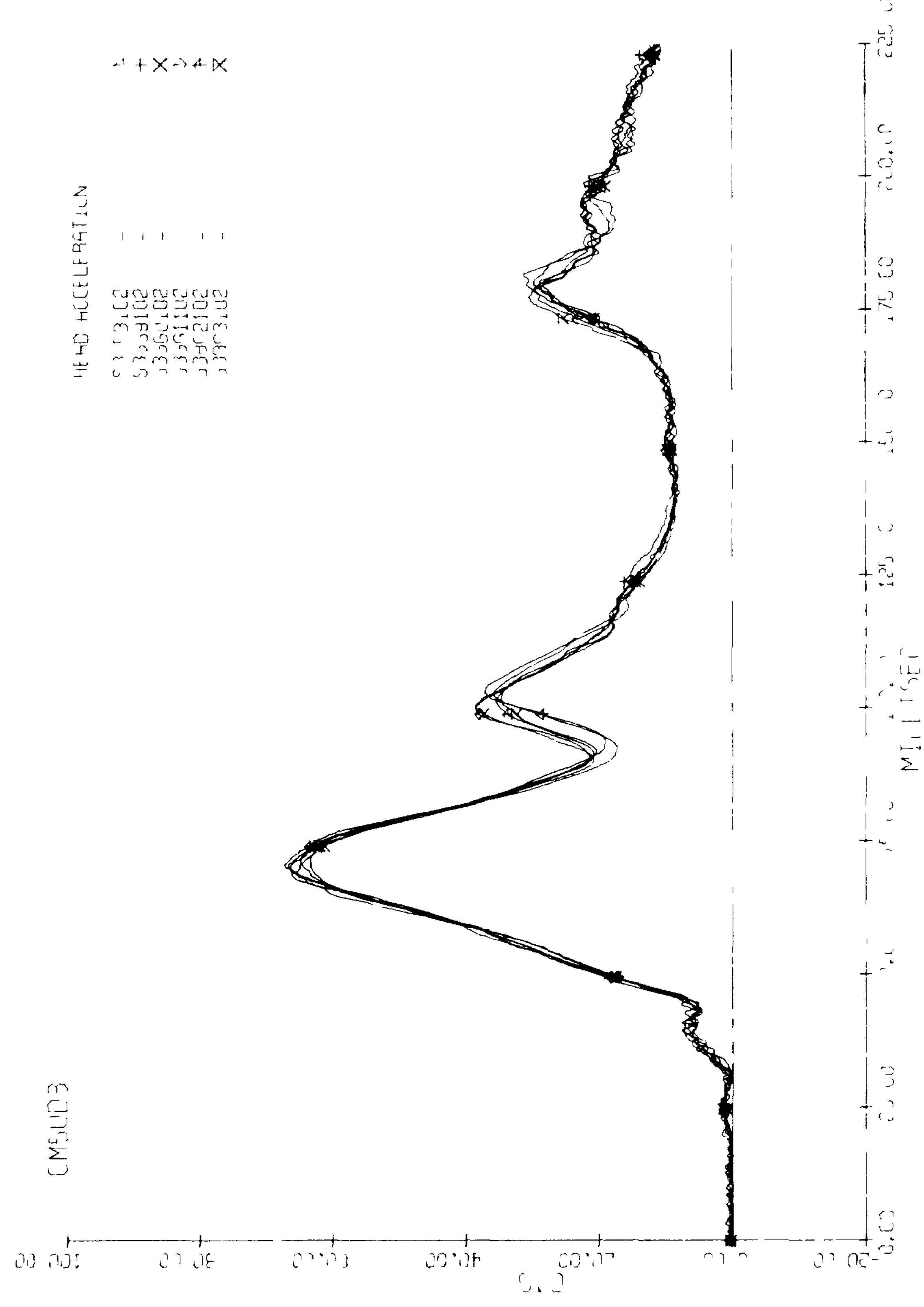
DUMMY NO.	D2			D3			D4			D2, D3, D4		
	$\overline{X}$	S	C.V.	$\overline{X}$	S	C.V.	$\overline{X}$	S	C.V.	$\overline{X}$	S	C.V.
SLED VEL	34.5	.1	.4	34.5	.2	.5	34.5	.1	.3	34.5	.4	.4
FIXT SI	232.2	2.5	1.1	231.4	2.1	.9	230.5	2.1	.9	231.4	2.2	1.0

REPEATABILITY AND REPRODUCIBILITY

GM CONTRACT DUMMY DESIGN 2

HEAD AND CHEST RESPONSES

DUMMY NO.	D2			D3			D2 and D3		
NO. OF TESTS	8			8			16		
	$\overline{X}$	S	C.V.	$\overline{X}$	S	C.V.	$\overline{X}$	S	C.V. *
HIC	619.8	20.1	3.3	588.4	9.7	1.6	604.1	22.3	3.7
HEAD SI	933.5	44.2	4.7	889.1	24.0	2.7	911.3	41.3	4.5
CHEST SI	435.9	19.7	4.5	440.9	17.3	3.9	438.4	18.1	4.1
FEMUR AND BELT LOADS									
LEFT FEMUR	247.2	9.0	3.6	270.1	15.7	5.8	258.6	17.1	6.6
RIGHT FEMUR	241.8	24.9	10.3	253.1	21.4	8.5	247.4	23.2	9.4
LAP	1716.3	42.6	2.5	1751.8	52.8	3.0	1734.0	49.9	2.9
SHOULDER	2557.9	41.6	1.6	2554.0	37.8	1.5	2555.9	38.5	1.5
TORQUE	3358.6	44.4	1.3	3426.5	137.2	4.0	3392.6	104.5	3.1
SLED AND FIXTURE PARAMETERS									
SLED MEAS VEL	34.3	.2	.6	34.3	.1	.3	34.3	.2	.5
FIXTURE SI	231.6	2.9	1.3	230.3	1.5	.7	230.9	2.4	1.0


HEAD ACCELERATION
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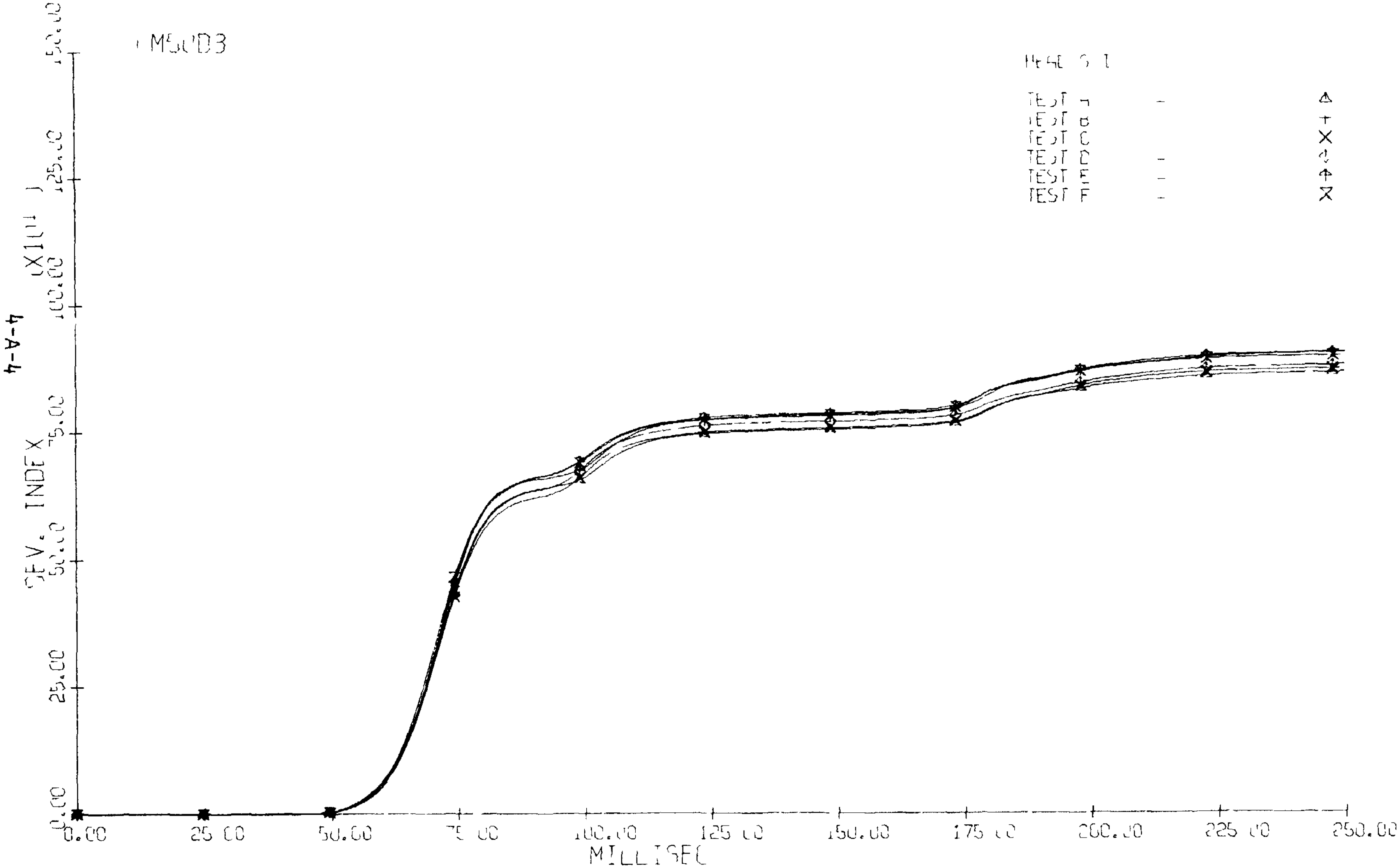
SEV. INDEX
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150.00
MILLISEC
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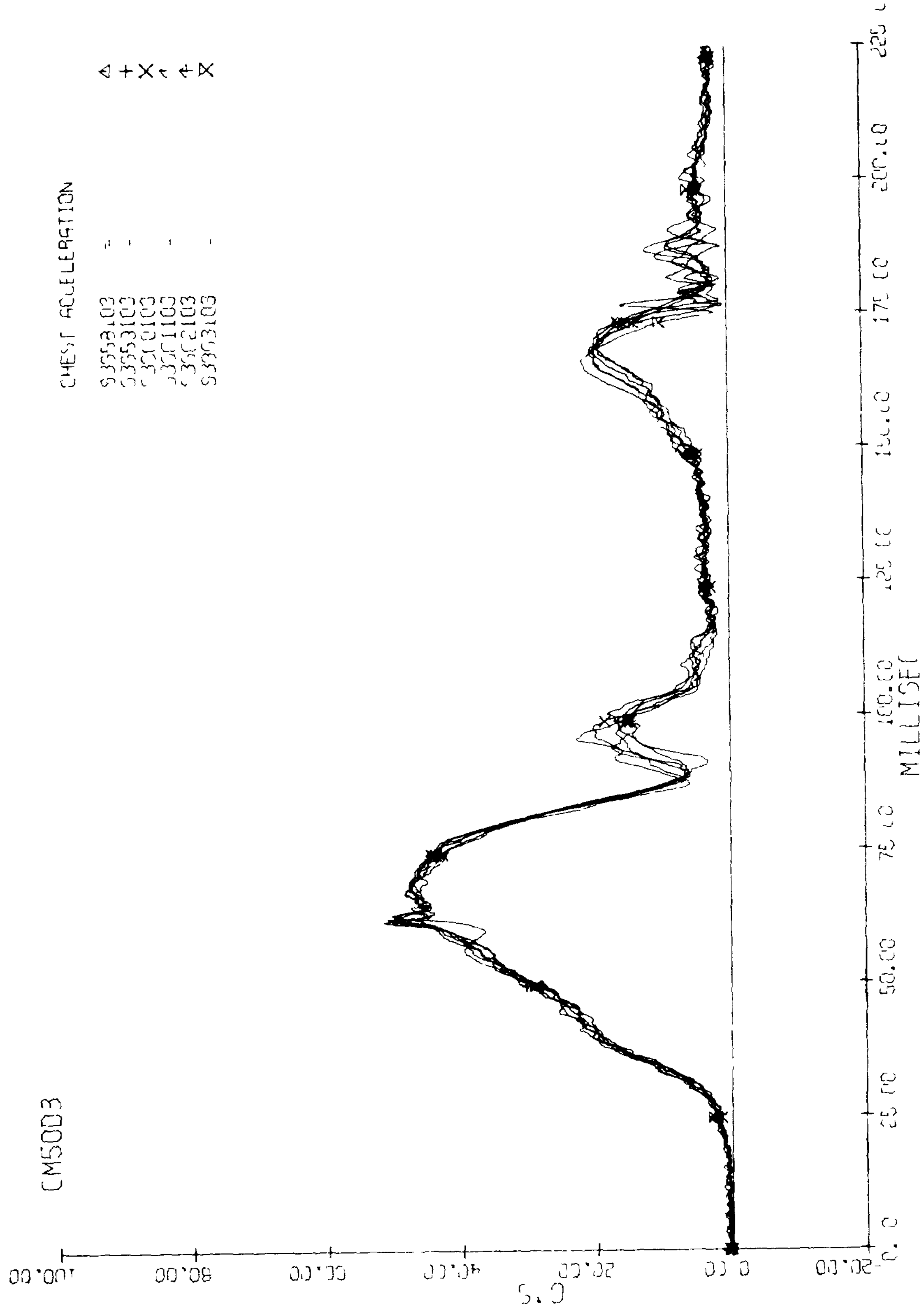
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
225.00
250.00
TEST A
TEST B
TEST C
TEST D
TEST E
TEST F


CM50D3
CHEST ACCELERATION
MILLISEC
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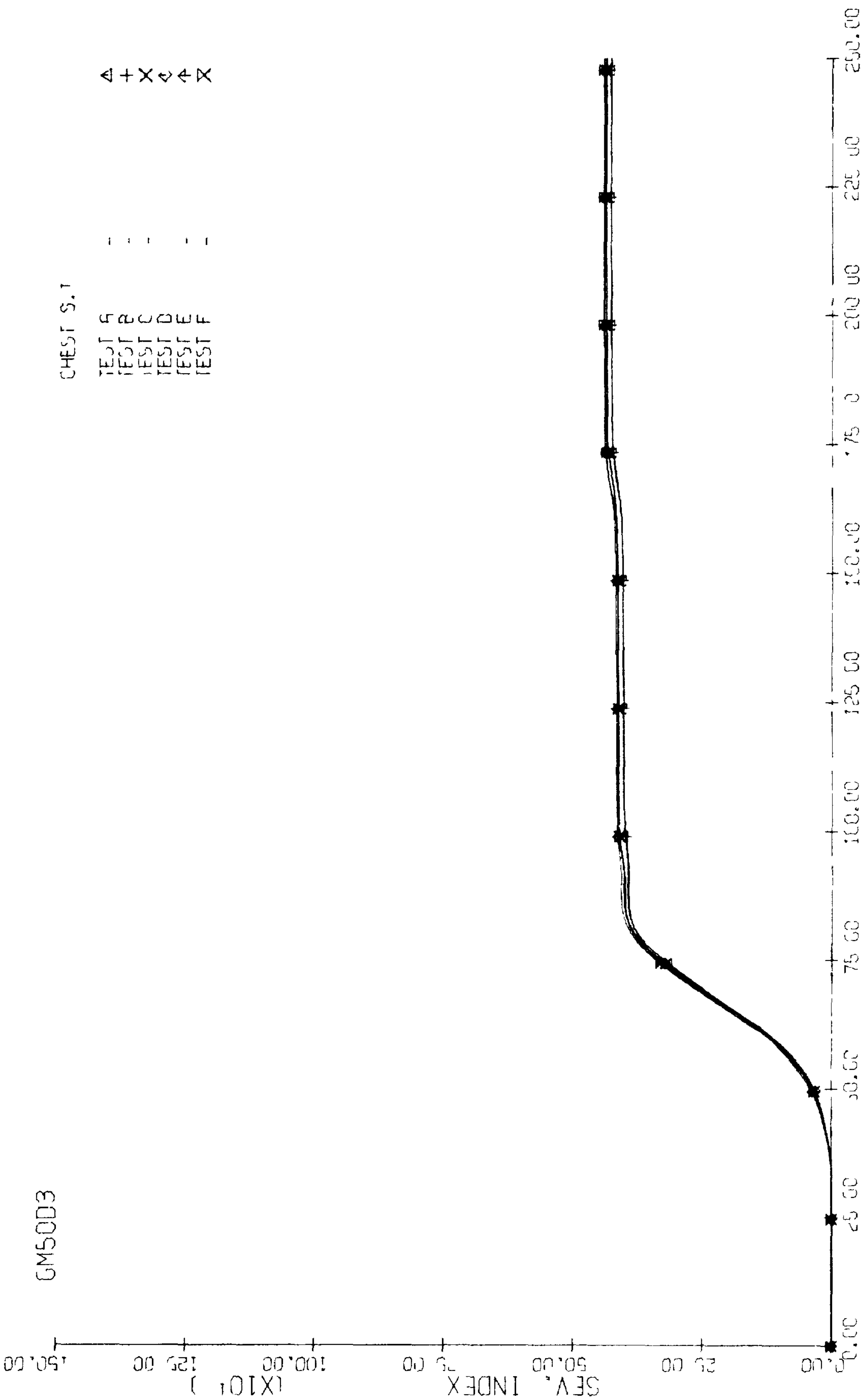
80.00
100.00



GM50D3
CHEST S.I
TEST A
TEST B
TEST C
TEST D
TEST E
TEST F
MILLISEC
SEV. INDEX
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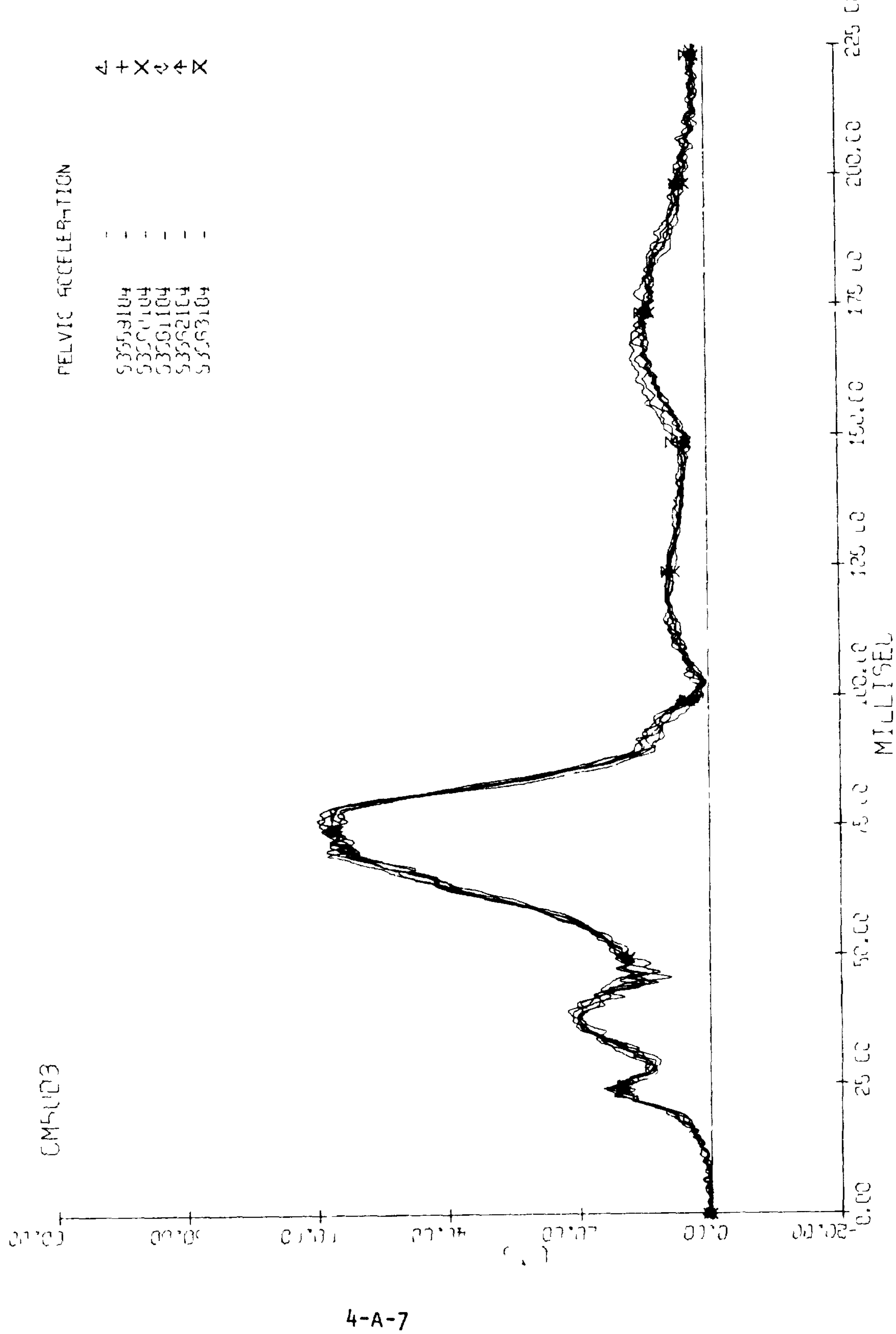
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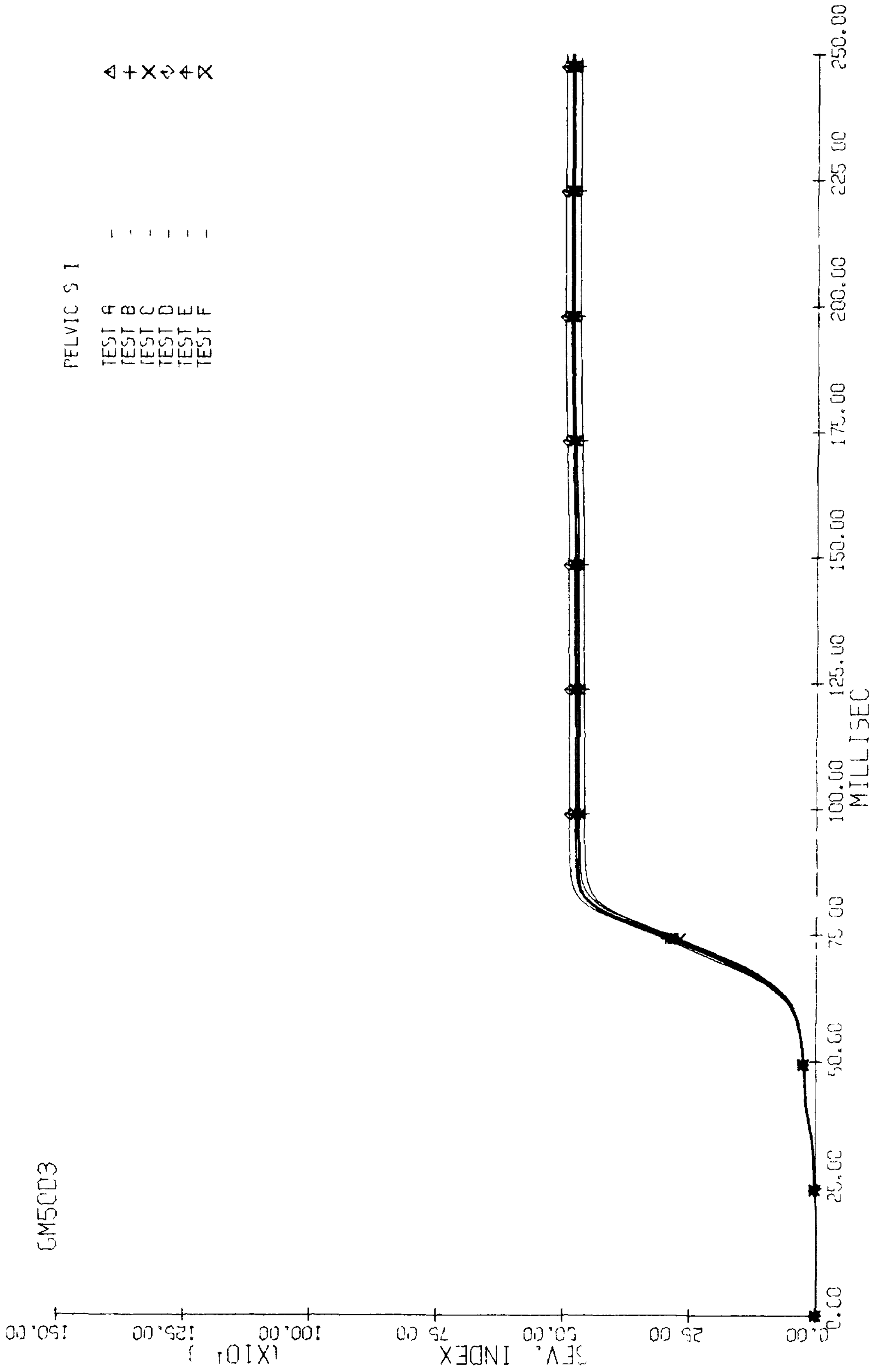
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PELVIC S I
TEST A
TEST B
TEST C
TEST D
TEST E
TEST F
MILLISEC
SEV. INDEX
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200.00
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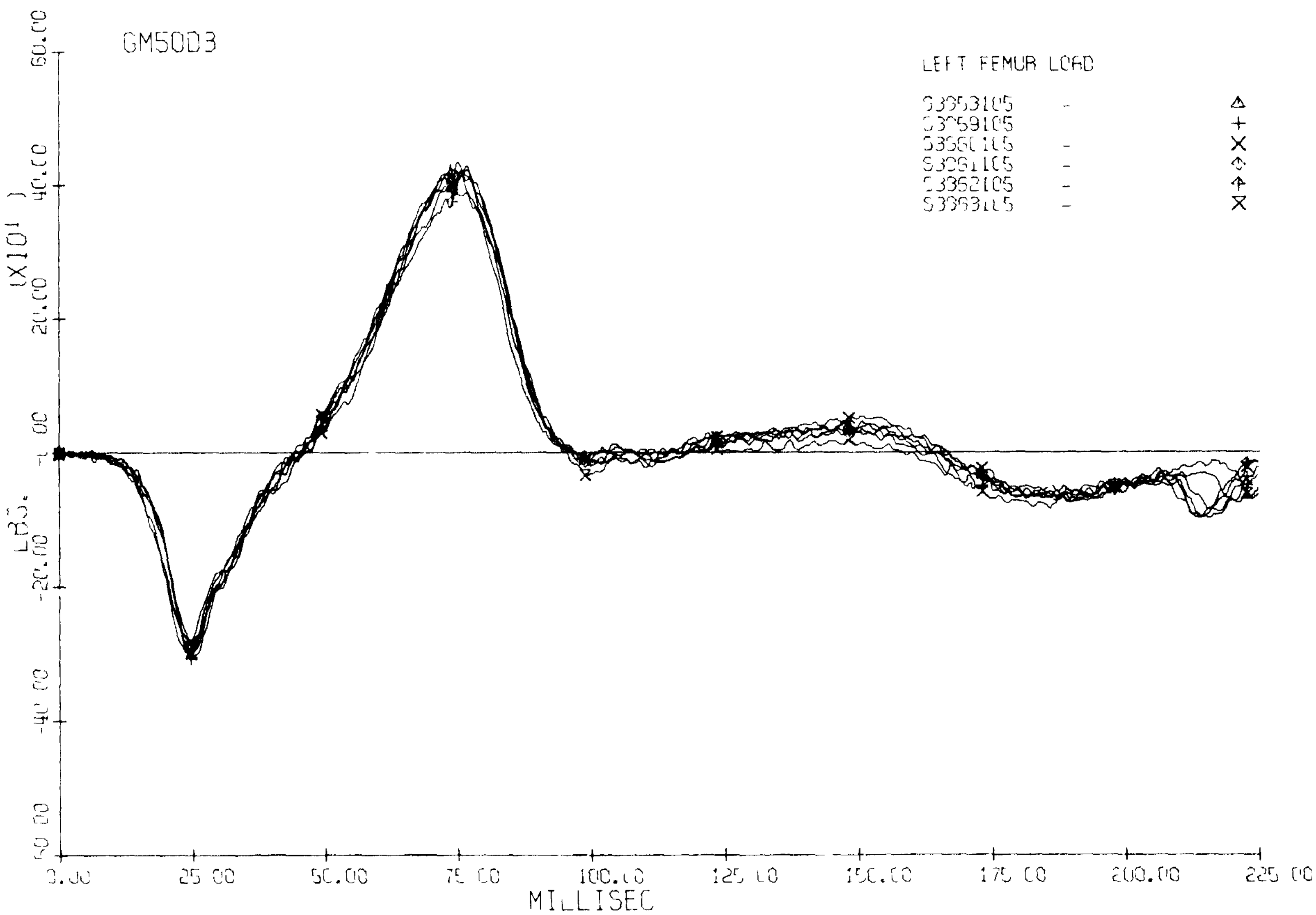
250.00


GM50D3
LEFT FEMUR LOAD
S3358105 - △
S3359105 +
S3360105 - X
S3361105 - ◇
S3362105 - ↑
S3363105 - ⌛
LBS. (X10¹)
60.00
40.00
20.00
0.00
-20.00
-40.00
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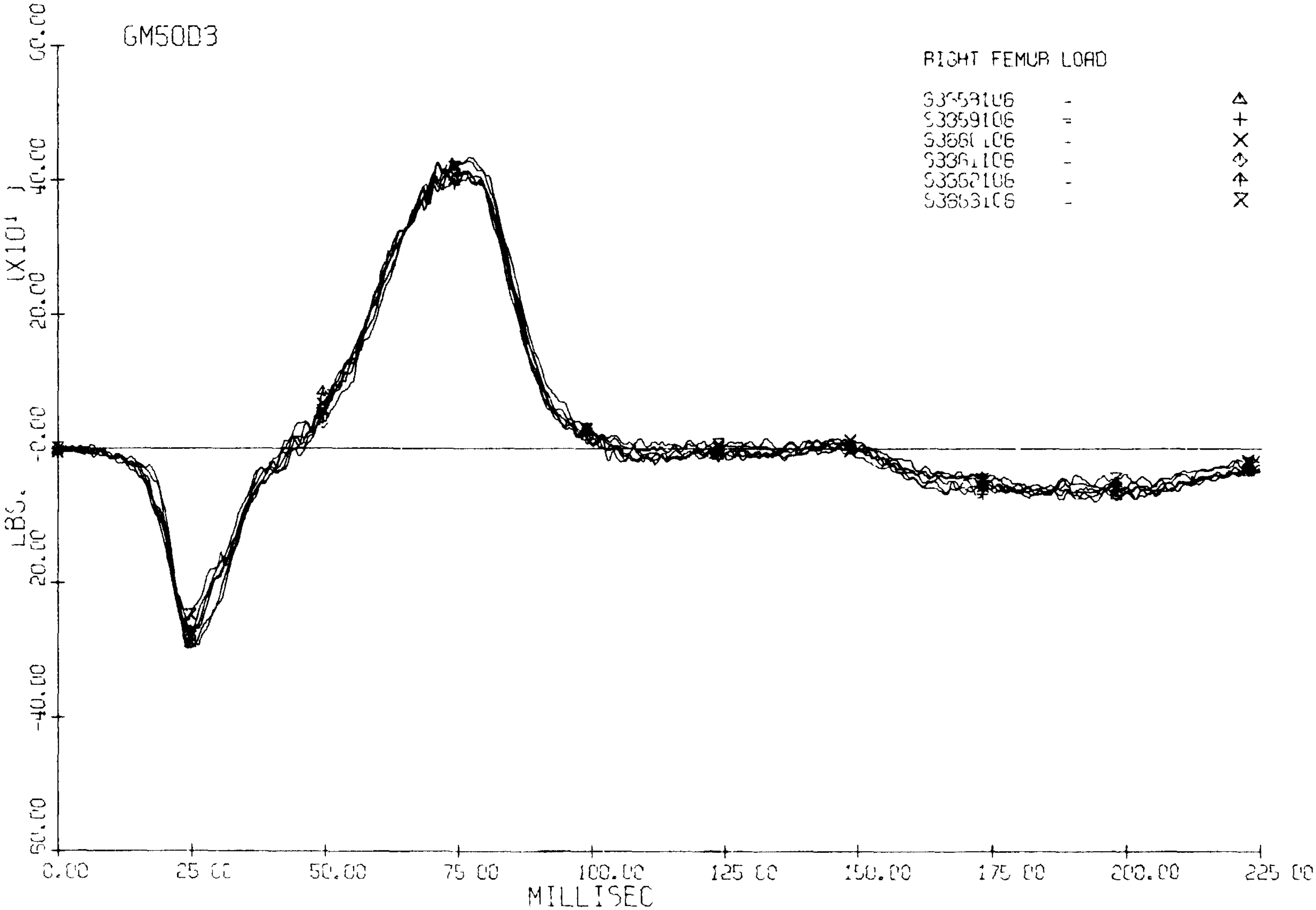
GM50D3
RIGHT FEMUR LOAD
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S3362106
LBS.
(X10¹)
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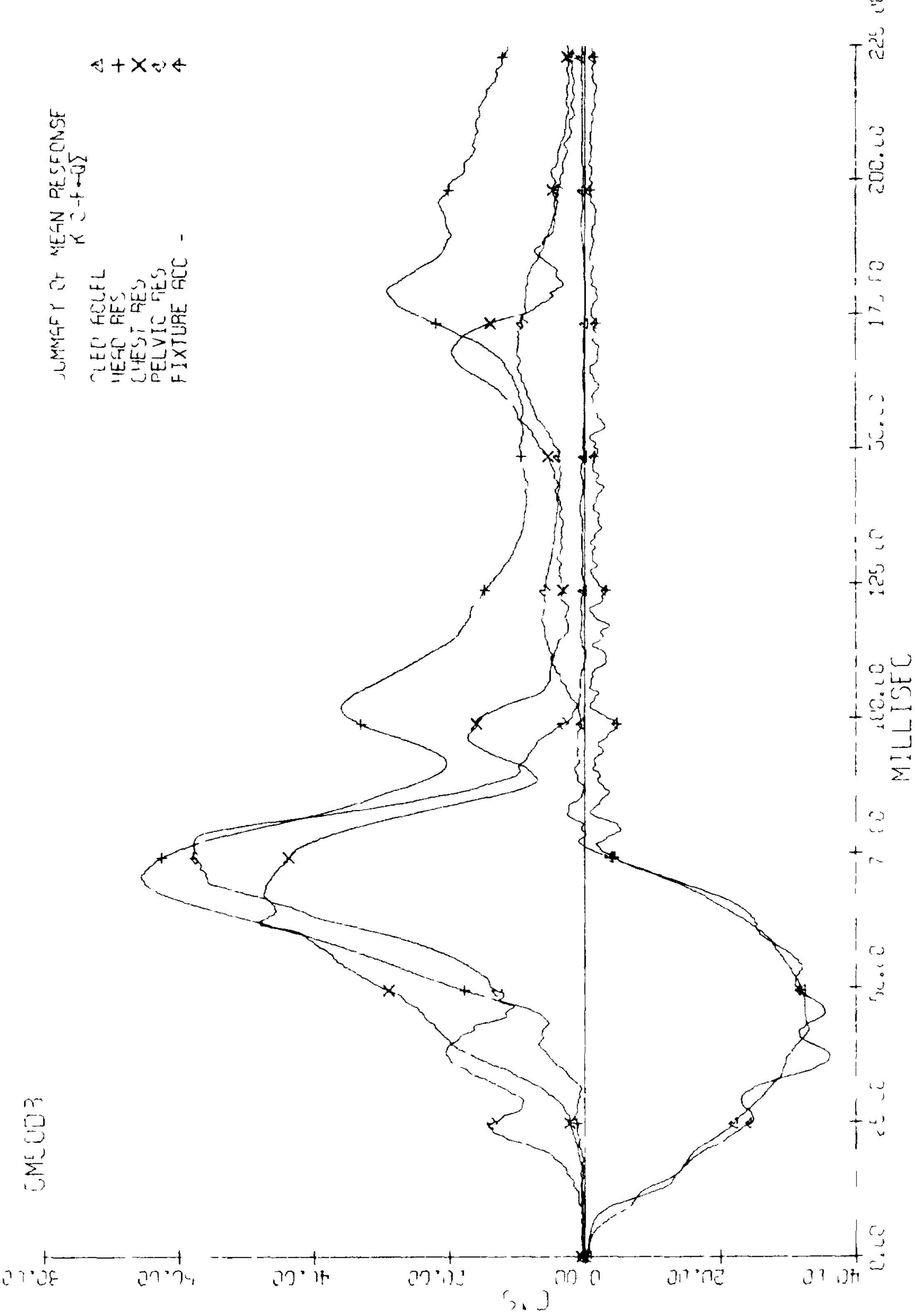
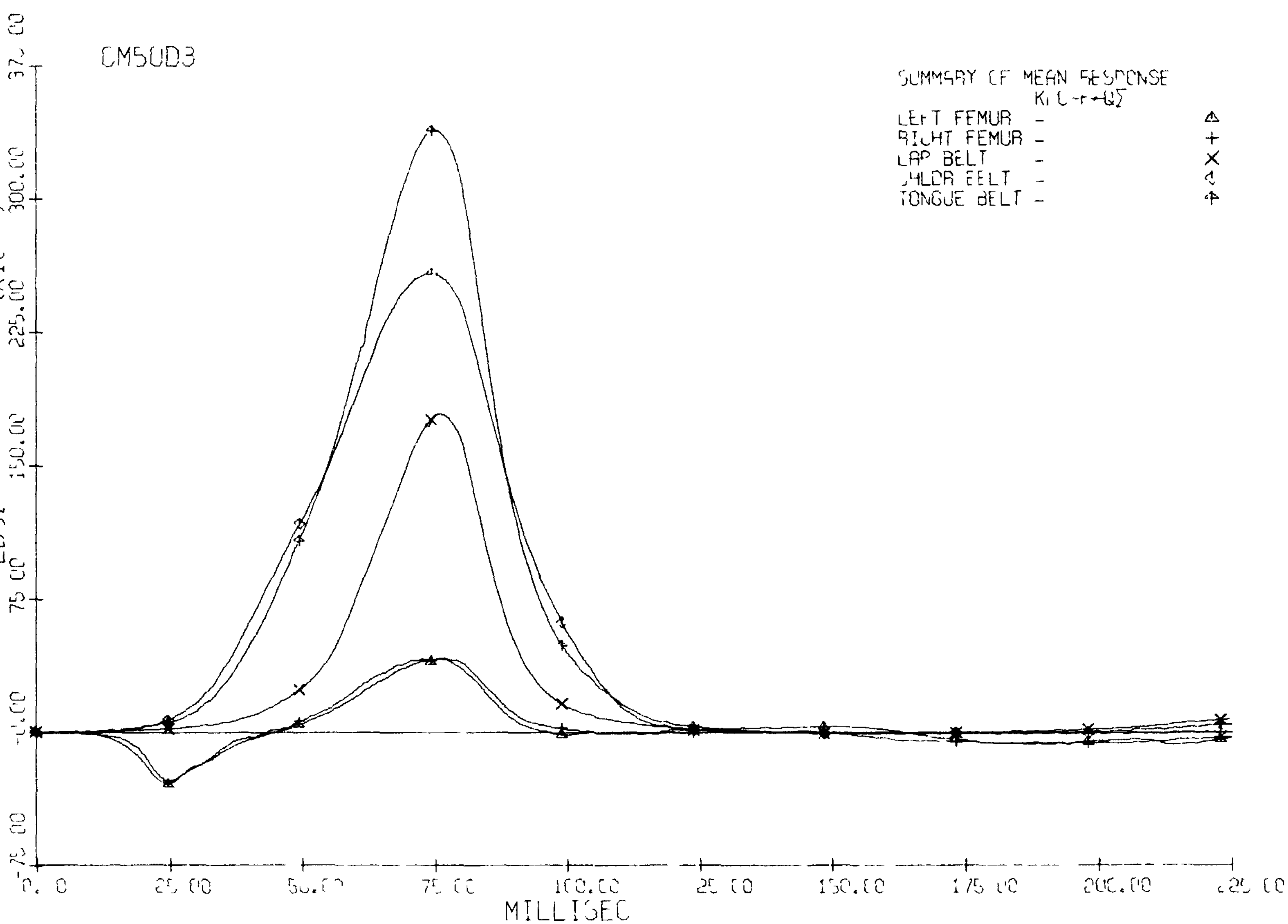
MILLISEC


MEAN
PELVIC
FIXTURE ACC
MILLISEC


CM50D3
SUMMARY OF MEAN RESPONSE
LEFT FEMUR -
RIGHT FEMUR -
LAP BELT -
TONGUE BELT -
LBS.
MILLISEC
0.0
25.00
75.00
100.00
150.00
200.00
75.00
150.00
225.00
300.00

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1. H. J. Mertz, R. E. Heathery, and C. C. Culver, "Performance Requirements and Characteristics of Mechanical Necks", presented and published in the Human Impact Response Symposium held at the General Motors Research Laboratories, Warren, Michigan, October 1972, Plenum Press, New York, 1973.

2. T. E. Lobdell, C. K. Kroell, D. C. Schneider, W. E. Hering and A. M. Nahum, "Impact Response of the Human Thorax", presented and published in the Human Impact Response Symposium held at the General Motors Research Laboratories, Warren, Michigan, October 1972, Plenum Press, New York, 1973.