February 1982
Final Report

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Traffic Safety
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A Systems Analysis Approach to Integrating Restraint Systems Into a Production Ready Small Car

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16. Abstract

This study involved the use of a "system analysis approach" to integrating air bag restraint systems into a "Production Ready Small Car." The term "System Analysis Approach" is used to convey the concept of using high speed digital computer techniques to design and integrate air bag restraint systems into a car that is optimally compatable with its crash environment. The design of a preliminary driver and passenger air bag restraint system using computer techniques is presented. The designs were installed in two test vehicles and subjected to 35 mph and 40 mph barrier tests. The test results are presented.

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METRIC CONVERSION FACTORS

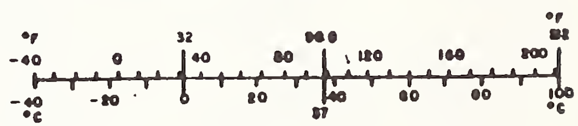
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

This report follows both chronologically and logically a previous report, written by Fitzpatrick Engineering, summarizing the design development and testing of preliminary inflatable restraint systems for the DeLorean sports car.[1] In this previous study, emphasis was placed upon the use of computer simulations and past experience to rapidly converge to a restraint system design that would perform well in the scheduled 35 and 40 mph barrier impact tests. In these tests, only the 50th percentile adult male ATD size was considered for the driver and passenger.

In the current study, additional program objectives were added to extend the scope of the total program. These added objectives included:

1. Use the test data derived in the previous study (for the 35 mph barrier crash) to further validate the computer models "DRACR" and "PAC" for the DeLorean sports car crash environment and restraint systems.
2. Use these validated computer programs to investigate other crash velocities, operating environments, design specifications, occupant sizes, occupant positions, and sensing and/or inflator staging scenarios. This part of the study we called a "parameter sensitivity analysis".

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1 "Systems Analysis Approach to Integrating Air Bags into a production Ready Small Car", Fitzpatrick Engineering, Final Report, Contract No. DTNH22-81-C-07330, November, 1981.

3. Recommend design options and hardware component selection for a total restraint system package that, based upon computer simulations, promises to most optimally meet the combined and sometimes conflicting requirements of the various occupant sizes, occupant positions and crash conditions applicable to the DeLorean sports car.

In the following section, the crash test results for a 36 mph barrier crash of the DeLorean sports car (conducted at Dynamic Science on September 14, 1982)[1] will be compared with computer predicted results.

---

1 Ibid., page 1-1.

2.0 COMPARISON OF PRELIMINARY CRASH TEST RESULTS WITH COMPUTER SIMULATIONS

This section compares the experimental test data from a 36 mph barrier impact test of the DeLorean sports car, with DRACR and PAC computer simulations.

2.1 DRIVER RESTRAINT SYSTEM

2.1.1 Description

The driver restraint system for the subject test consisted of the following components:[1]

- Knee Restraint
- Collapsible E/A Steering Wheel
- Collapsible E/A Steering Column ("locked" against axial collapse for the subject test)
- Air Bag Inflator,Thiokol/Mercedes Part No. IU92520-4
- Sensor
- Air Bag

The knee restraint consisted of aluminum honeycomb (1/4 - 5052-.0007, 45 psi crush strength),"faced" with a 6061-TO aluminum/vinyl cover, and the support structure.

The energy absorbing steering wheel was a 1979 Volvo GT wheel with the spokes stiffened by the addition of .067 inch thick steel straps (one on each spoke).

The energy absorbing steering column was a DeLorean Design with a re-

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[1] "Systems Analysis Approach to Integrating Air Bags into a Production Ready Small Car", Fitzpatrick Engineering, Final Report, Contract No. DTNH22-81-C-07330, Nov. 1981.

inforced steering shaft. In the subject crash test, the column was "locked" so that it would not stroke during impact.

The air bag inflator was an "off-the-shelf" Thiokol/Mercedes gas generator design (Part No. IU 92520-04). This generator is a "driver" type. In the subject test, one generator was used for the driver's bag and two generators (staged 7 msec apart) were used for the passenger bag.

The air bag inflators were activated using a contact switch located on the bumper, acting in series with a built-in electronic delay of approximately 10 milliseconds (from bumper contact until squib ignition).

The air bag was designed by Fitzpatrick Engineering and manufactured by Talley Industries. The bag was made from a neoprene coated nylon material having a density of 8.2 oz/yd^2. The nylon material was type 66, 840 denier. The bag shape was circular (unpressurized) with a diameter of 27.5 inches.

2.1.2 DRACR Computer Model and Assumptions

The DRACR computer model was used to simulate the driver ATD and its restraint system for the subject barrier impact test. The DRACR model represents the driver occupant as a three segment "linkage" having finite width but no thickness. The segments of the "linkage" consist of the head, torso and lower body masses. In DRACR, the interaction of the torso and head masses with the ACRS bag envelope is visualized as a two-dimensional plane intersecting a three-dimensional ellipsoidal volume. The bag volume is supported by steering wheel and steering column mass elements which are free to translate and rotate in space. Figure 2-1 illustrates the DRACR model.

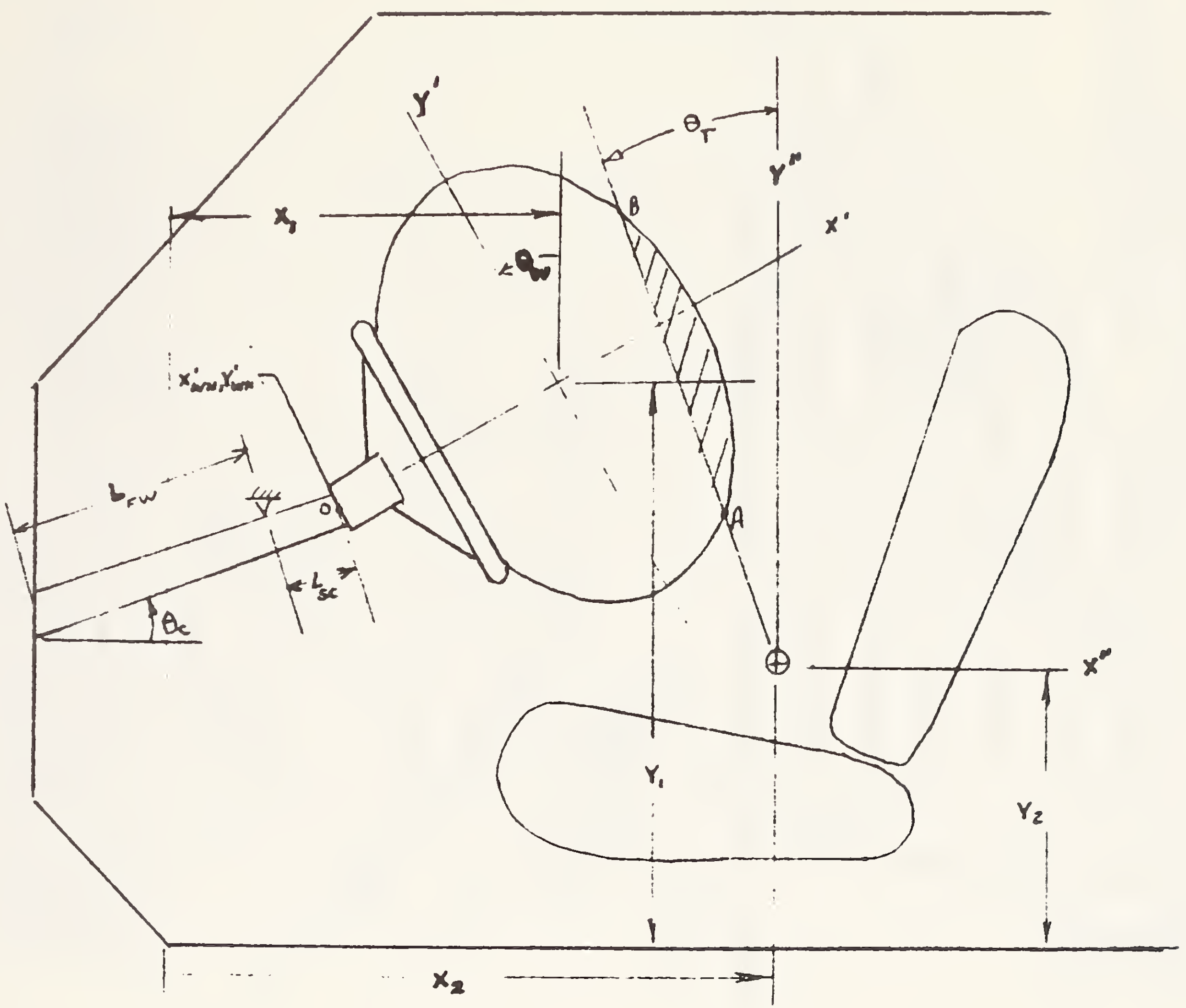


Figure 2-1. Compartment, Bag and Driver Coordinate Systems, DRACR.

In this study, the two-dimensional plane represents the mid-plane of the driver occupant. To compensate for the "flesh thickness", the "H" point of the occupant is moved forward a distance L_{flesh} as shown in Figure 2-2.

DRACR/PAC Occupant - Geometry and Mass Characteristics

The DRACR/PAC Occupant is illustrated in Figure 2-3. Its geometry and mass characteristics are based on the data presented in SAE J963, for a 50th percentile adult male ATD.[1] The following geometrical parameters are required in the DRACR/PAC models:

- R_H = Distance from Neck Pivot to Head c.g.
- R_N = Distance from "H" pt. to Neck Pivot
- R_T = Distance from "H" pt. to Torso c.g.
- RTOPH = Distance from "H" pt. to Top of Head (when $\theta_{Head} = \theta_{Torso}$)

These parameters were calculated for the 50th percentile adult male ATD, as follows:

1. Calculate R_H

From the study of Haffner and Cohen[1],

- M_{head} = 13.45 lbm
- $I_{neck_{pivot}}$ = 1.5 lbf-in-sec^2

Thus,

$$I_{neck_{pivot}} = M_{head} R_H^2 = 1.5$$

$$R_H = \sqrt{I_{neck_{pivot}} / M_{head}}$$

[1] In a study by Haffner and Cohen, "Mechanical Simulation of Head-Neck Response" (p. 301), head masses to 13.5 lbm were noted. This is significantly heavier than the 11.2 lbm noted in SAE J963. Several computer runs were conducted in this study to evaluate the effects of head mass on head acceleration and HIC.

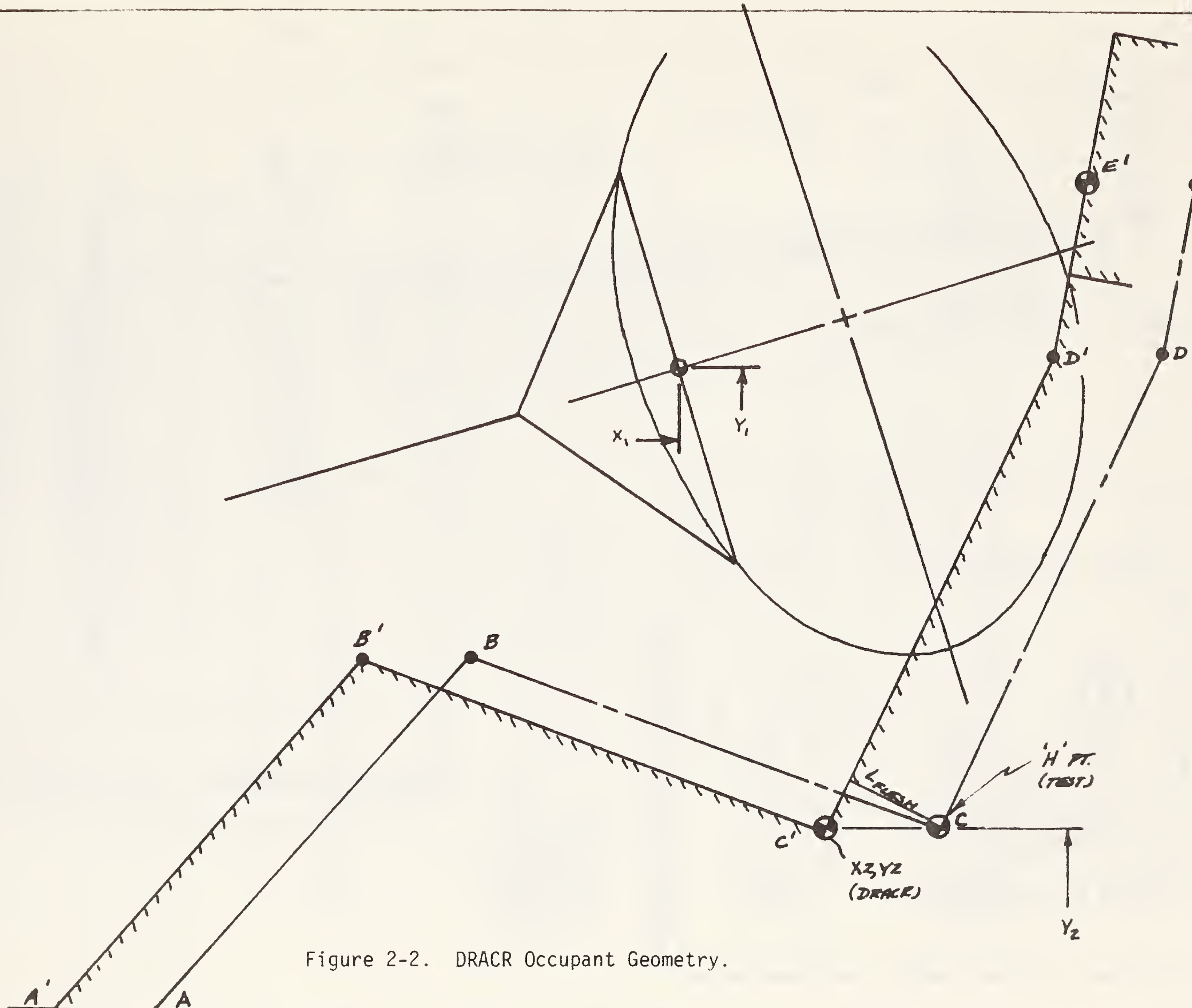


Figure 2-2. DRACR Occupant Geometry.

SEGMENT WEIGHTS (50th % Male)	
1. Head	11.2 lbs.
2. Shoulders & Up. Thorax ...	17.3
3. Low. Thorax & Up. Abdom...	23.0
4. Low. Abdom., Buttocks & Up. Thighs	37.5
5. Up. Arm (each)	5.4
6. Forearm (each)	3.4
7. Hand (each)	1.4
8. Upper Leg (each)	17.6
9. Lower Leg (each)	6.9
10. Foot (each)	2.8
Total	164.0 lbs.

DRACR/PAC WEIGHTS	
1. Head	11.2 lbs.
2. Torso (2+3+2*5+2*6)	57.9
3. Hip Mass (4+2*8)	72.7
Total	141.8 lbs.

Ref: SAE Technical Report J963

RH = 6.5"
RT = 13.7"
RN = 19.1"
RTOPH = 27.2"
L_{Flesh} = 3.7"

W_H = 7.0"
W_B = 15.0"

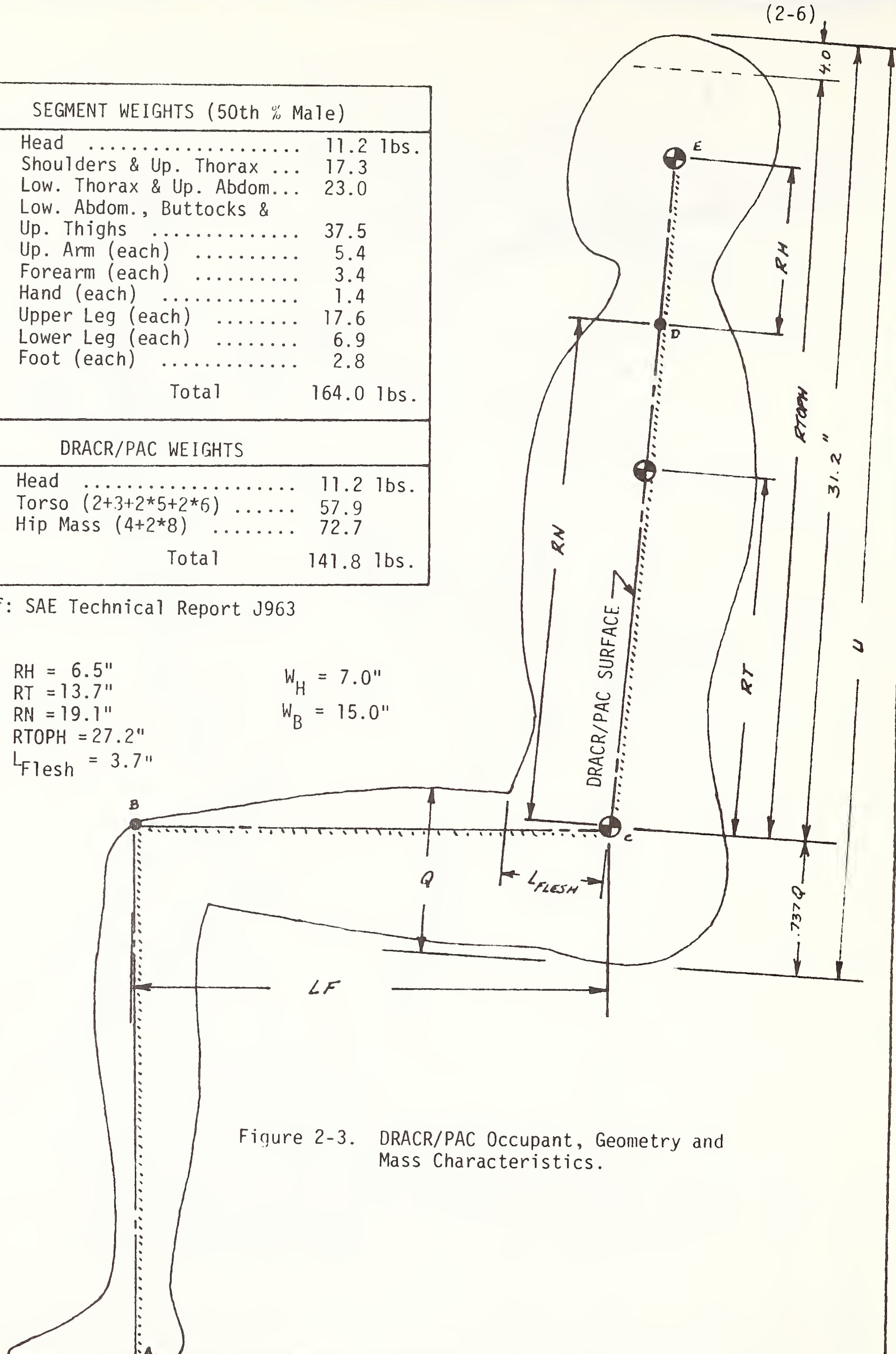


Figure 2-3. DRACR/PAC Occupant, Geometry and Mass Characteristics.

R_H = 1.5(386.4)/13.45

= 6.5 in

2. Determine R_N

The parameter R_N was determined from the geometry data in SAE J963.[1] It is assumed here that the neck pivot point is at the shoulders. Thus, using the nomenclature in Appendix A:

R_N = I + J - (U-H)

= 14.1 + 9.5 -(35.7-31.2)

= 19.1 in

3. Calculate R_T

The parameter R_T was calculated from the geometry data in SAE J963. Figure 2-4 summarizes the data used. In determining the torso c.g., it was assumed that the torso mass is comprised of two parts, an upper part (M_{T_1}) and a lower part (M_{T_2}). The upper part consists of the shoulders, upper thorax and 1/2 of the upper arms. Thus,

M_{T_1} = 17.3 + 1/2(2)(5.4)

= 22.7 lbs

The lower torso mass (M_{T_2}) is comprised of the lower thorax and upper abdomen with a combined weight of,

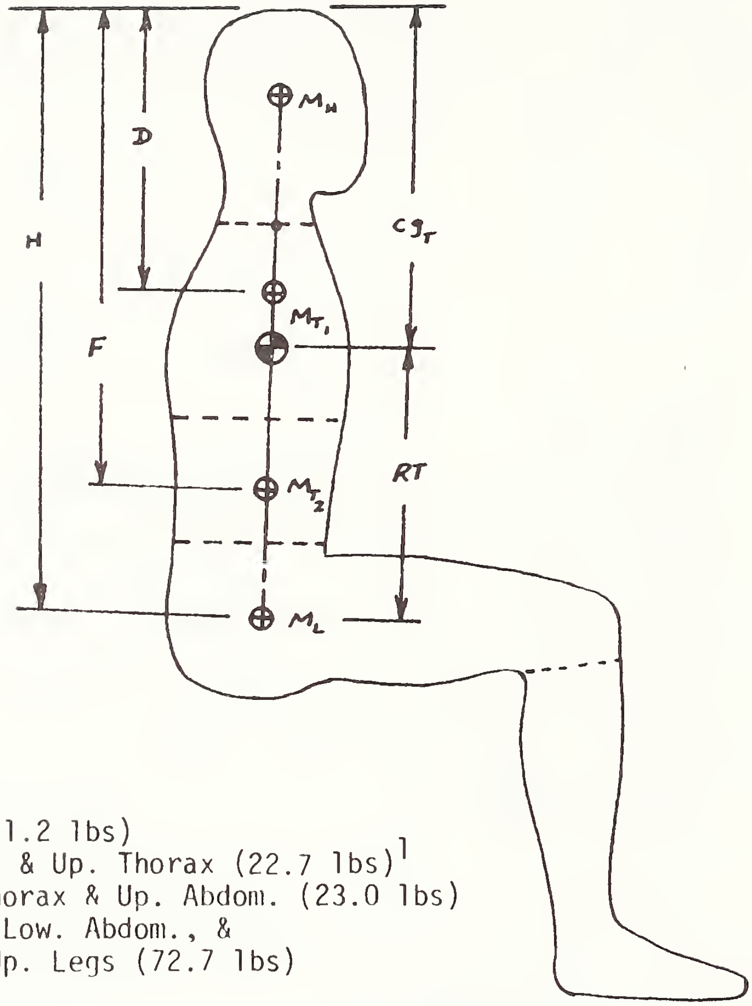
M_{T_2} = 23.0 lbs

R_T is calculated as follows (see Figure 2-4):

$cg_T = (M_{T_1} \cdot D + M_{T_2} \cdot F)/(M_{T_1}+M_{T_2})$

= (22.7(14.1) + 23.0(20.8))/(22.7+23.0)

[1] See Appendix A for nomenclature.



M_H = Wt. of Head (11.2 lbs)
M_{T1} = Wt. of Should. & Up. Thorax (22.7 lbs)[1]
M_{T2} = Wt. of Low. Thorax & Up. Abdom. (23.0 lbs)
M_L = Wt. of Butt., Low. Abdom., & Up. Thighs + Up. Legs (72.7 lbs)

H = 31.2 in.
D = 14.1 in.
F = 20.8 in.

* Ref: SAE J963

1 Includes 1/2 up. arm mass (5.4 lbs)

Figure 2-4. C.G. Vertical Locations of Body Masses.

Thus,

$$cg_T = 17.47 \text{ in}$$

Relative to the "H" point,

$$R_T = H - cg_T$$
$$= 31.2 - 17.47$$
$$= \underline{13.7} \text{ in}$$

The effective mass of the torso was assumed to be equal to,

$$M^1_{T_{eff}} = M_{T_1} + M_{T_2} + 1/2 M_{Arm_{up}} + M_{Forearm}$$
$$= 22.7 + 23.0 + 5.4 + 6.8$$
$$= \underline{57.9} \text{ lbs}$$

ACRS Bag Pumping Performance

The DRACR and PAC computer models include the thermodynamic equations governing bag pumping, venting and those processes associated with "working" the bag. Both DRACR and PAC require as input the following data:

- Mass flow rate history of inflator(s)
- Stagnation temperature of gas entering the bag
- Universal gas constant
- Polytropic gas exponent for flow, compression and expansion
- Atmospheric pressure

The inflator mass flow rate history was determined from tank test data, provided by Thiokol. Figure 2-5 shows the inflator characteristics assumed for the DRACR and PAC simulations. Appendices B and C list the thermodynamic

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[1] I.e., it is assumed that c.g. of ($1/2\ M_{Arm_{up}} + M_{Forearm}$) is located at $R_T = 13.7$ in.

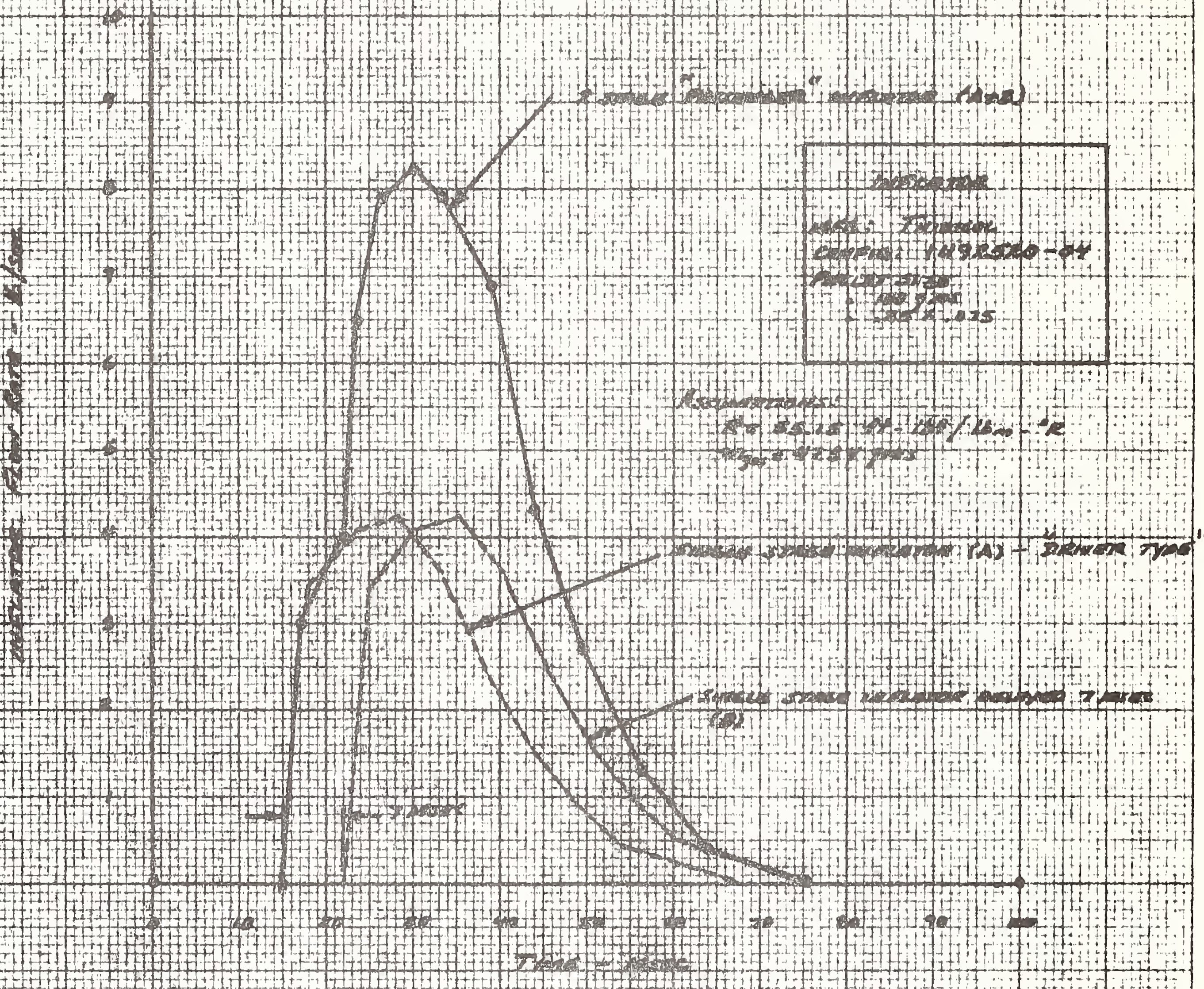


Figure 2-5. Air Bag Inflator Mass Flow Rate Characteristics.

input data used in the simulations.

Steering Wheel Axial and Rotational Crush Characteristics

The assumed axial crush characteristics of the steering wheel are shown in Figure 2-6. It was assumed that the steering wheel was "locked" against rotation (relative to column) since little wheel rotation occurred during the actual test.

Steering Column Axial and Rotational Crush Characteristics

In the subject crash test, the column was not allowed to stroke. Therefore, arbitrarily high stroking resistance values were assumed for the DRACR simulations.

Regarding column rotation, test data indicate a maximum column rotation of approximately 10 degrees. It is believed that this rotation occurred after the dummy's head/torso contacted the steering wheel rim (approximately 75 msec into the crash event). Therefore, in the DRACR simulations it was assumed that the column was fixed against rotation (simulation applicable for the 0-75 msec time frame).

Neck Resistance

The assumed neck resistance for the DRACR/PAC simulations is shown if Figure 2-7.

Seat Friction and Knee Restraint Crush Resistance

Figure 2-8 shows the assumed characteristics for seat friction. A "trial-and-error" procedure was used to determine the knee restraint characteristics, also shown in Figure 2-8. In this procedure, knee

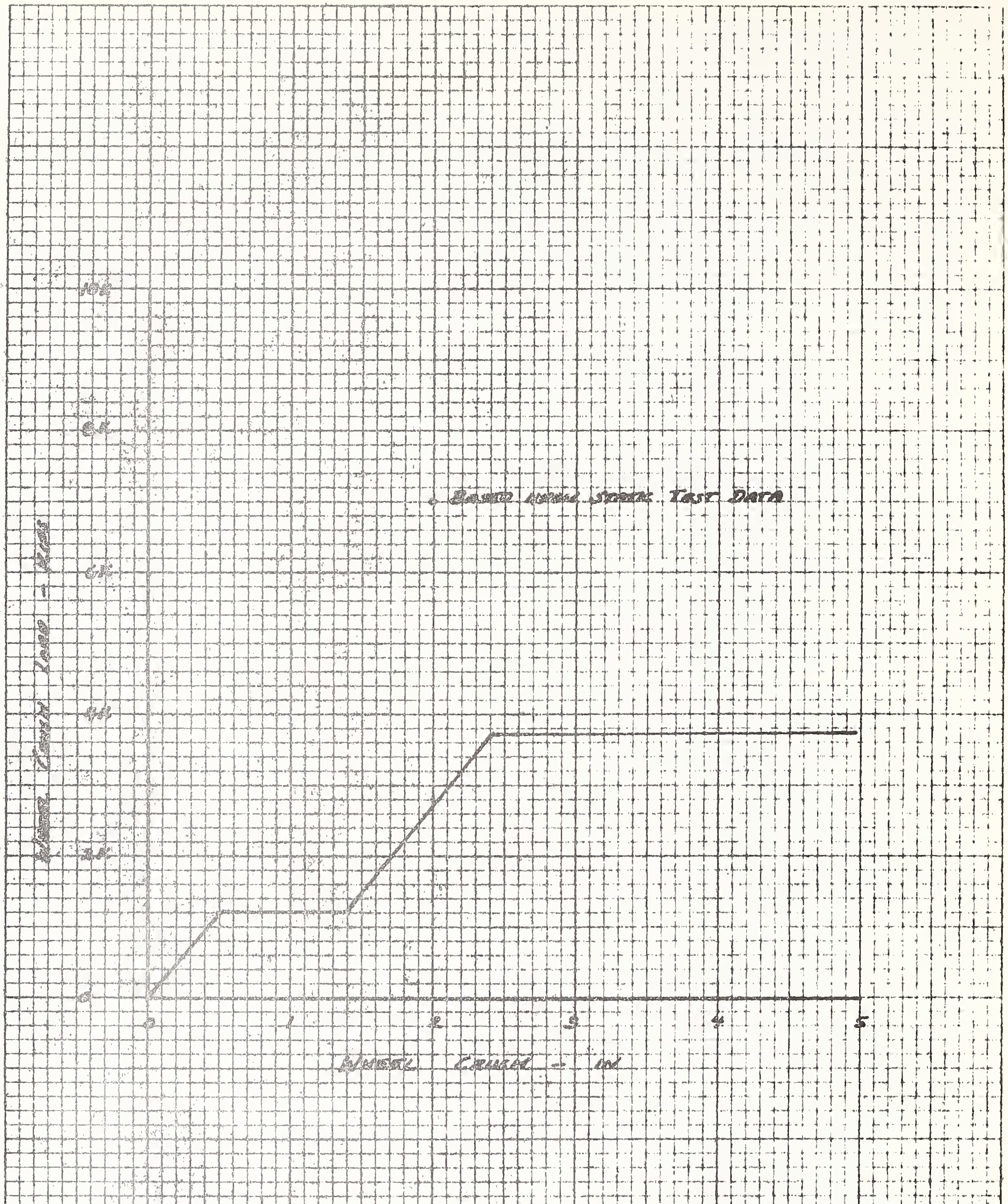
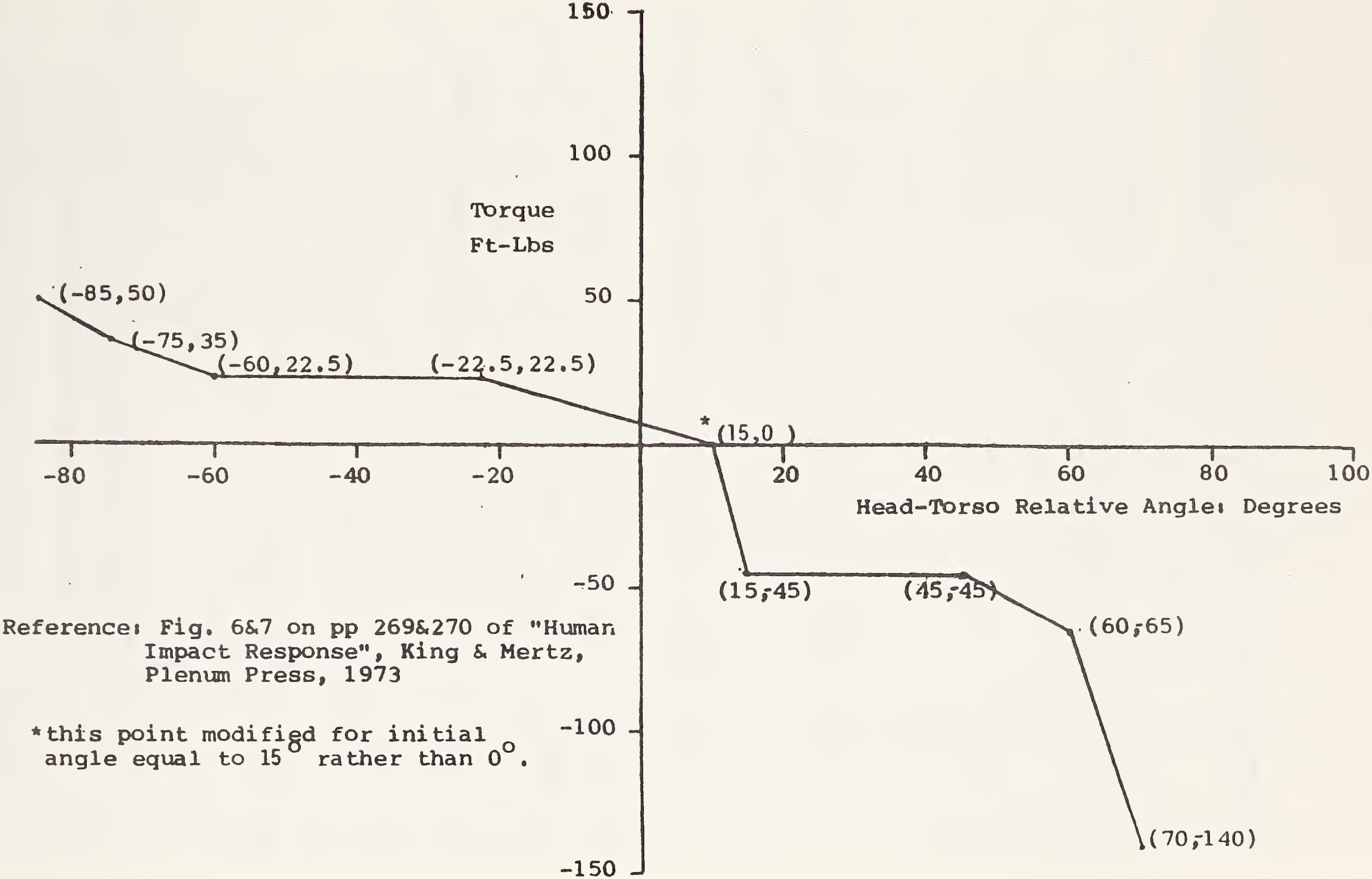


Figure 2-6. Assumed Axial Crush Characteristics of Steering Wheel.

Neck Torque Versus Head-Torso Relative Angle



Reference: Fig. 6&7 on pp 269&270 of "Human Impact Response", King & Mertz, Plenum Press, 1973

*this point modified for initial angle equal to 15° rather than 0°.

Figure 2-7

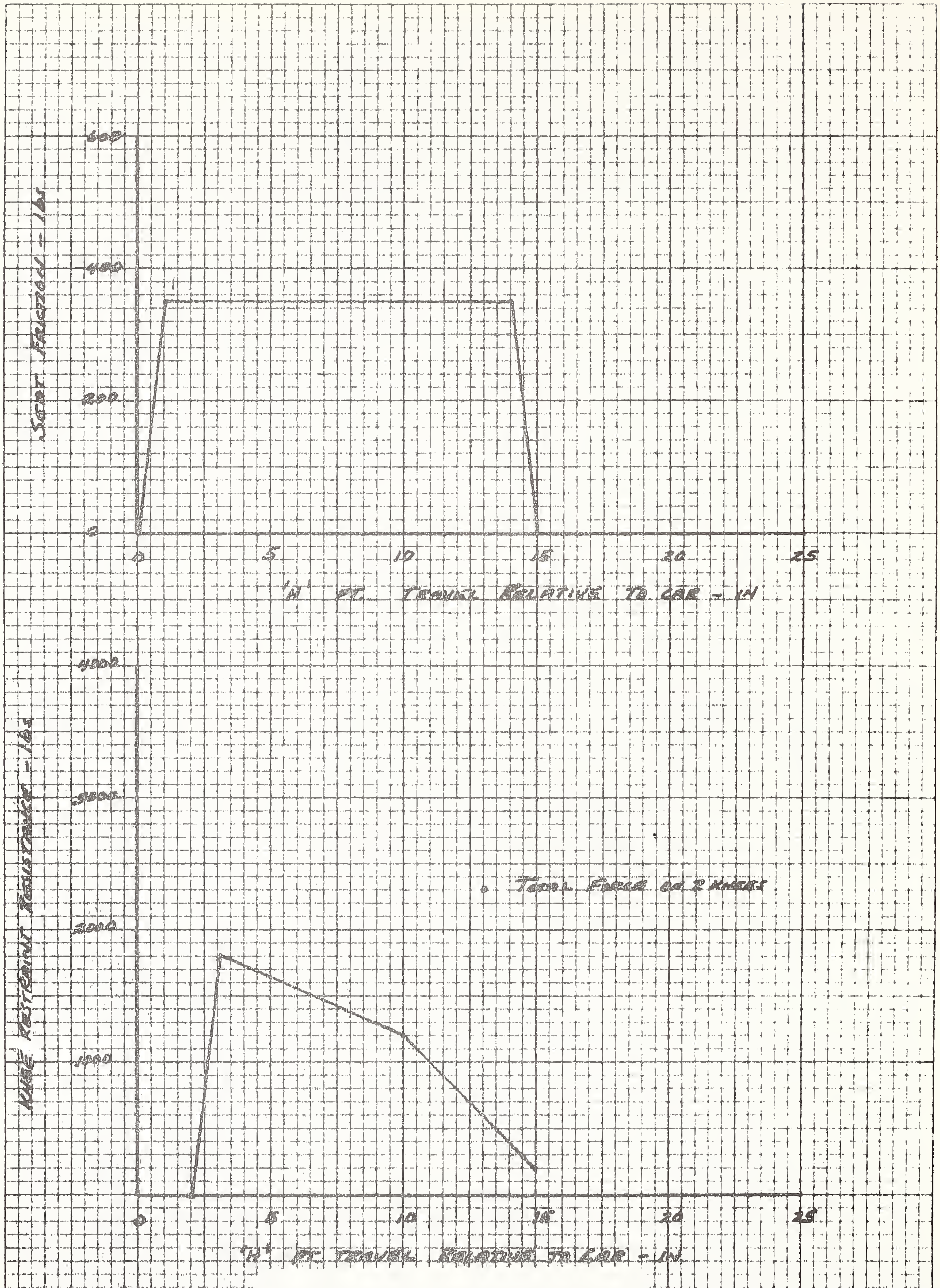


Figure 2-8. Assumed Seat Friction and Knee Resistance Characteristics.

resistance values were varied until the desired match between the calculated and measured femur loads was achieved.[1]

Vehicle Crash Pulse

Figure 2-9 shows the crash pulse (acceleration-time) coordinates assumed in DRACR. These coordinates are based on accelerometer data for location #2 (driver side rocker panel, near "B" post).[2]

2.1.3 Comparison of DRACR Simulations With Barrier Impact Test Data

Appendix B lists the DRACR input data and the simulation results for the 36 mph barrier impact test. Figure 2-10 shows the pre-impact configuration of the driver ATD. It should be noted that in the DRACR simulations the steering wheel hub location was three inches higher than that shown in Figure 2-10. This was done to account for the "H" point drop in the driver's trajectory, which occurred in the test.

The DRACR predictions are summarized and compared with the actual test data in Figures 2-11 thru 2-18. Figure 2-19 shows the position of the driver, near maximum bag penetration (approximately 85 msec into the crash event), as predicted by DRACR. The following discussion summarizes the observations made for the DRACR simulation:

1. Vehicle Response Calculations - Excellent correlation with test data (Figure 2-11).
2. Femur Load Calculations - Knee restraint characteristics in DRACR were determined by "trial-and-error" (restraint charac-

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1 See Appendix D for modifications to DRACR femur load calculation routine.

2 Ibid., page 2-1.

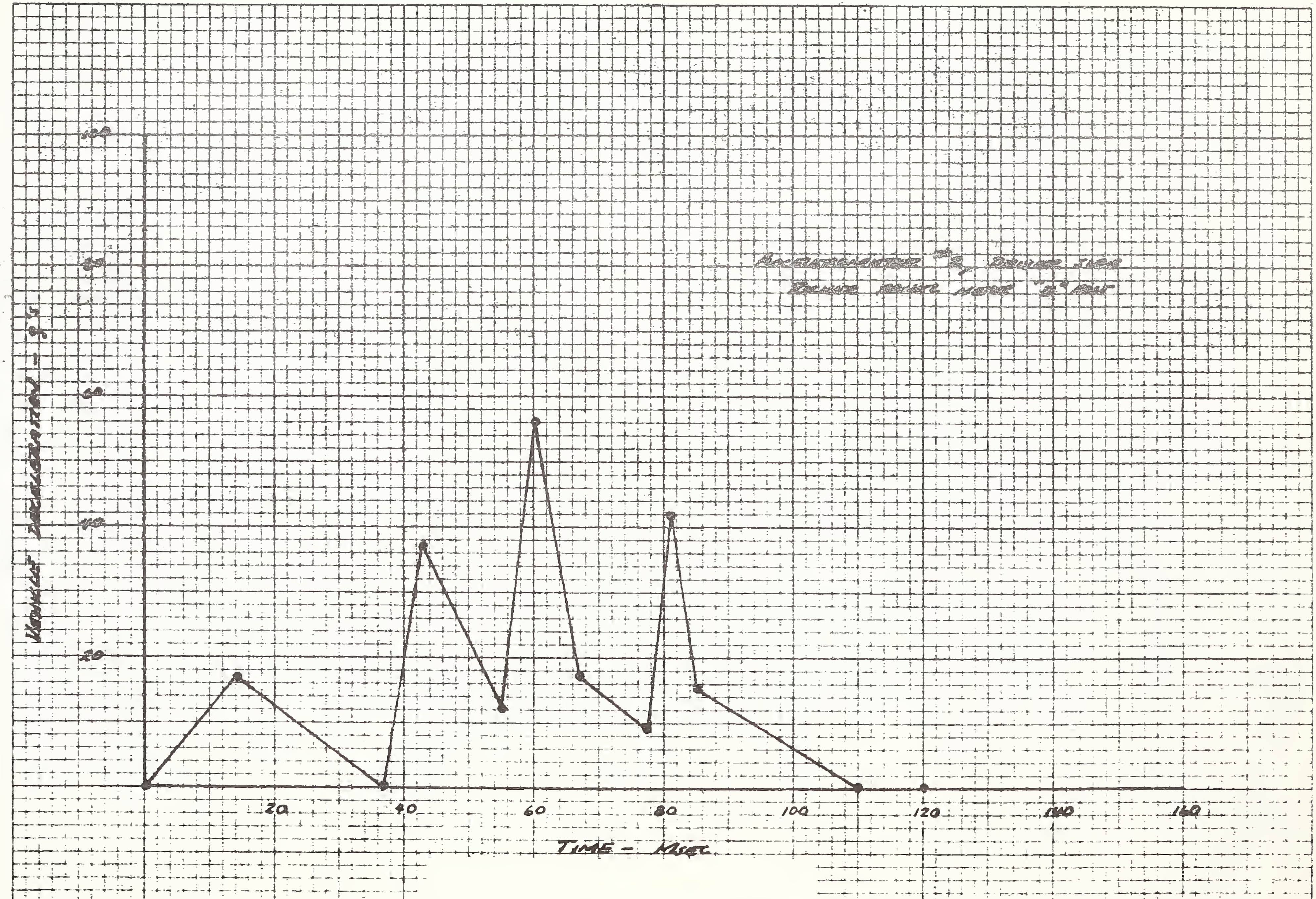
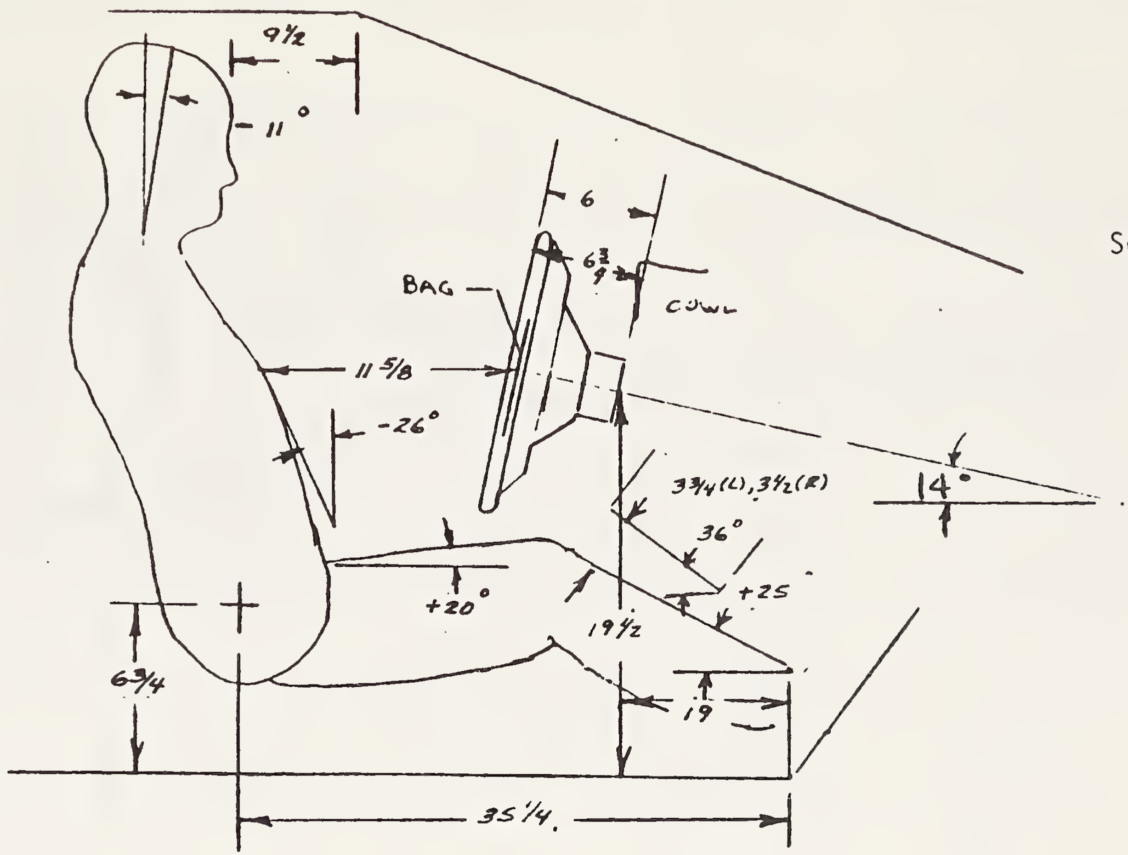


Figure 2-9. DRACR Acceleration-
Time Coordinates.

DMC Test #1 9-24-81



Seat In Mid Position

Figure 2-10. Pre-Impact Configuration of Driver ATD.

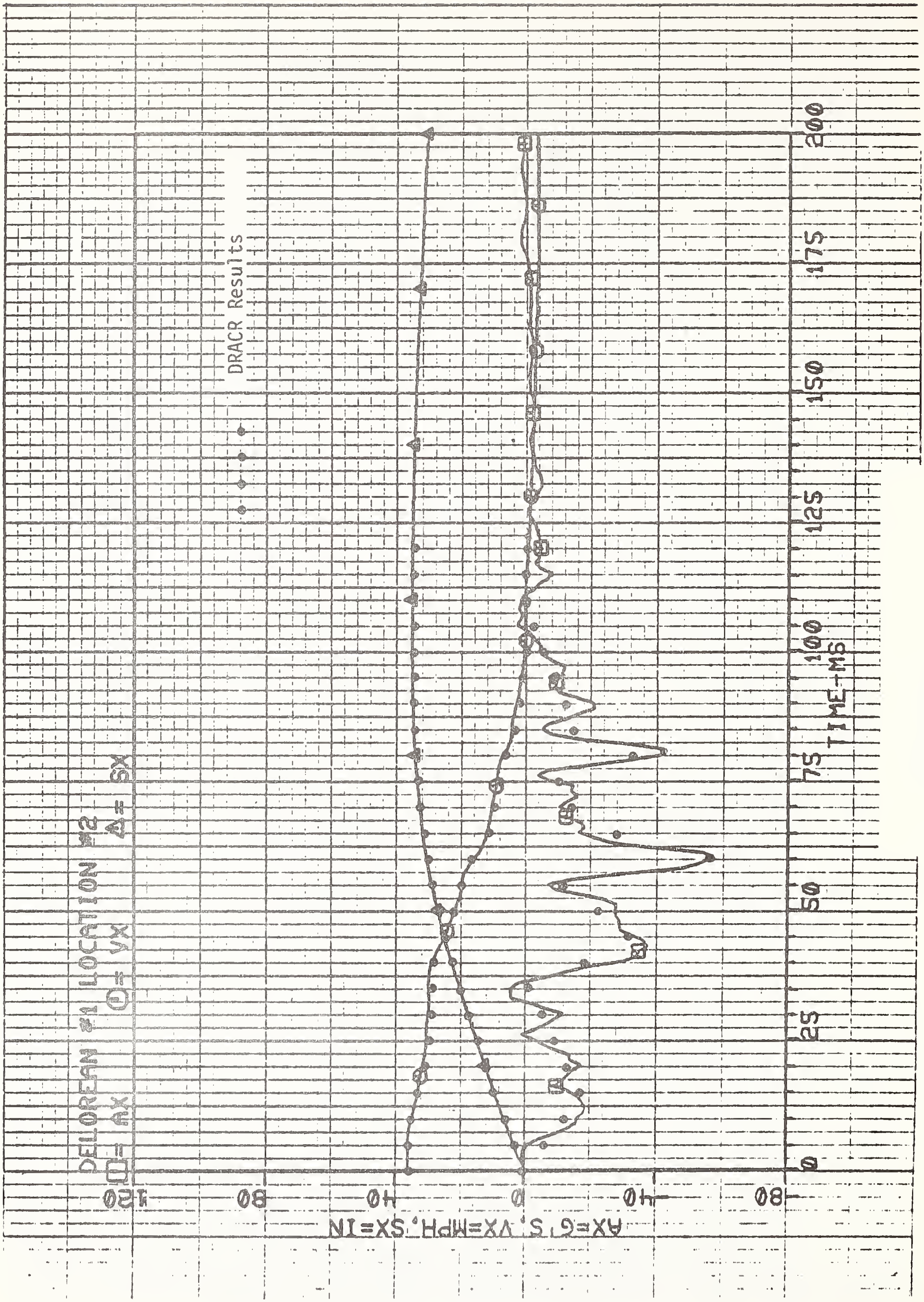

DELOREAN #1 LOCATION #2
□= AX ⊙= VX △= SX
DRACR Results
TIME-MS
AX=G'S, VX=MPH, SX=IN
0
25
50
75
100
125
150
175
200
120
80
40
0
-40
-80

Figure 2-11

teristics varied until desired match between measured and calculated femur loading history was achieved). Test data seems to indicate failure of knee restraint support structure and/or interaction of occupant's lower torso with steering wheel (note the oscillatory force-time curve in Figures 2-12 and 2-13).

3. Bag Pressure Calculations - Good correlation with test data (see Figure 2-14).
4. Calculation of Torso A-P Acceleration - The calculated torso A-P accelerations are somewhat higher than the measured values for times less than 95 msec (see Figure 2-15). This is probably due to the rotational effects of the steering column (which are not very well understood for this test). The DRACR simulation assumes that the column rotation occurs after head/torso interaction with the steering wheel (approx. 85 msec into the crash event). Thus, in the simulation the column was fixed against rotation. Other DRACR simulations, however, were conducted in which the steering column rotational stiffness was varied. In some of these simulations, better correlation of the torso A-P accelerations were achieved (however, the bag pressure did not correlate very well with these runs).[1]

   For times greater than 95 msec, the disparity between the calculated and measured torso A-P accelerations are a result of the head/torso interaction with the steering wheel (this inter-

[1] A sled test program is being planned, for validating the DRACR model under a more controlled impact condition.

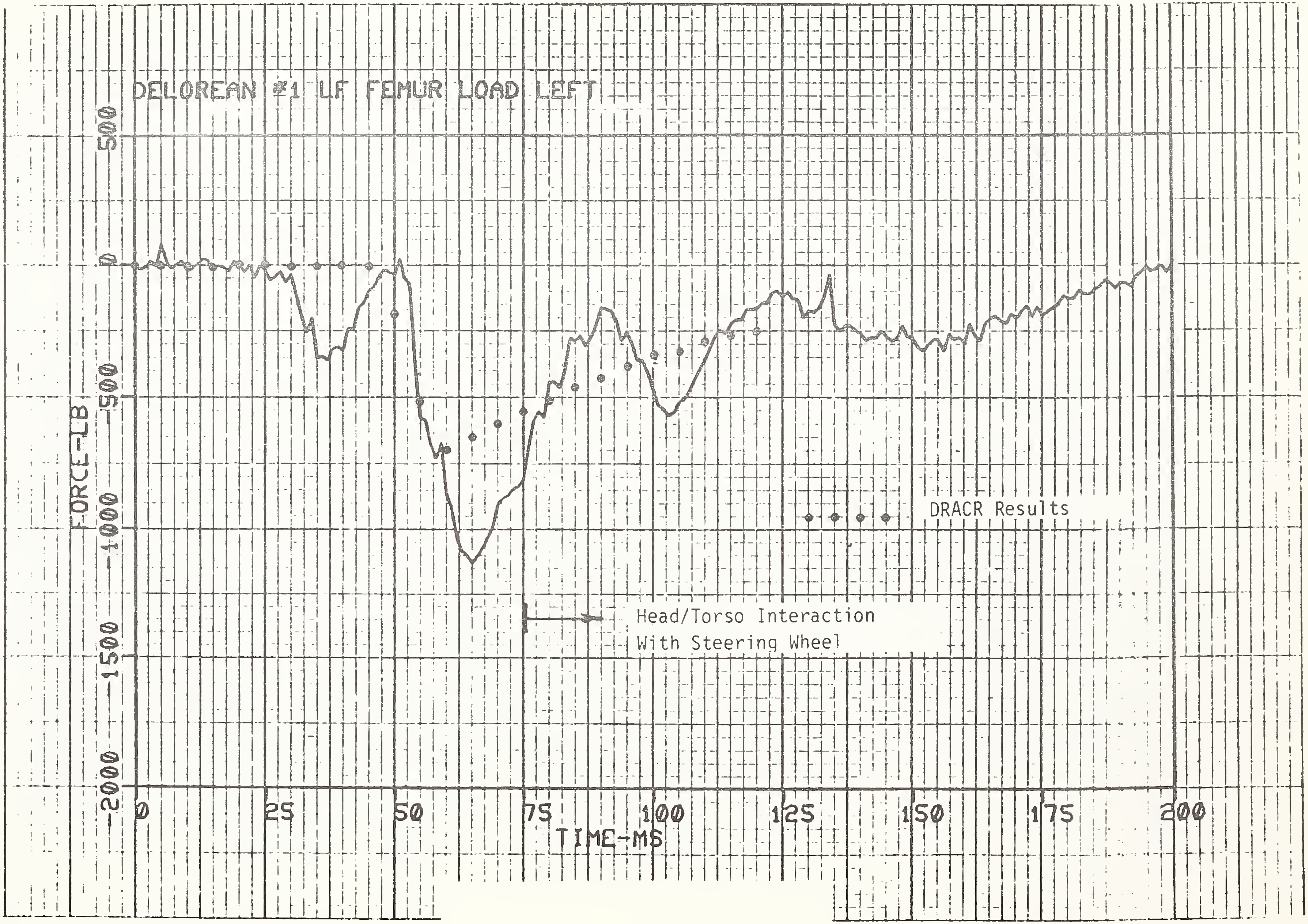

DELOREAN #1 LF FEMUR LOAD LEFT
FORCE-LB
500
0
-500
-1000
-1500
-2000
0
25
50
75
100
125
150
175
200
TIME-MS
DRACR Results
Head/Torso Interaction
With Steering Wheel

Figure 2-12

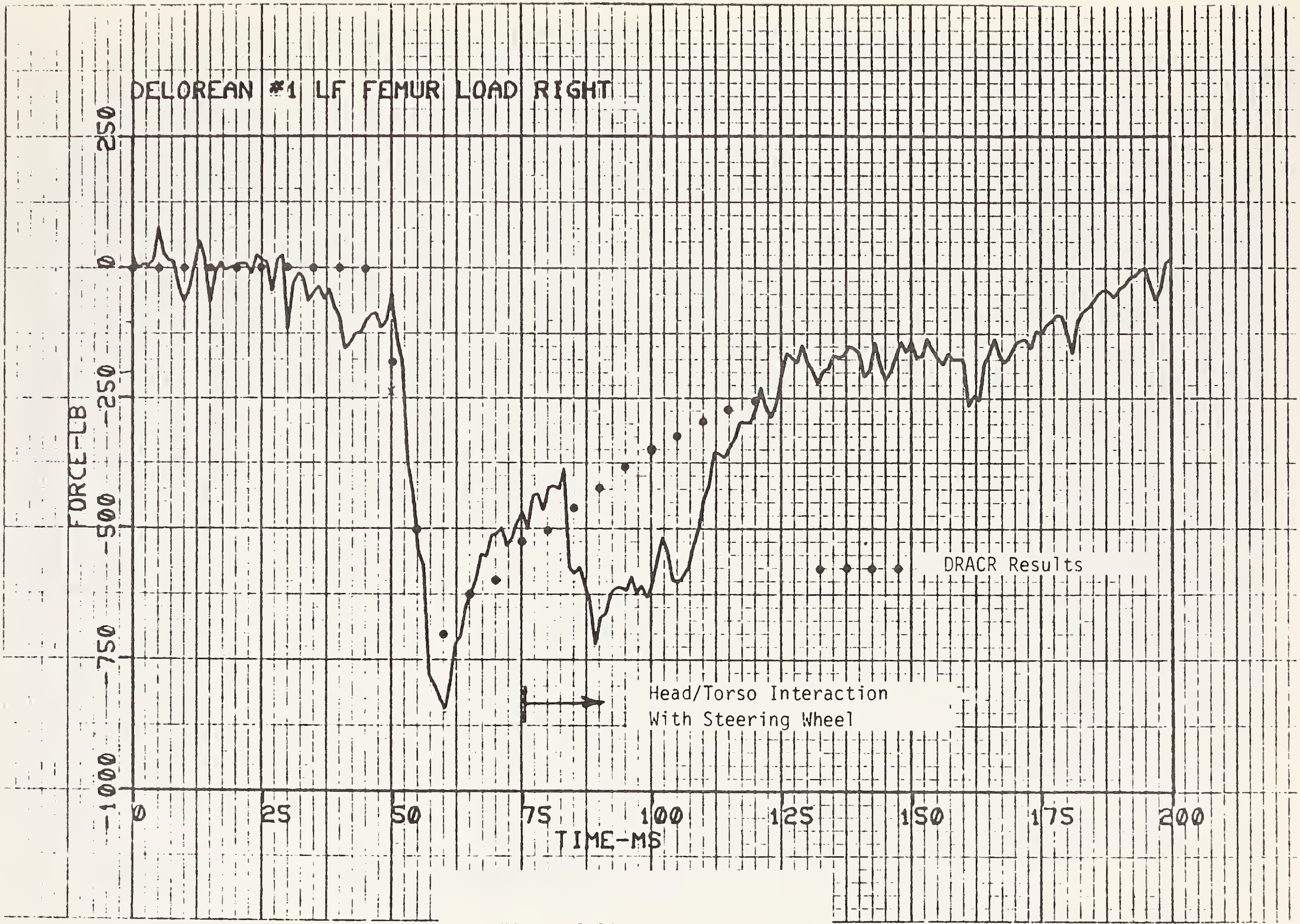
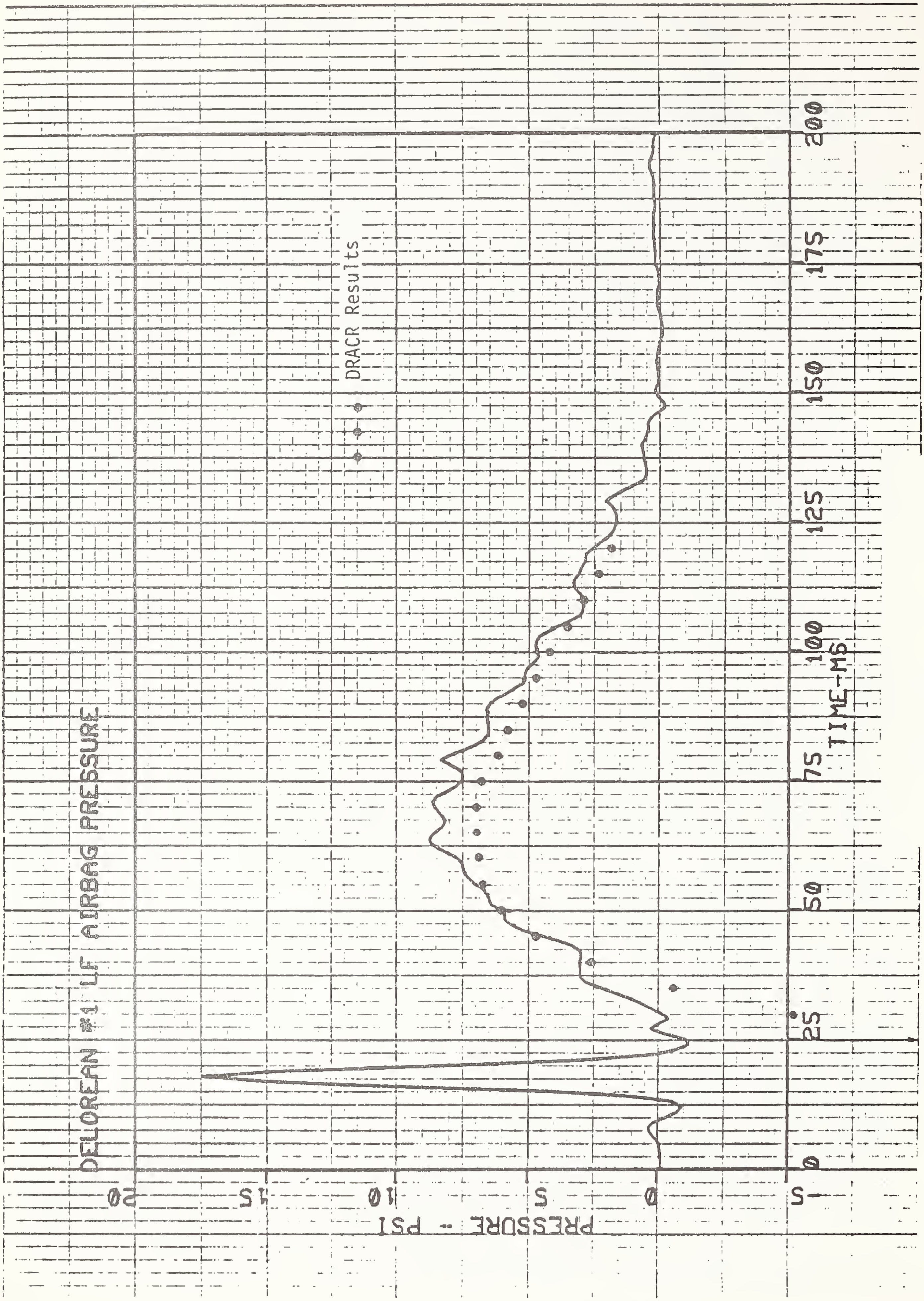

DELOREAN #1 LF FEMUR LOAD RIGHT
250
0
-250
-500
-750
-1000
FORCE-LB
0
25
50
75
100
125
150
175
200
TIME-MS
DRACR Results
Head/Torso Interaction
With Steering Wheel

Figure 2-13


DELOREAN #1 LF AIRBAG PRESSURE
DRACR Results
TIME-MS
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25
50
75
100
125
150
175
200
PRESSURE - PSI
20
15
10
5
0
5

Figure 2-14

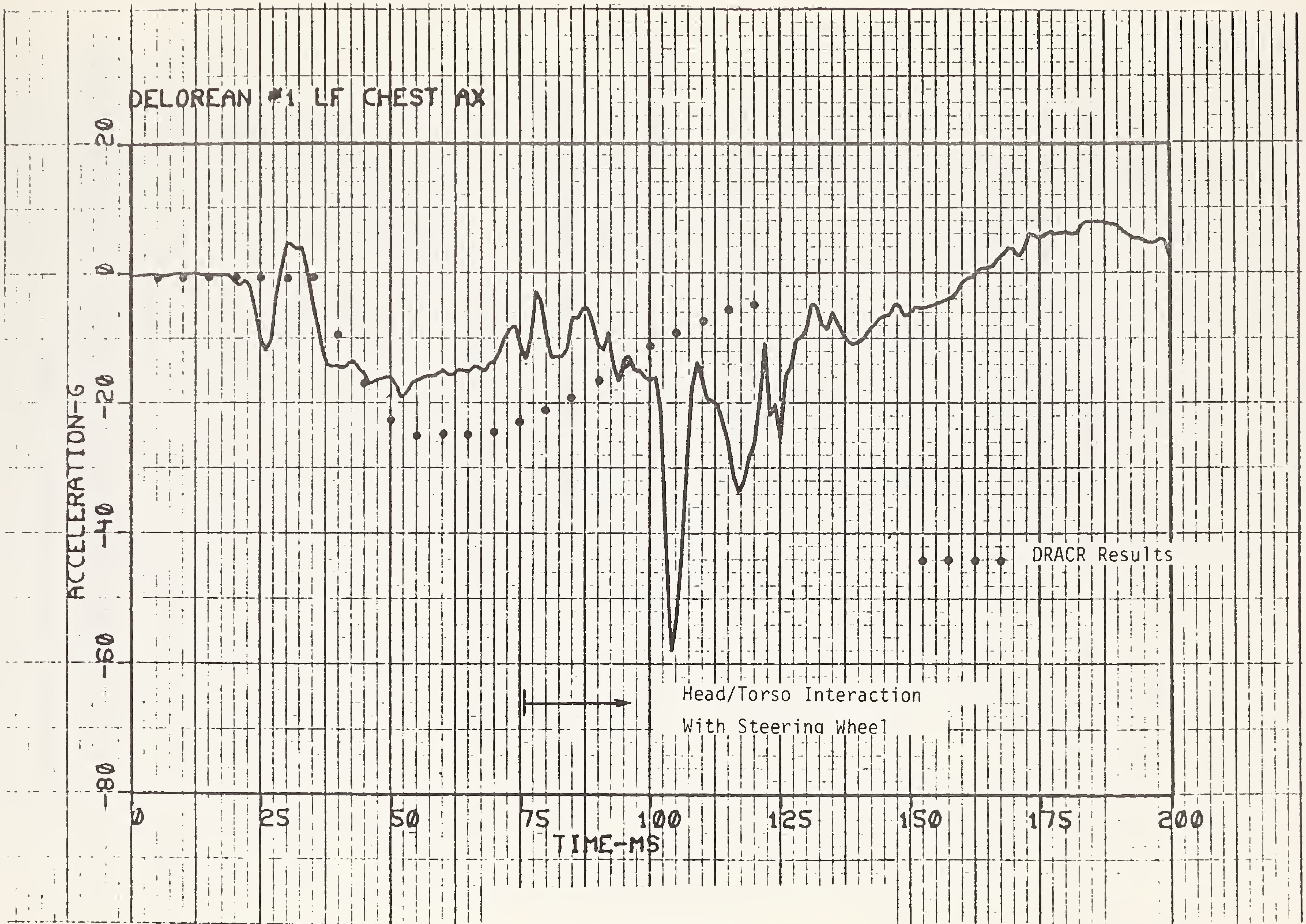
DELOREAN #1 LF CHEST AX
20
0
-20
-40
-60
-80
ACCELERATION-G
0
25
50
75
100
125
150
175
200
TIME-MS
DRACR Results
Head/Torso Interaction
With Steering Wheel

Figure 2-15

action is not modeled in DRACR).

5. Calculation of Torso S-I Accelerations - The large disparity between the calculated and measured torso S-I accelerations (Figure 2-16) is a result of the head/torso interaction with the steering wheel.[1]

6. Calculation of Head A-P Accelerations - Good correlation exists between the calculated and measured head A-P accelerations for time less than 75 msec (Figure 2-17). The large disparity noted for times greater than 75 msec are a result of the head/torso interaction with the steering wheel.

7. Calculation of Head S-I Accelerations - The large disparity between the calculated and measured head S-I accelerations is a result of the head/torso interaction of the steering wheel (Figure 2-18).

8. Comparison of Calculated and "Measured" HIC:

	Calculated	"Measured"
HIC	291[2]	404
T1	.045 sec	.048 sec
T2	.115 sec	.175 sec

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[1] Note that although % deviation is fairly high, g levels are low and do not influence the resultant torso g's much.

[2] Calculations only carried out to 120 msec.

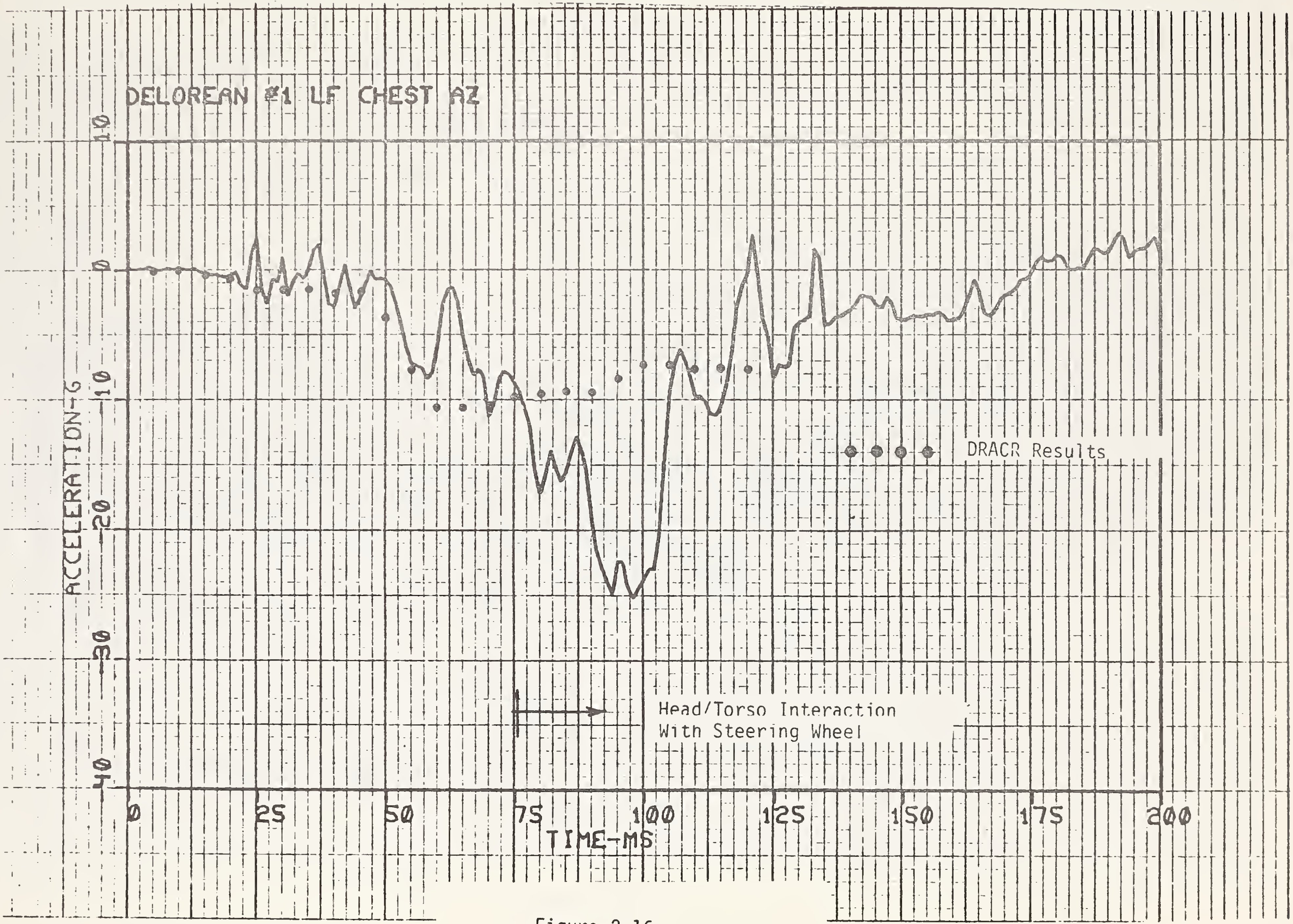

DELOREAN #1 LF CHEST AZ
ACCELERATION-G
10
0
10
20
30
40
0
25
50
75
100
125
150
175
200
TIME-MS
DRACR Results
Head/Torso Interaction
With Steering Wheel

Figure 2-16

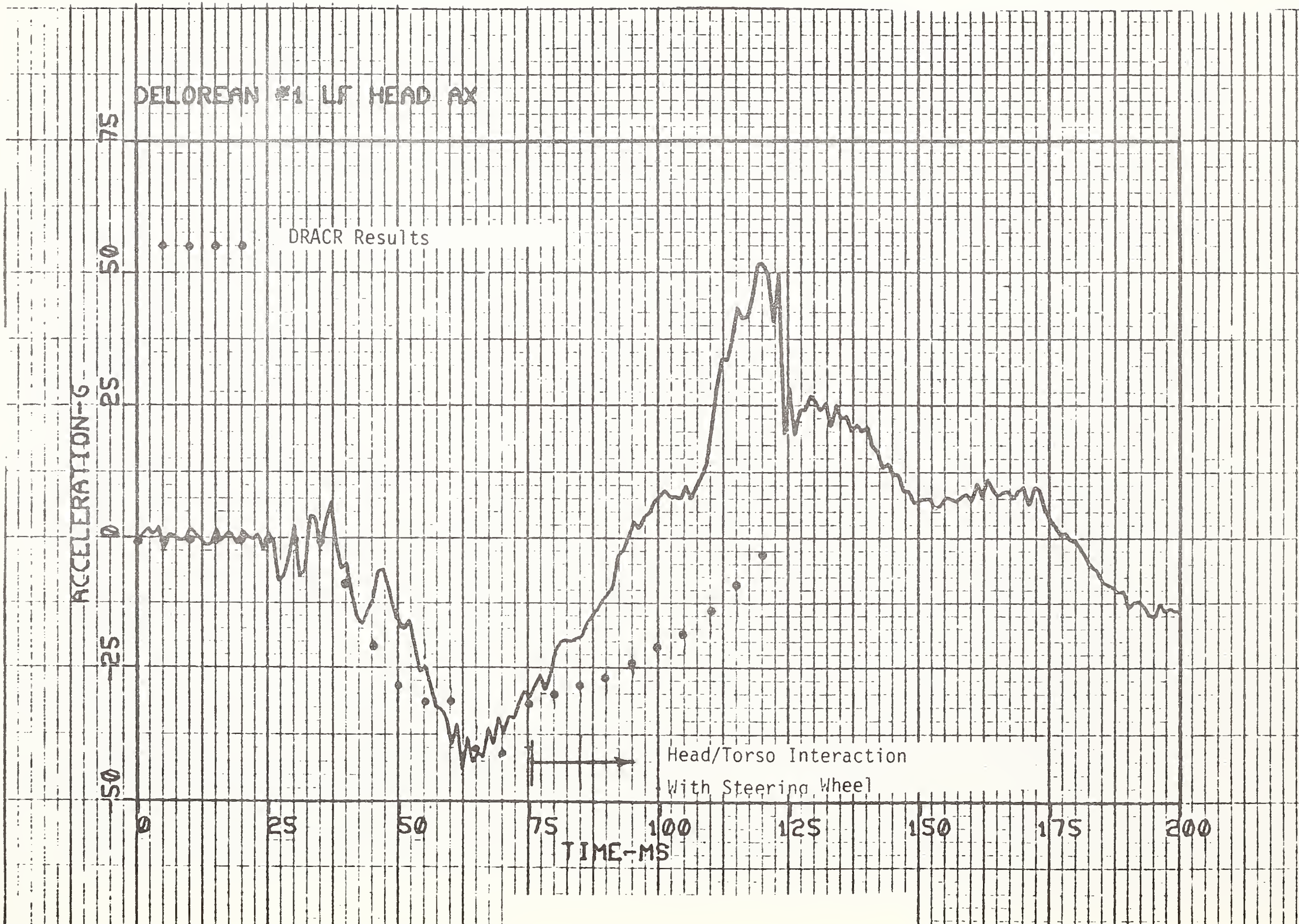

DELOREAN #1 LF HEAD AX
DRACR Results
Head/Torso Interaction
With Steering Wheel
ACCELERATION-G
75
50
25
0
25
50
TIME-MS
0
25
50
75
100
125
150
175
200

Figure 2-17

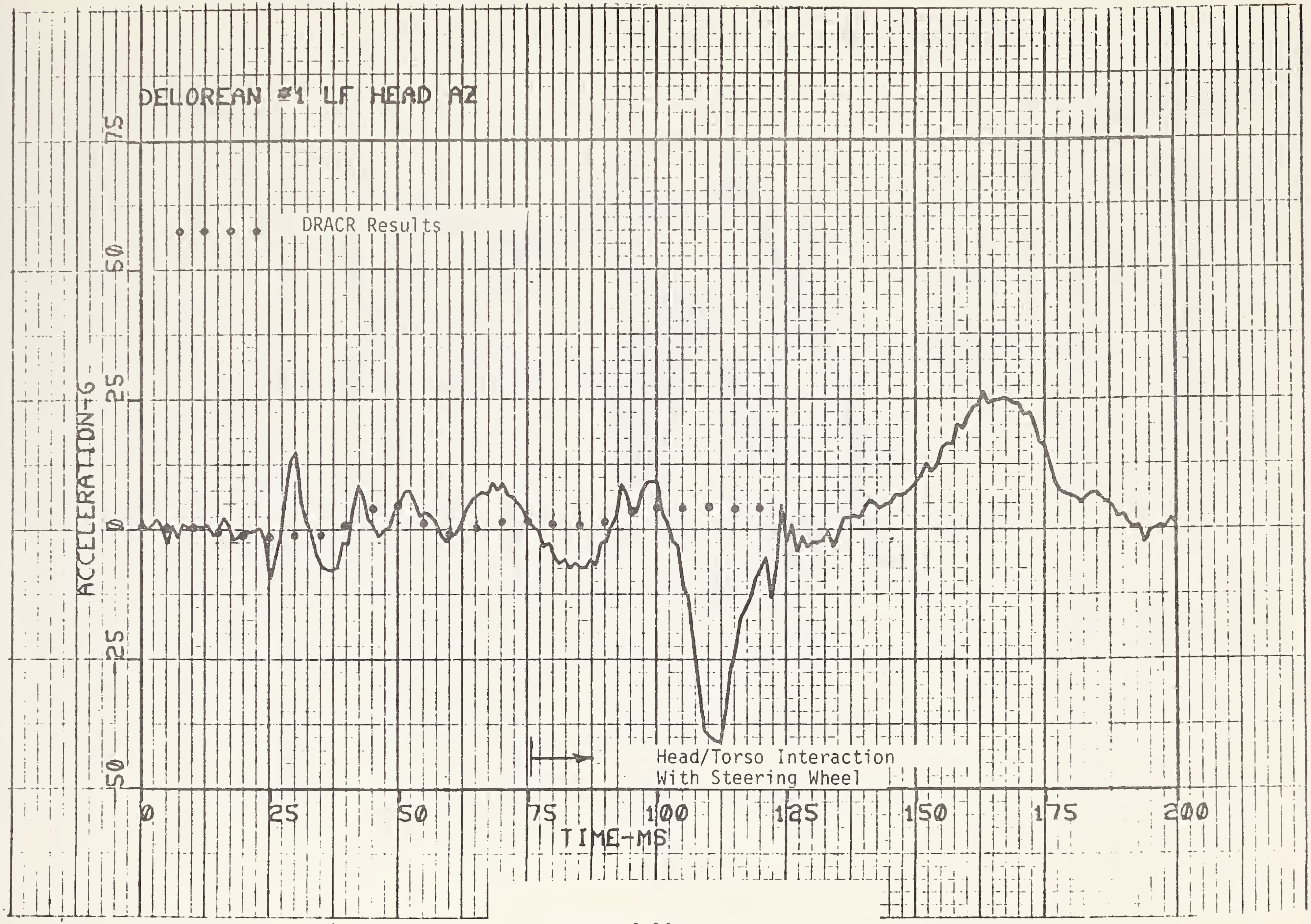

DELOREAN #1 LF HEAD AZ
DRACR Results
ACCELERATION-G
75
50
25
0
25
50
Head/Torso Interaction
With Steering Wheel
0
25
50
75
100
125
150
175
200
TIME-MS

Figure 2-18

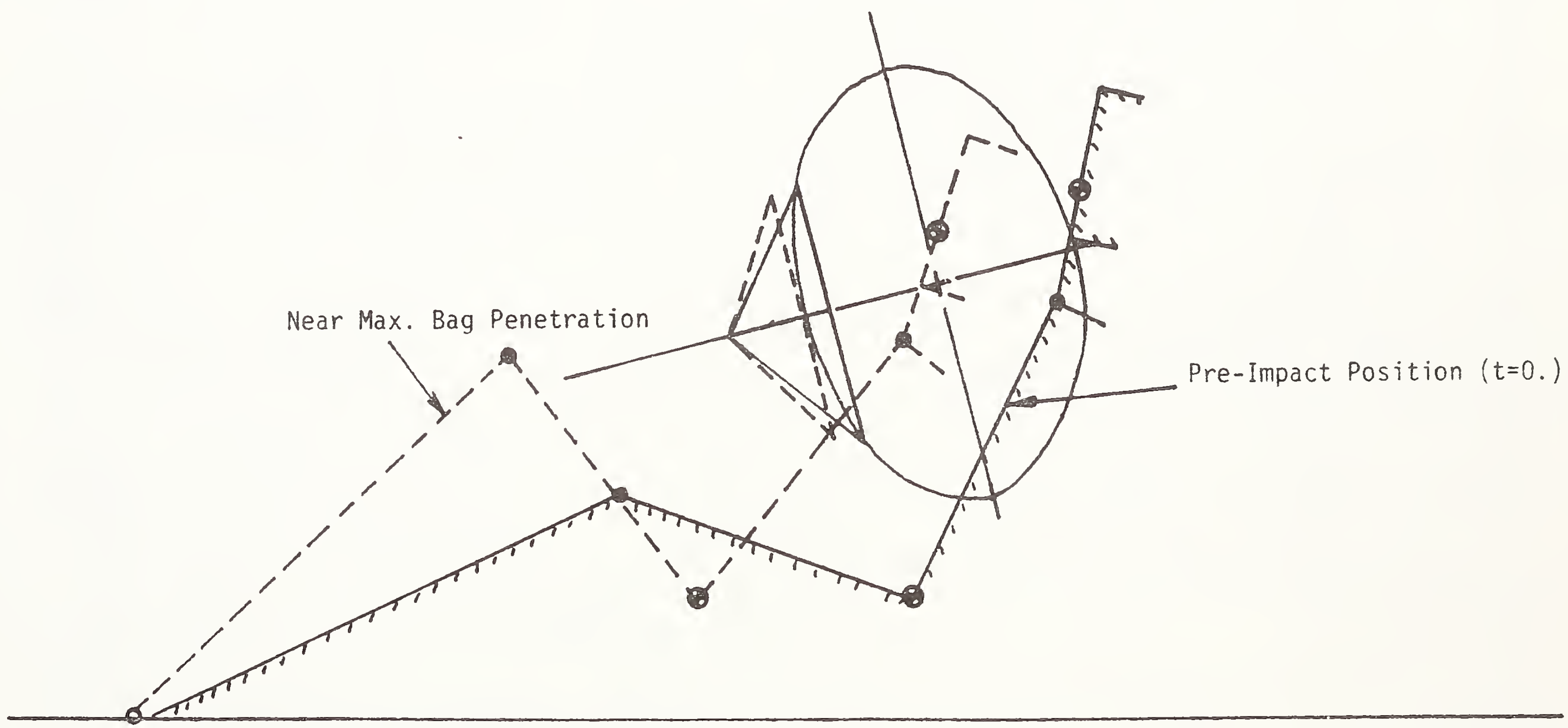


Figure 2-19. DRACR Model Prediction of Occupant Near Maximum Bag Penetration (Approximately 85 msec Into Crash Event).

2.2 PASSENGER RESTRAINT SYSTEM

2.2.1 Description

The passenger restraint system for the subject test consisted of the following components:[1]

- Knee Restraint
- Air Bag Inflator
- Sensor
- Air Bag

The knee restraint consisted of aluminum honeycomb (1/4-5052-.0007, 45 psi crush strength) "faced" with a 6061-TO aluminum/vinyl cover. Also included are the support structure and attachments.

The air bag inflator consisted of two "off-the-shelf" Thiokol/Mercedes gas generators (Part No. IU 92520-04). These generators were of the "driver" type.

In the subject test, air bag inflation was activated by a contact switch located on the bumper, acting in series with a built-in electronic delay of approximately 10 milliseconds (from bumper contact to squib ignition of the first gas generator). Ignition of the second gas generator was delayed an additional 7 milliseconds.

The air bag was designed by Fitzpatrick Engineering and manufactured by Talley Industries. The bag was made from a neoprene coated nylon material having a density of 8.2 oz/yd^2. The nylon material was type 66,

---

[1] Ibid., page 2-1.

840 denier. The bag shape was cylindrical, with a diameter of 23.0 inches and a length of 23.5 inches.

2.2.2 PAC Computer Model and Assumptions

The PAC computer model was used to simulate the passenger ATD and its restraint system for the subject barrier impact test. Figure 2-20 illustrates the PAC model. The model represents the passenger occupant as a three segment linkage having finite width but no thickness. The segments comprising the "linkage" are the head, torso and lower body masses. One additional mass element is added to represent the sternum for bag-slap calculations (see Figure 2-20). In PAC, the interaction of the torso and head masses with the bag envelope is visualized as two-dimensional planes intersecting a three-dimensional ellipsoidal volume. In this study, the two-dimensional planes represent the mid-plane of the occupant. To compensate for the "flesh thickness", the "H" point of the occupant is moved forward a distance L_{Flesh} as indicated in Figure 2-21.

PAC - Occupant, Geometry and Mass Characteristics

The PAC occupant geometry and mass characteristics are the same as the DRACR occupant characteristics discussed in Section 2.1.2.

ACRS Bag Pumping Performance

PAC includes the thermodynamic equations governing bag pumping and venting and those processes associated with "working" the bag. PAC requires as input the following data:

- Mass Flow Rate History of Inflator
- Stagnation Temperature of Gas Entering Bag

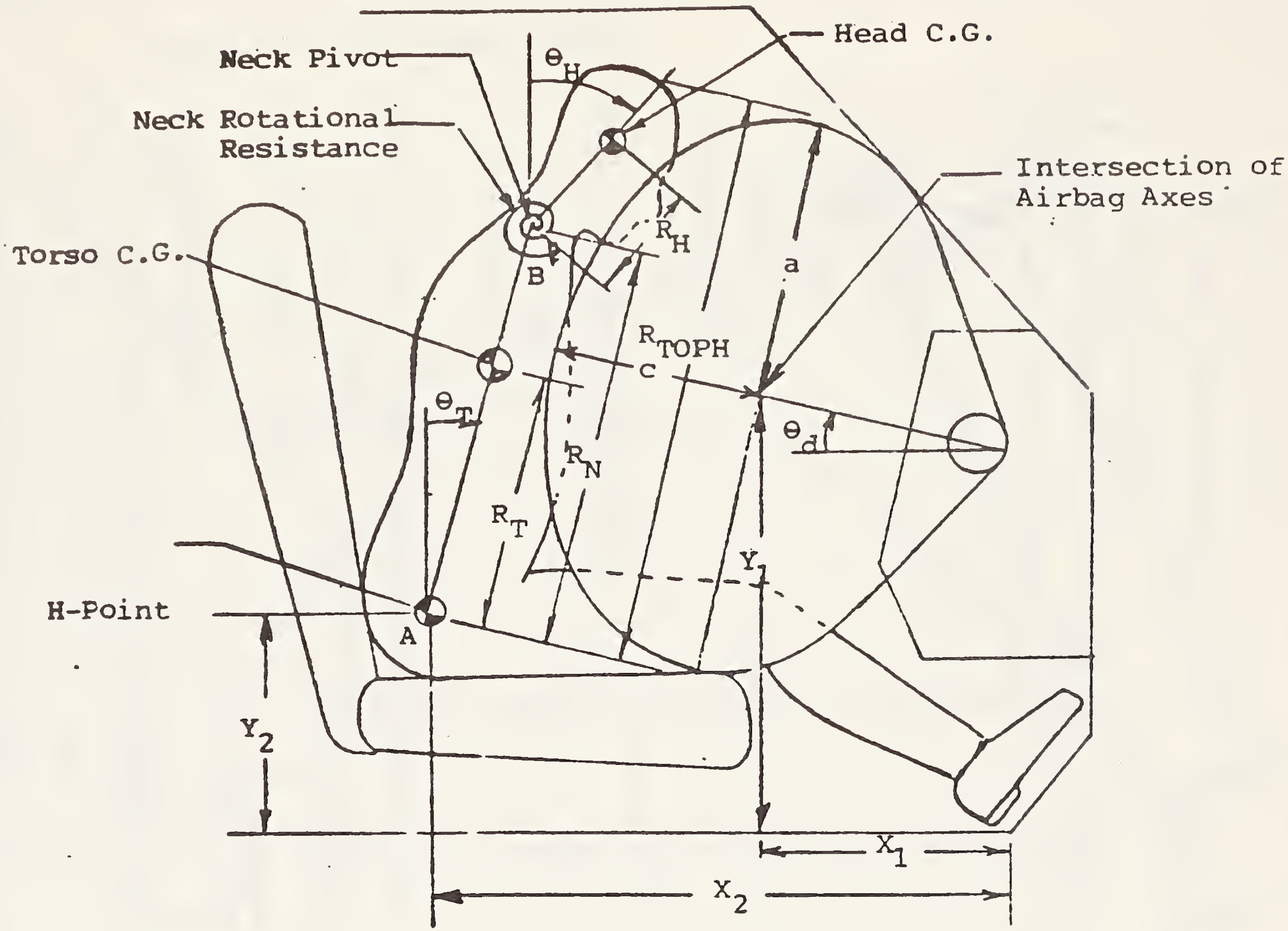


Figure 2-20. PAC Computer Model.

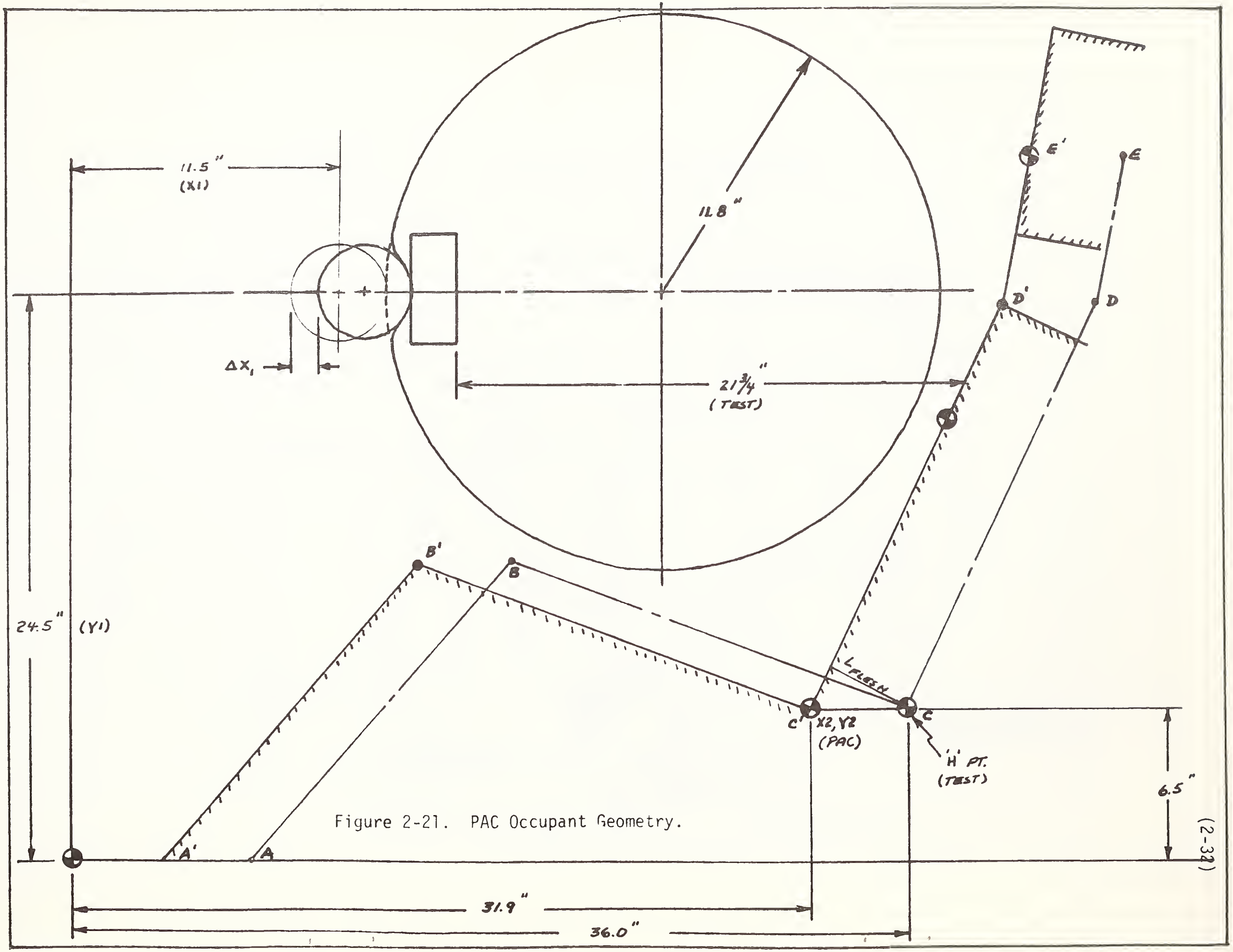


Figure 2-21. PAC Occupant Geometry.

- Universal Gas Constant
- Polytropic Gas Exponent for Flow, Compression and Expansion
- Atmospheric Pressure

Two Thiokol/Mercedes inflators were used to pressurize the passenger bag. These inflators were identical to the inflator used for the driver bag. The two inflators were "staged" 7 msec apart to give the flow rate history shown in Figure 2-5.

Neck Resistance

Figure 2-7 shows the neck resistance characteristics assumed for the PAC simulations.

Seat Friction and Knee Resistance

Figure 2-22 shows the assumed characteristics for seat friction and knee restraint.

Sternal and Chest Force v.s. Deflection Characteristics

Figure 2-23 shows the assumed characteristics for the sternal and chest "springs".

Vehicle Crash Pulse

Figure 2-24 shows the crash pulse (acceleration-time) coordinates assumed in PAC, based on test data.[1]

2.2.3 Comparison of PAC Simulations With Barrier Impact Test Data

Figure 2-25 shows the pre-impact configuration of the passenger ATD, for the subject barrier test. The input data and the PAC computer

---

[1] Accelerometer location #3, located behind passenger seat (near "B" post).

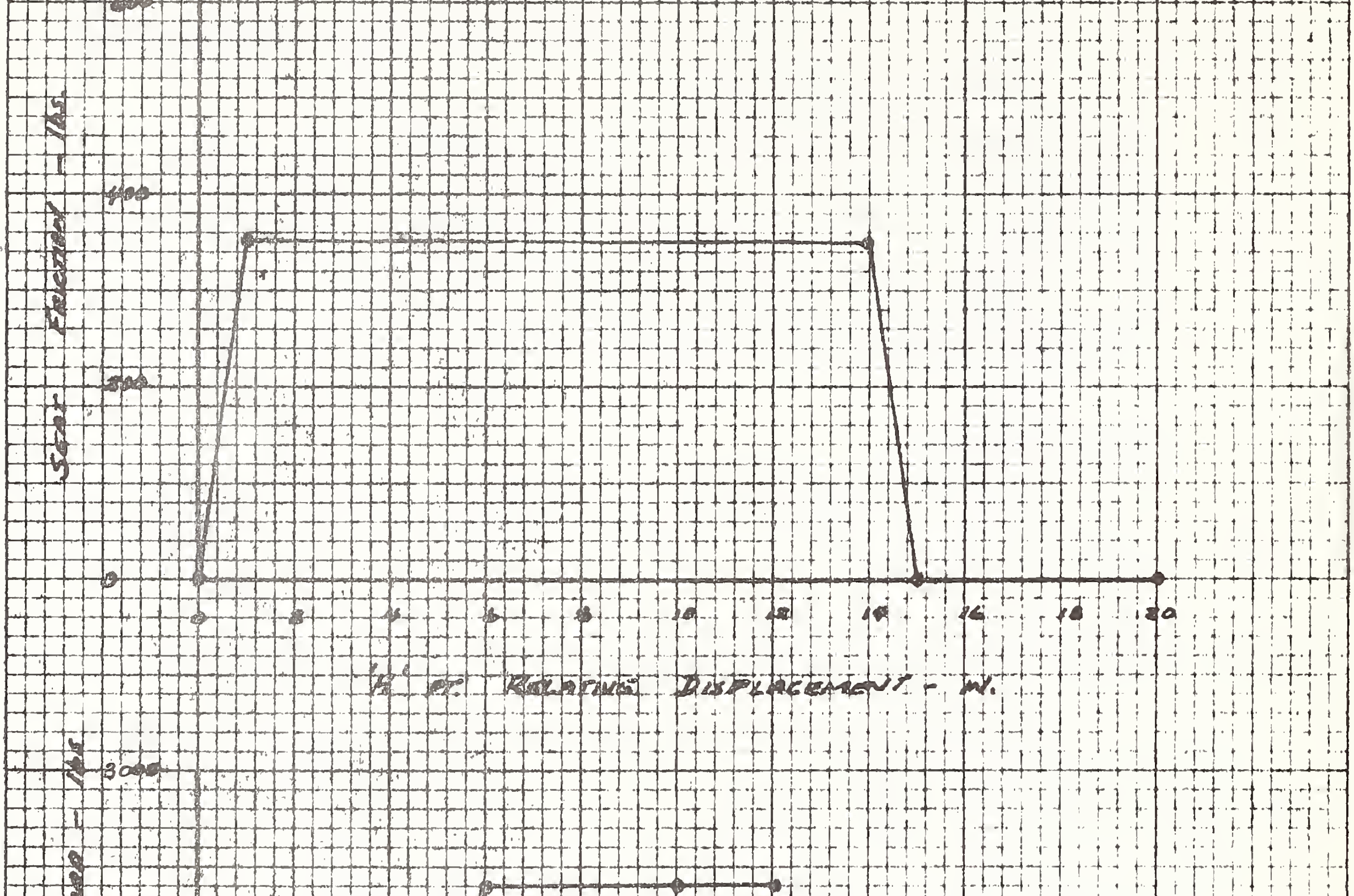


Figure 2-22. Assumed Characteristics for Seat Friction and Knee Restraint Resistance.

L.S.P. 12 Dec '81

Sternal and Chest Force vs Deflection Properties

50^{th} Percentile Male

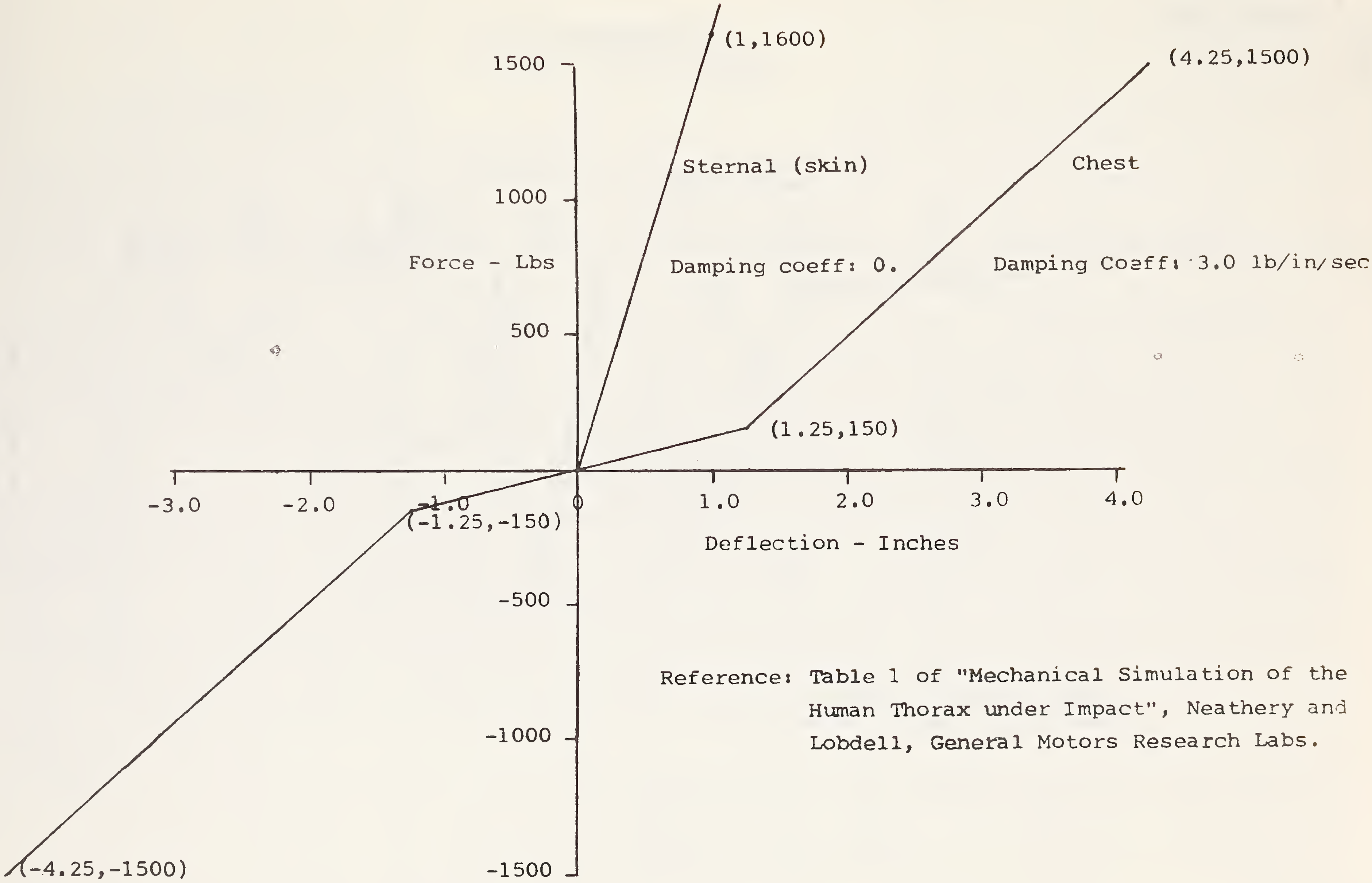


Figure 2-23

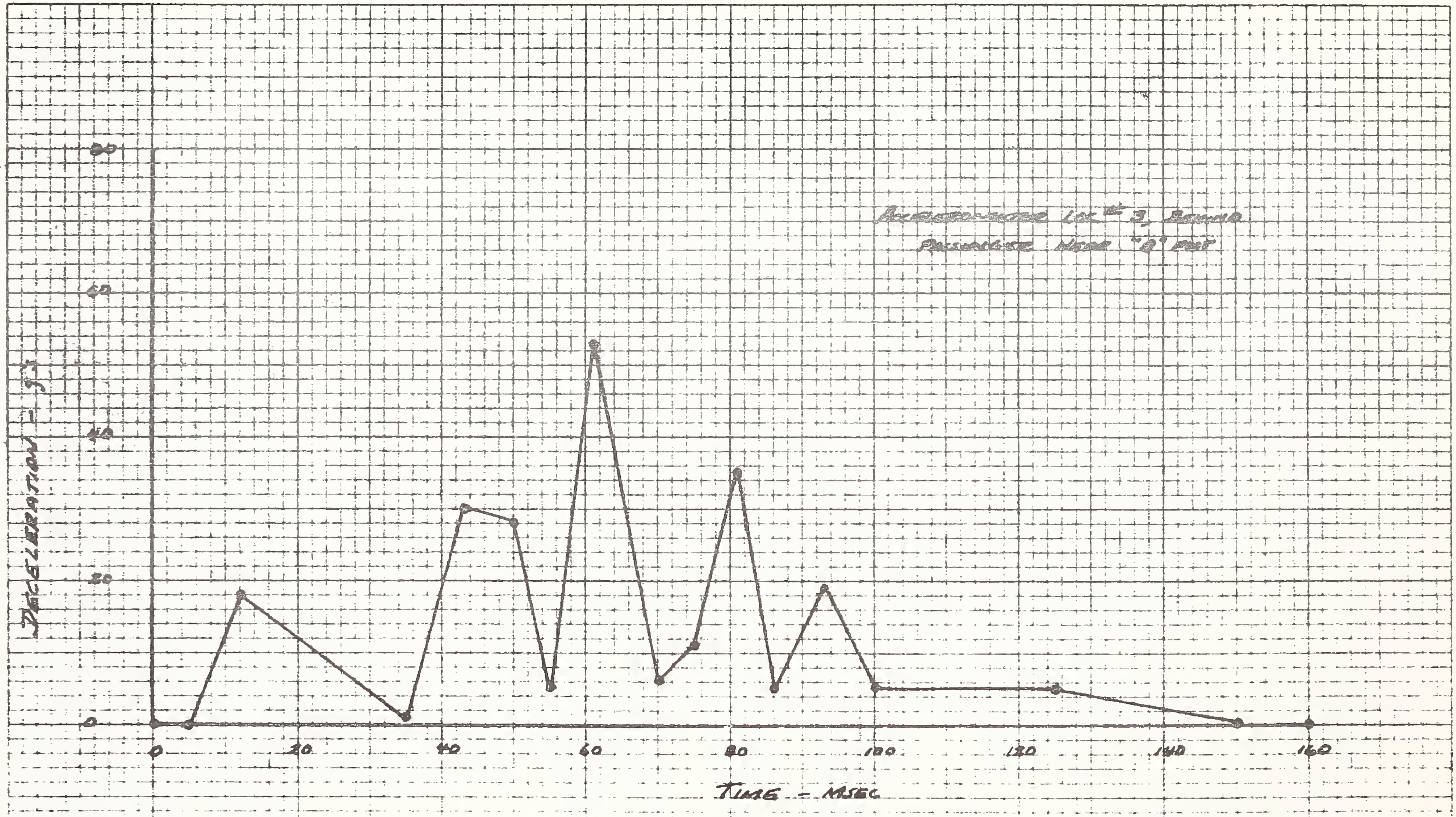
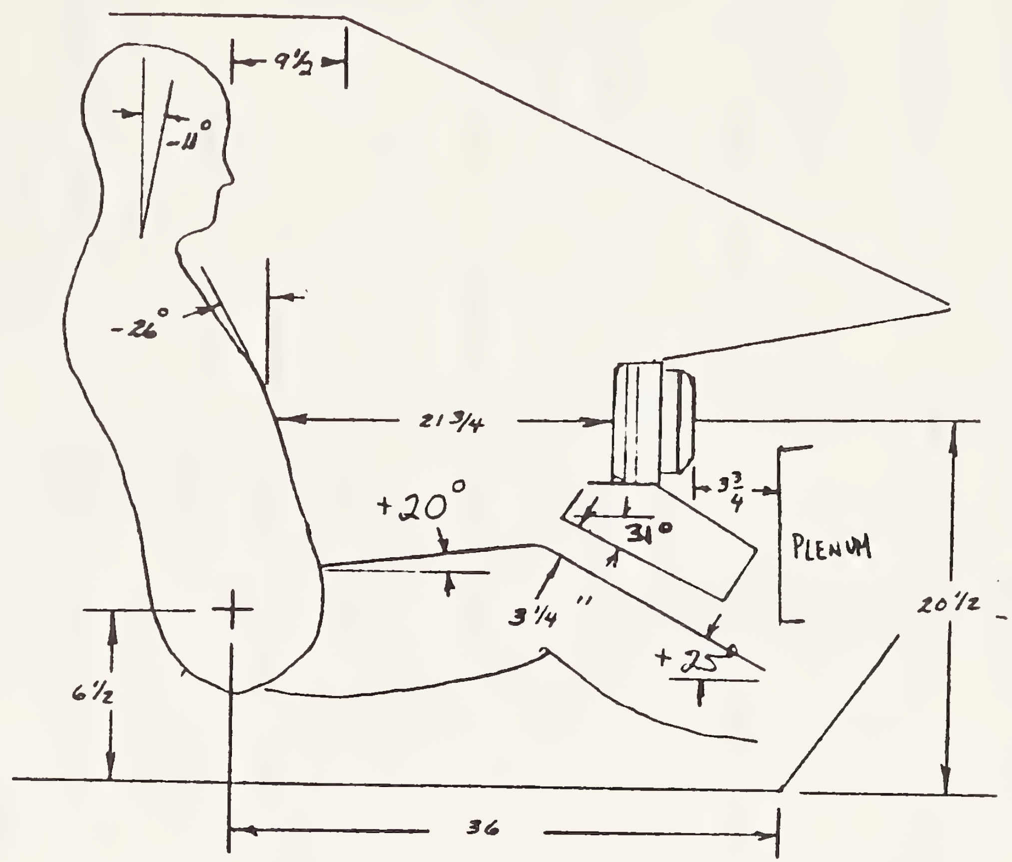


Figure 2-24. Acceleration-Time Coordinates, PAC Input.

L.S.P. 12/17/81.

PASSENGER

DMC Test No. 1, 9-24-91



Seat in Mid Position

Figure 2-25. Passenger Pre-Impact Position.

simulation results are listed in Appendix C. The results are summarized and compared to the actual test data in Figures 2-26 thru 2-35. Figure 2-36 shows the position of the occupant, near maximum bag penetration (approximately 105 msec) as predicted by PAC.

The following summarize the observations for the PAC simulation.

1. Vehicle Response Calculations - Excellent correlation with test data (Figure 2-26).
2. Femur Load Calculations - Figures 2-27 and 2-28 show good correlation between the calculated and measured femur loads.[1]
3. Bag Pressure Calculations - Figure 2-29 compares the calculated and measured bag pressure history. Good agreement exists between the measured and calculated values. The small deviation between the two is believed to be due to the simplifying assumptions in PAC regarding bag shape. In the PAC simulation, a cylindrical bag shape was assumed. However, in the actual test the bag took on an ellipsoidal shape during deployment (major axis in the direction of deployment). Later in the event, the bag shape changed to a cylinder then to an ellipsoid with the minor axis now in the direction of impact. Figure 2-30 illustrates this phenomenon. This change in the bag shape is not modeled in PAC.
4. Torso A-P Accelerations - Figure 2-31 compares the calculated and measured torso A-P accelerations. It is seen that good correlation exists between the calculated and measured peak acceleration. The slight disparity for times less than 95 msec is believed to be

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1 See Appendix D for modifications to the DRACR and PAC femur load calculation routine.

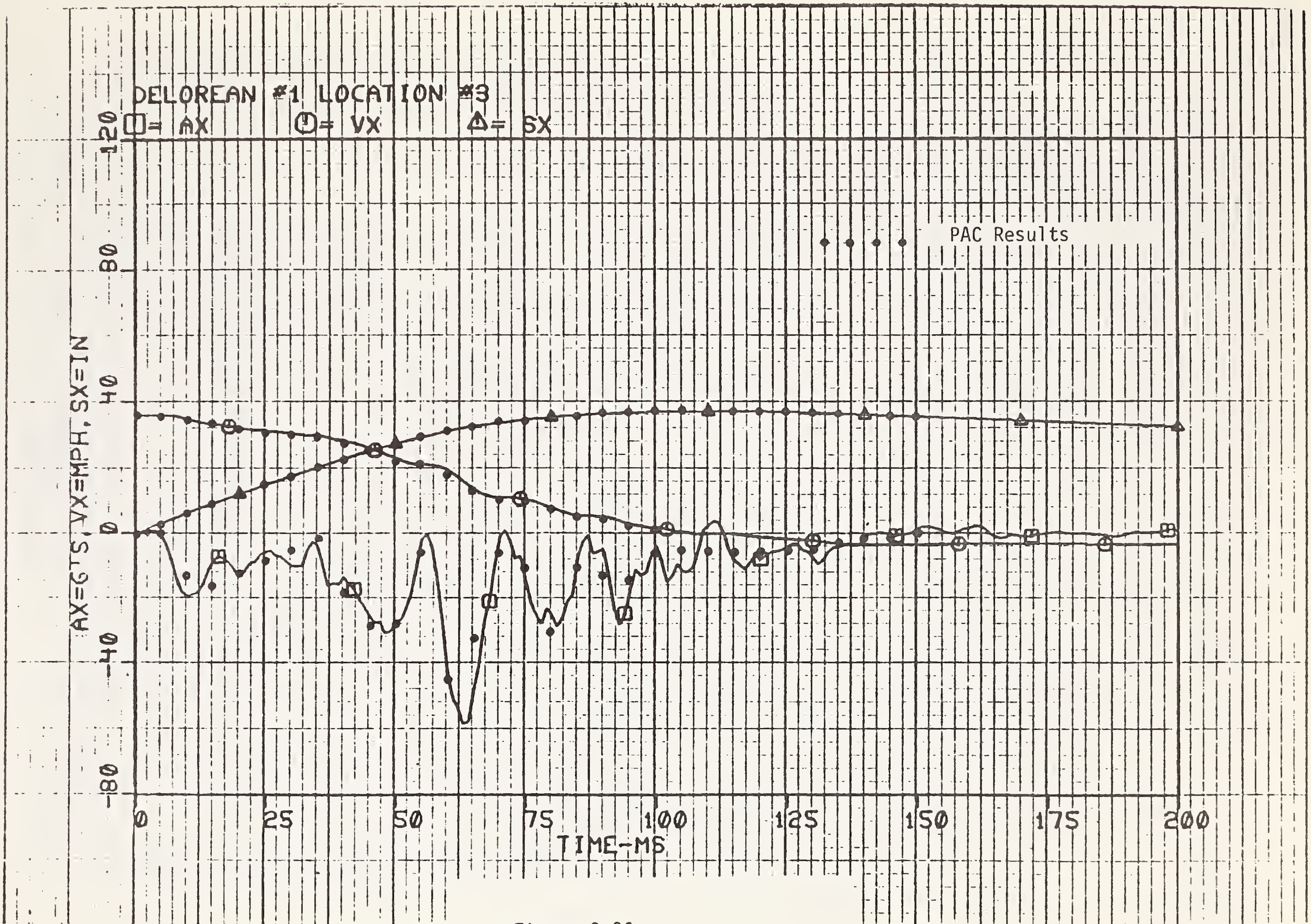
DELOREAN #1 LOCATION #3
□= AX
⊕= VX
Δ= SX
PAC Results
AX=G'S, VX=MPH, SX=IN
120
80
40
0
-40
-80
0
25
50
75
100
125
150
175
200
TIME-MS

Figure 2-26

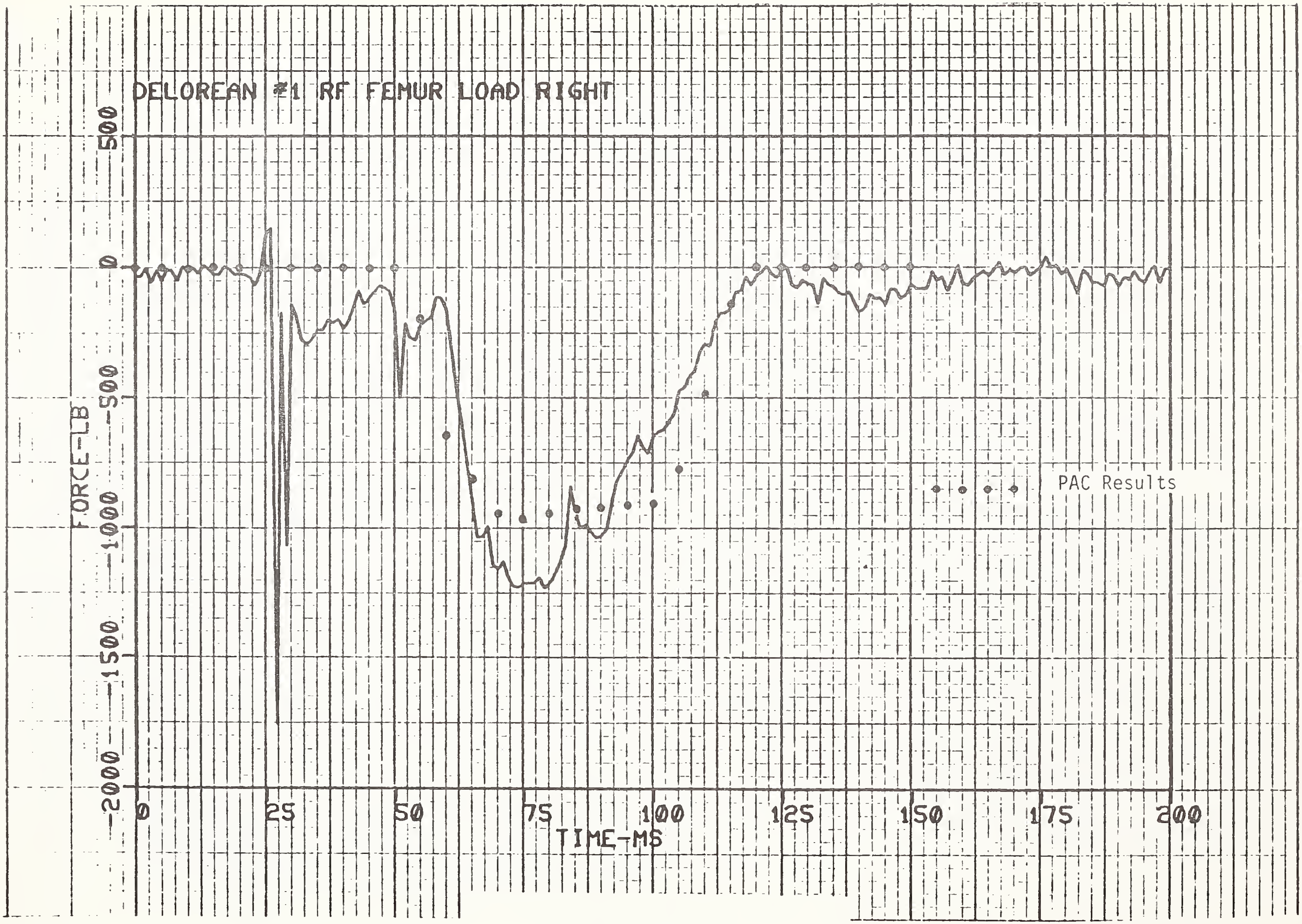
DELOREAN #1 RF FEMUR LOAD RIGHT
FORCE-LB
500
0
-500
-1000
-1500
-2000
0
25
50
75
100
125
150
175
200
TIME-MS
PAC Results

Figure 2-27

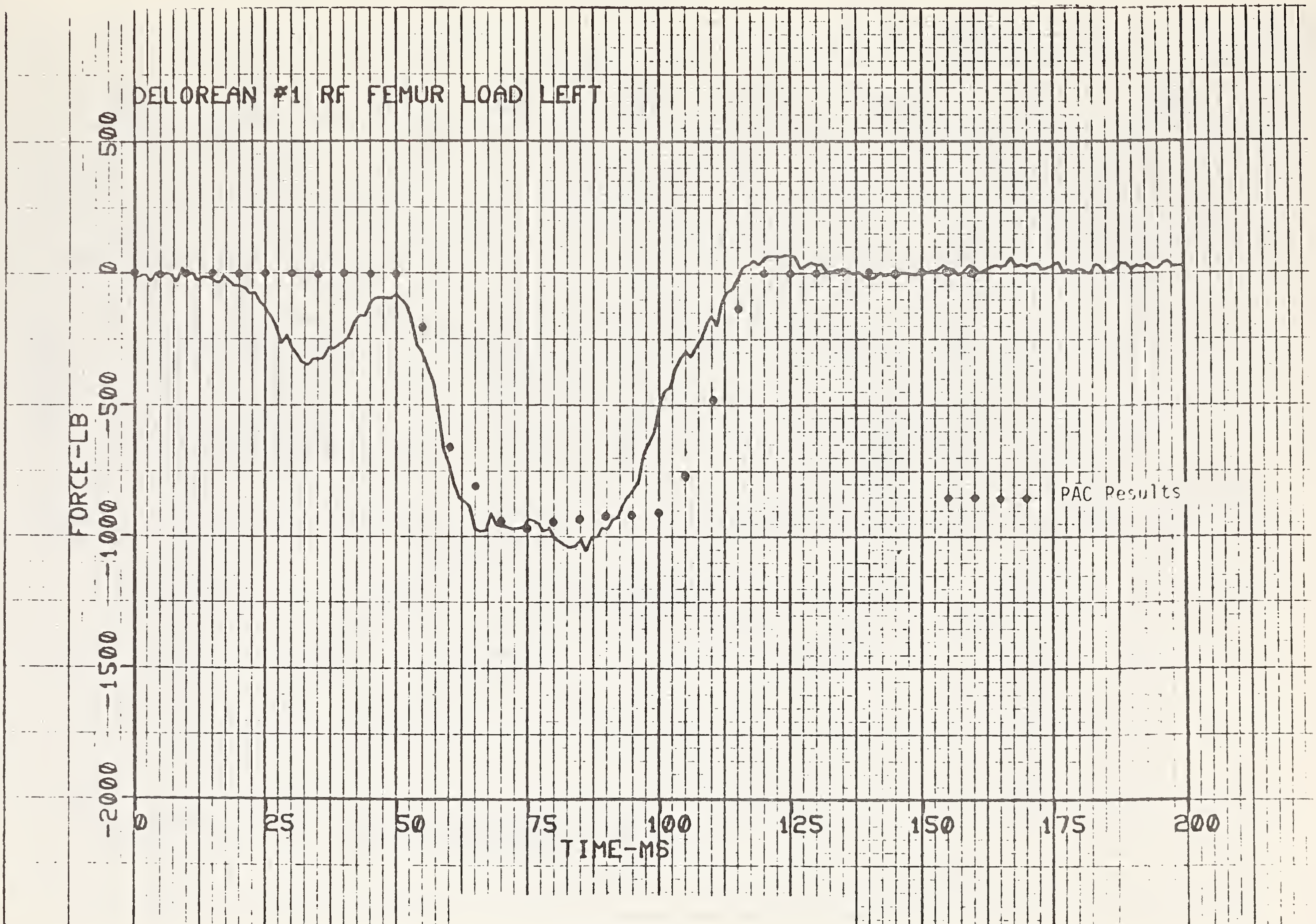
DELOREAN #1 RF FEMUR LOAD LEFT
PAC Results
FORCE-LB
500
0
-500
-1000
-1500
-2000
0
25
50
75
100
125
150
175
200
TIME-MS

Figure 2-28

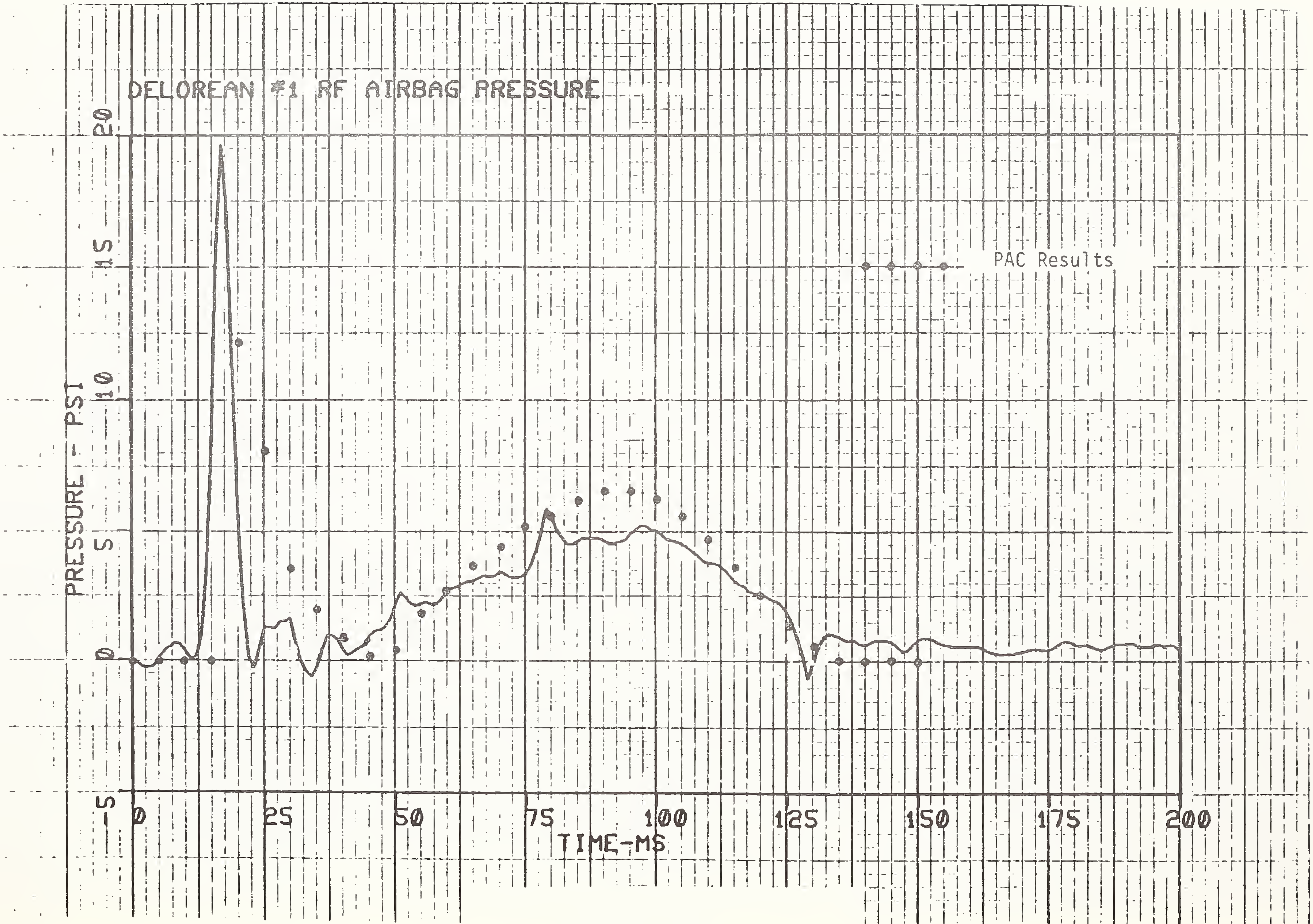
DELOREAN #1 RF AIRBAG PRESSURE
PAC Results
PRESSURE - PSI
20
15
10
5
0
-5
0
25
50
75
100
125
150
175
200
TIME-MS

Figure 2-29

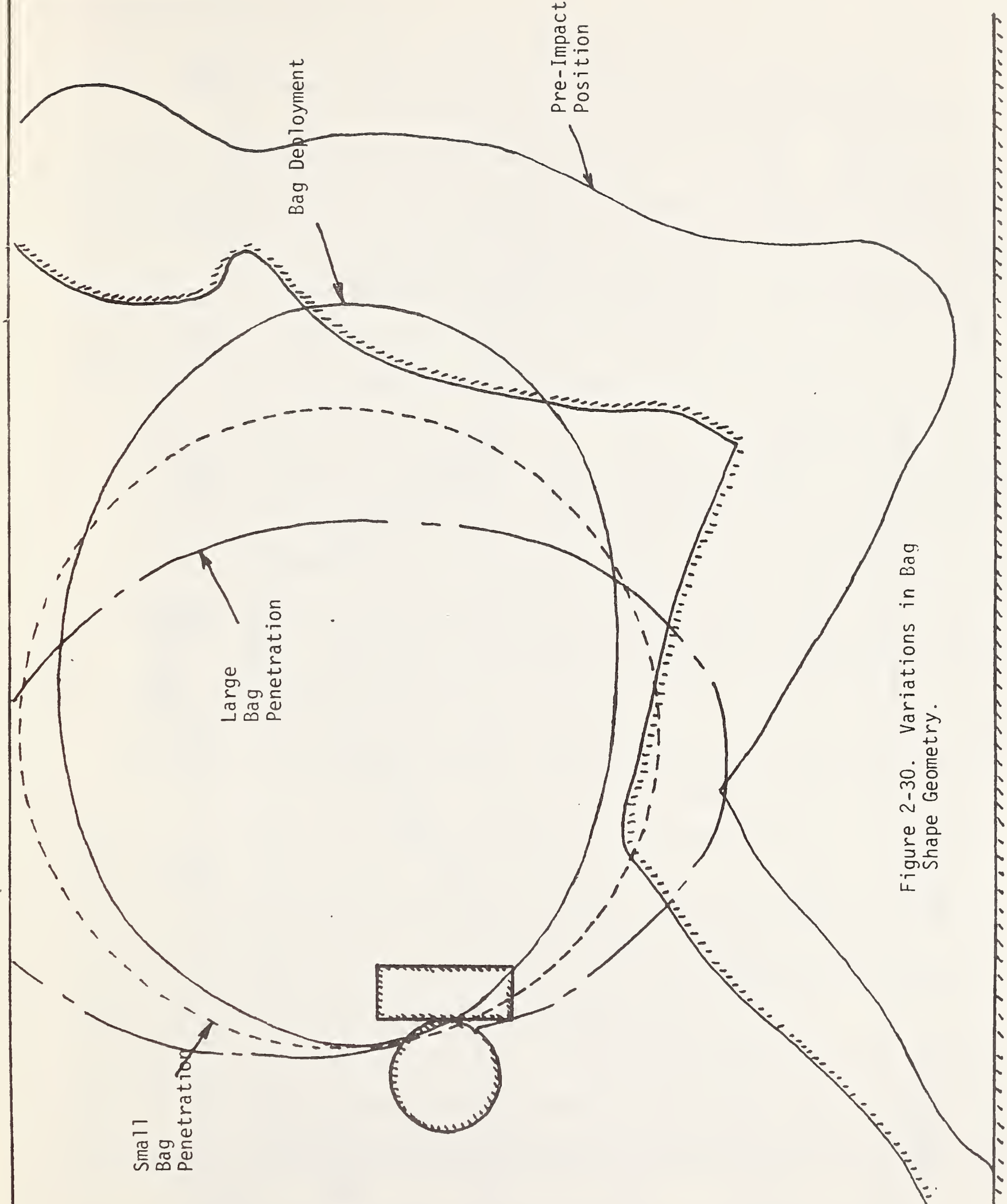

Figure 2-30. Variations in Bag
Shape Geometry.

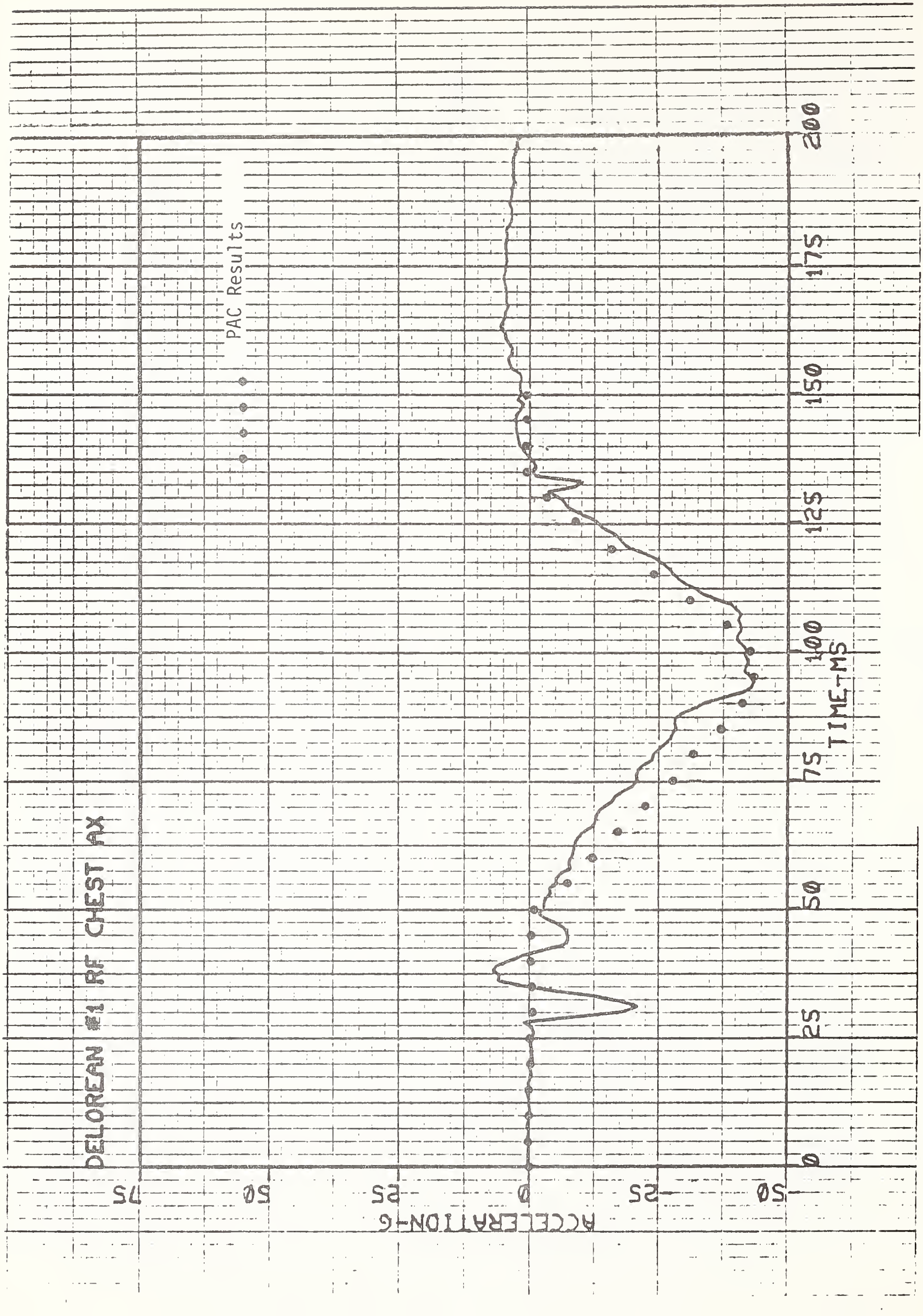
DELOREAN #1 RF CHEST AX
PAC Results
TIME-MS
0
25
50
75
100
125
150
175
200
ACCELERATION-G
75
50
25
0
25
50

Figure 2-31

due to the simplifying assumptions for bag shape in PAC.

5. Torso S-I Accelerations - Figure 2-32 compares the calculated and measured torso S-I accelerations. For times greater than 70 msec, large discrepancies between the calculated and measured accelerations exist.[1] These discrepancies are believed to be due to the simplifications in the PAC model. This can best be explained by referring to Figure 2-33. In the actual test, the dummy is seated on a seat cushion (which behaves as a spring-mass system). During impact, "lap loads" are generated on the dummy as the bag wraps around the dummy's thighs. These lap loads will impart a positive (downward) torso S-I acceleration as the dummy is accelerated into the seat cushion. In the PAC model (see Figure 2-20) a rigid seat cushion is assumed; Hence, there are no contributions to the torso S-I accelerations, from the lap loads, in the calculations.

6. Head A-P Accelerations - Figure 2-34 compares the calculated and measured head A-P accelerations. As noted in the figure, PAC simulations were conducted for two different head sizes (11.2 lbm and 13.5 lbm). This was done to evaluate the effects of head mass on head response. The small disparity between the calculated and measured head A-P accelerations is believed to be due to the simplified bag shape assumptions in PAC.

7. Head S-I Accelerations - Figure 2-35 compares the calculated and measured head S-I accelerations. The large disparity between the calculated and measured values (after 100 msec) is due to the inter-

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[1] Although the % deviation is fairly high, the g levels are low; Hence, this deviation will not have much effect on the resultant g's.

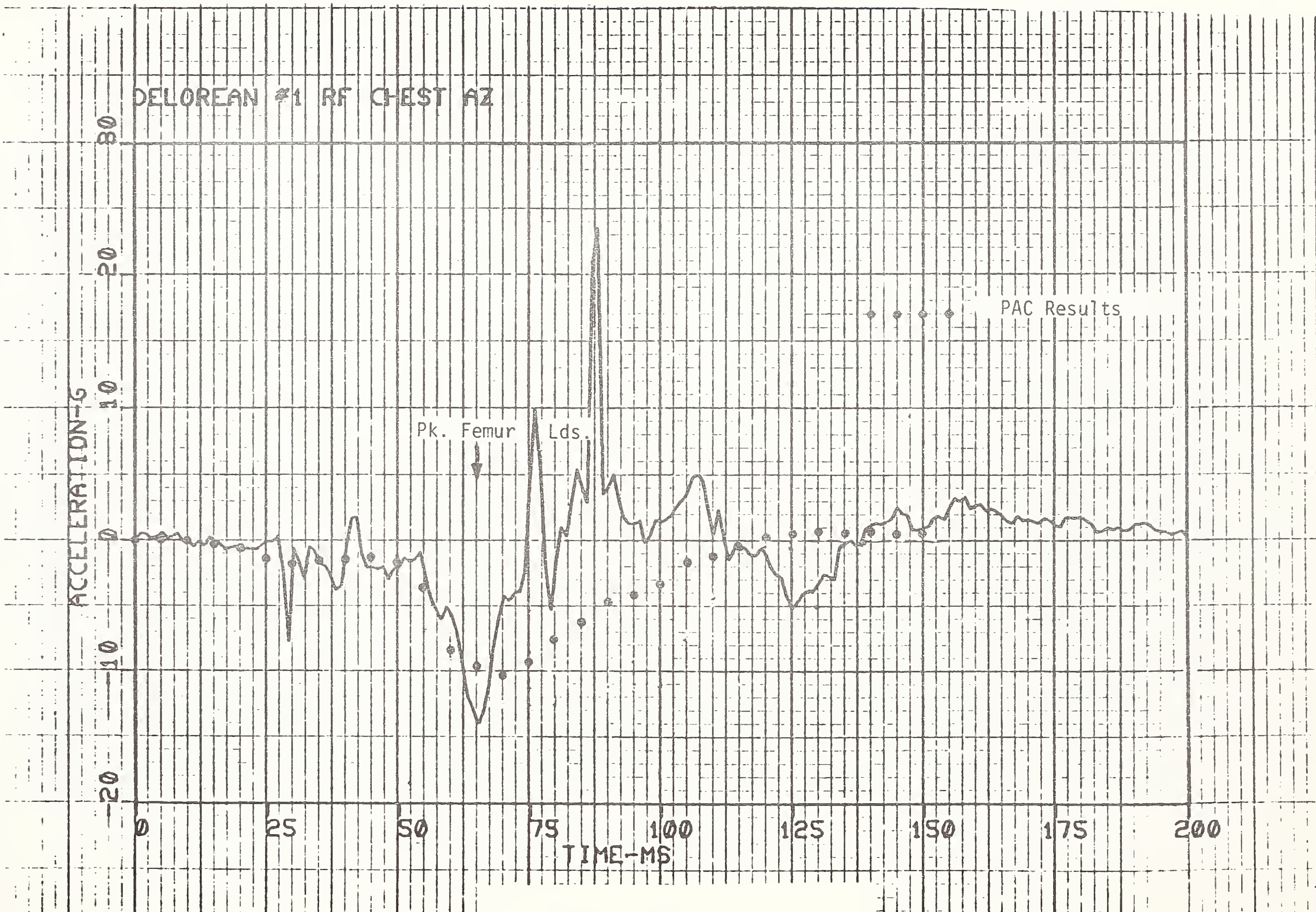

DELOREAN #1 RF CHEST AZ
PAC Results
Pk. Femur Lds.
ACCELERATION-G
30
20
10
0
-10
-20
0
25
50
75
100
125
150
175
200
TIME-MS

Figure 2-32

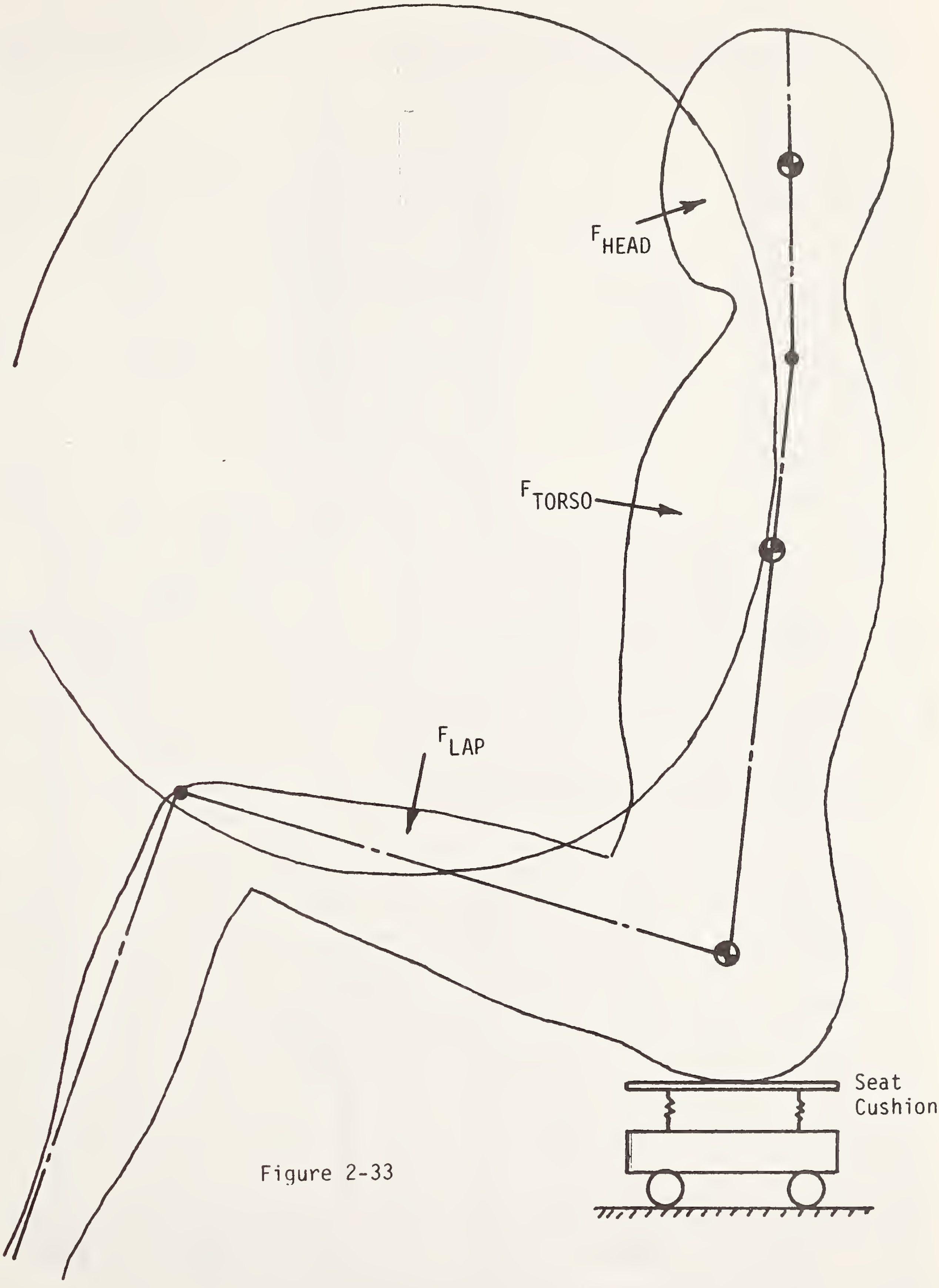


Figure 2-33

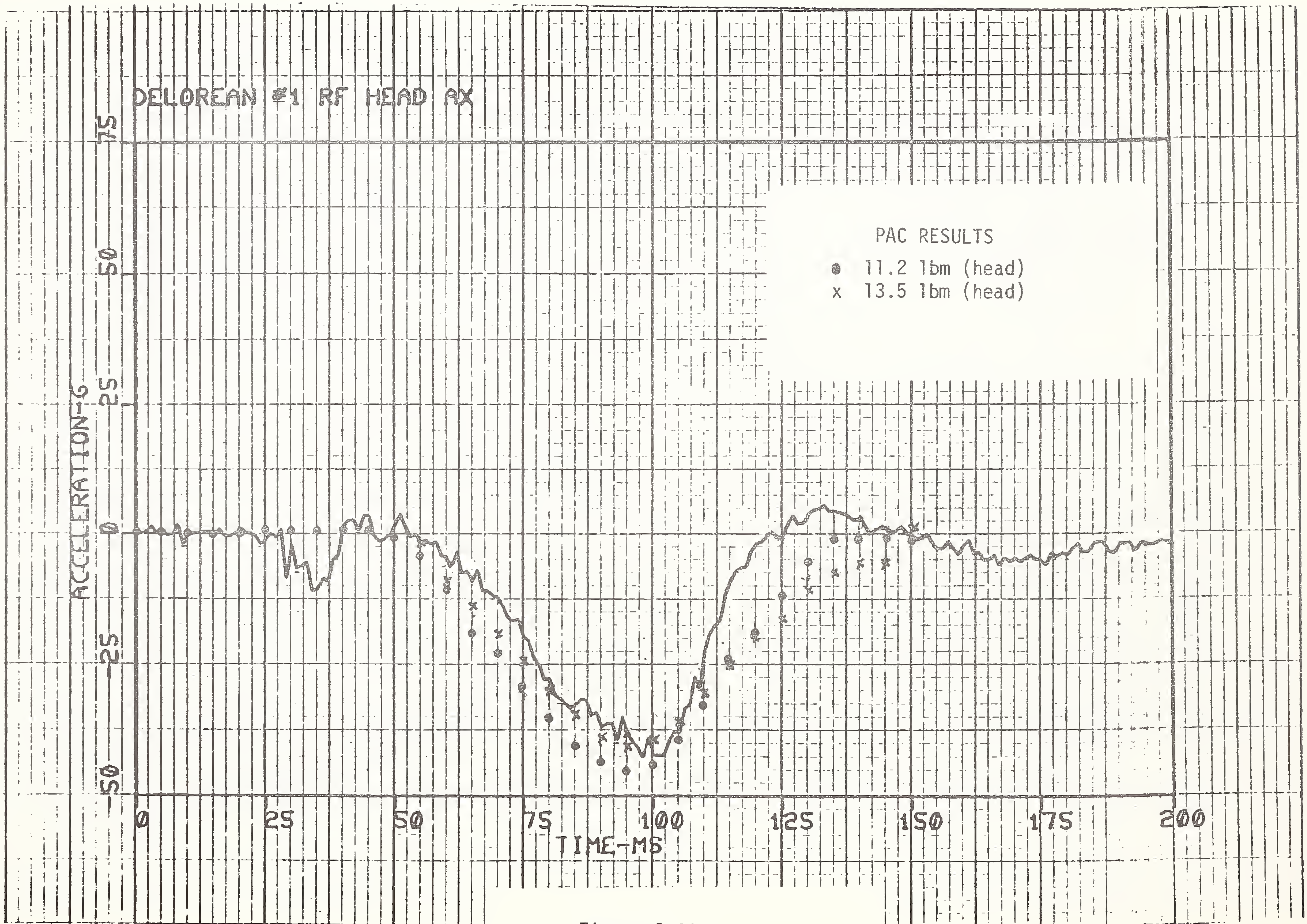

DELOREAN #1 RF HEAD AX
PAC RESULTS
● 11.2 lbm (head)
x 13.5 lbm (head)
ACCELERATION-G
75
50
25
0
-25
-50
0
25
50
75
100
125
150
175
200
TIME-MS

Figure 2-34

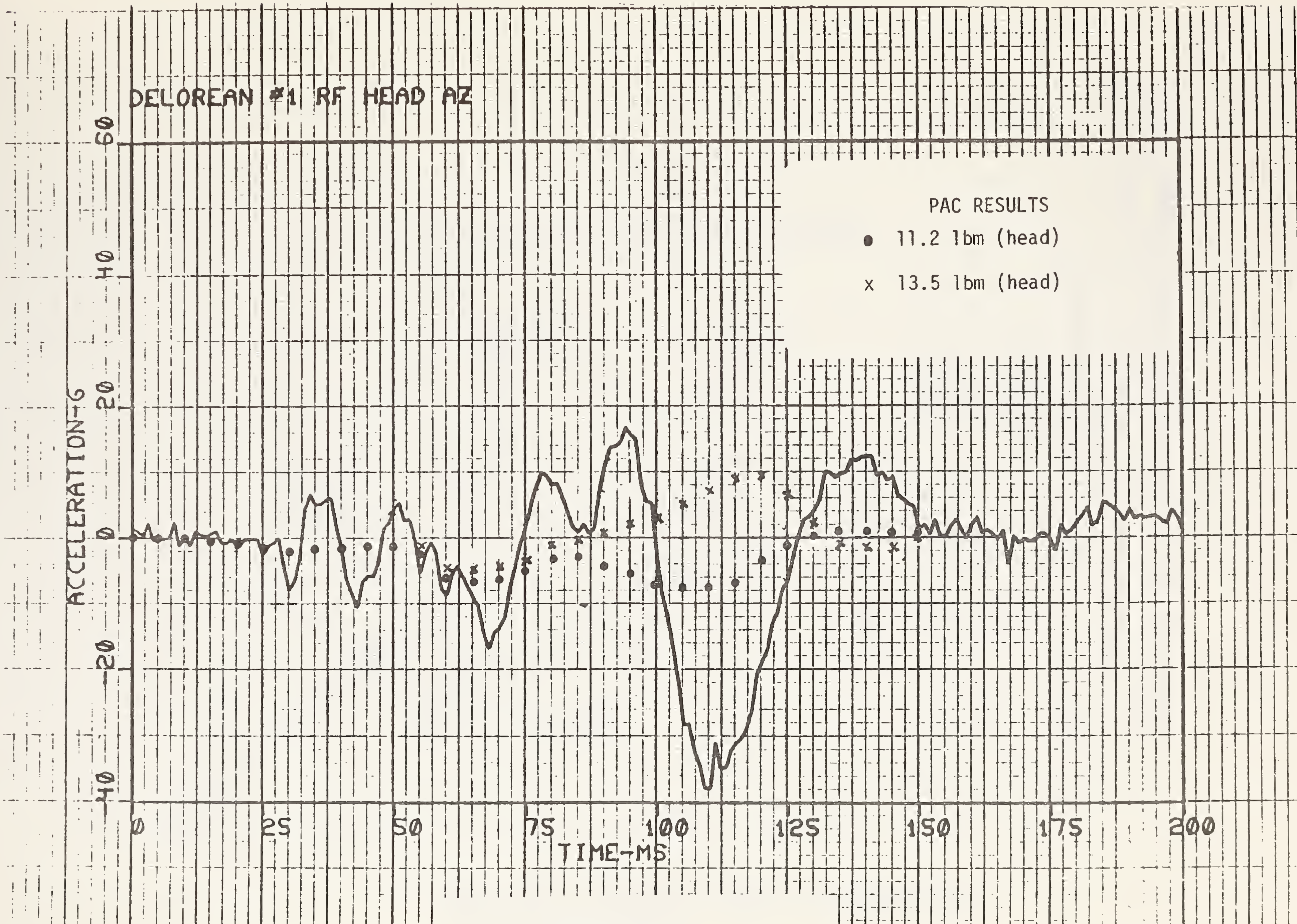

DELOREAN #1 RF HEAD AZ
PAC RESULTS
● 11.2 lbm (head)
x 13.5 lbm (head)
ACCELERATION-G
60
40
20
0
20
40
0
25
50
75
100
125
150
175
200
TIME-MS

Figure 2-35

action of the head with the "A" pillar during rebound (based on film observations). This interaction is not modeled in PAC.

8. Comparison of Calculated and "Measured" HIC:

	PAC	"Measured"
HIC	398 (330)	371
T1	.070 (.070) sec	.076 sec
T2	.120 (.120) sec	.119 sec

( ) denotes 13.5 lbm head

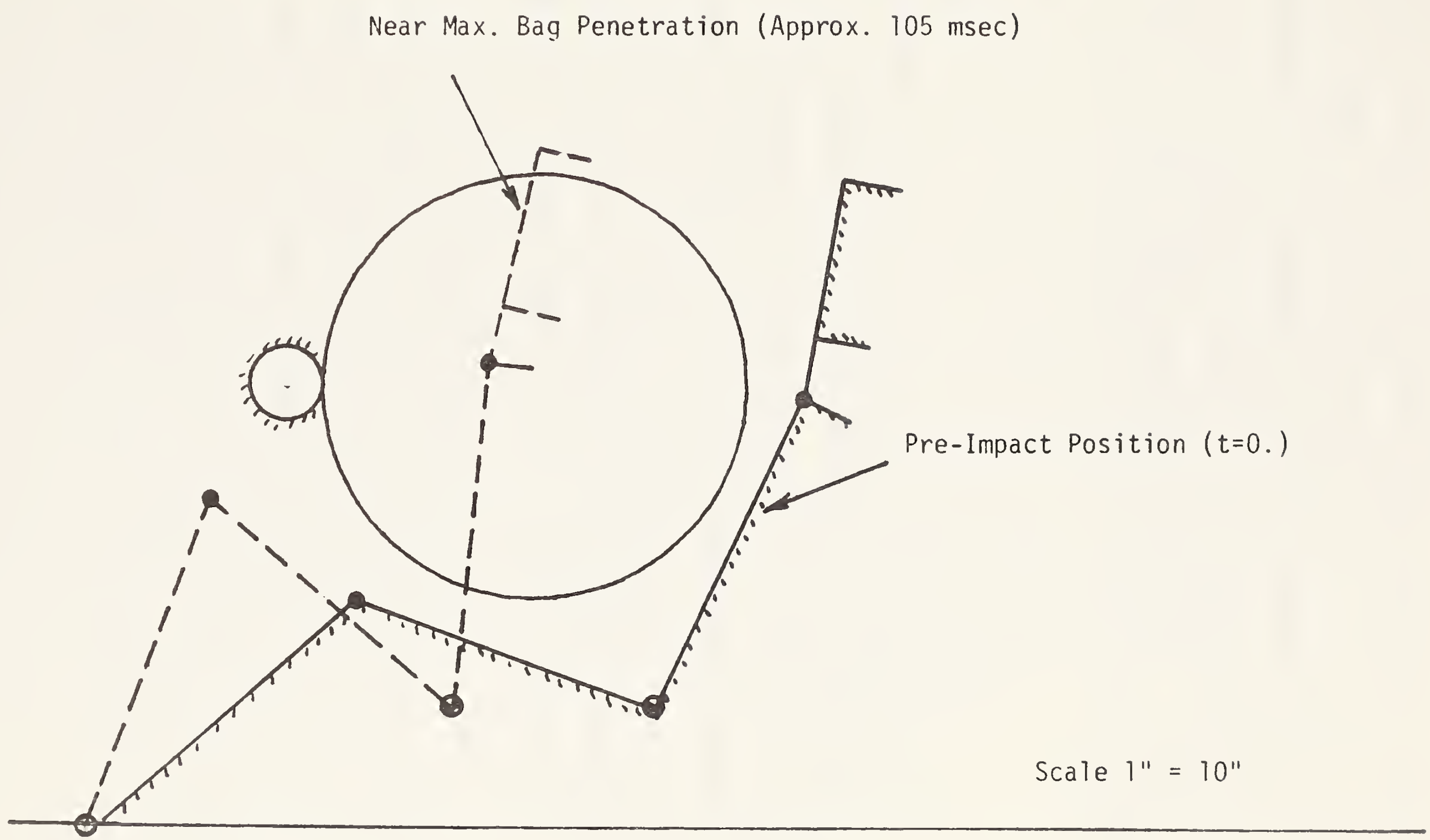


Figure 2-36. PAC Model Prediction of Occupant Near Maximum Bag Penetration (Approximately 105 msec Into the Crash Event).

3.0 RESTRAINT SYSTEMS PARAMETRIC ANALYSIS

Now that we have used the DeLorean crash test data to establish and setup the DRACR and PAC program input files, we are ready to use these two programs to extrapolate beyond the information gained in the crash tests. Here we will derive a total restraint system package that meets a wider range of performance objectives. We have chosen the format of a "parameter sensitivity analysis" to accomplish this goal.

3.1 METHOD

The methodology used in deriving the total restraint system design is best summarized by listing the steps that were followed in conducting this study. In general, it may be said that this approach was followed for both the driver restraint system and the passenger restraint system. In all cases, the computer predicted injury measure was selected as the basis for deciding on the relative "goodness" of a given design. The steps taken in this study are listed below:

1. Perform an inflator (gas generator) comparison. Here various gas generators (or inflators, the terms are used interchangeably in this report) were evaluated in order to select the ones that would best meet the objectives of this study. Primary consideration was given to availability (the inflator must be an available, "off the shelf" item with its production line intact and ready to go), to cost, and to performance. In order

to make this selection, various occupant sizes and occupant positions were investigated for each inflator.

2. Using the selected inflators deemed as the most promising, investigate the effect of impact speed and the sensing and/or inflator staging times.

3. Discuss the results of the simulations.

4. Make certain recommendations and conclusions.

With the overall program objectives stated and our methodology established, let us now discuss the specific results of the design selections via the computer simulation process. We will discuss the driver restraint system first followed by the passenger restraint system.

3.2 RESULTS OF COMPUTER SIMULATION STUDY - DRIVER SYSTEM

The baseline ACRS design and the baseline crash conditions, assumed in this part of the study, are discussed in Section 2.1 (one exception here is that the steering column is capable of stroking during impact). The baseline ACRS components and baseline crash conditions are summarized as follows:

1. ACRS Components
   - o Inflator - Thiokol/Mercedes Part No. IU 92520-4.
   - o Steering Wheel - Modified 1979 Volvo GT Wheel (spokes stiffened with .067" steel straps).
   - o Steering Column - A DeLorean Design.
   - o Air Bag - Circular Pattern (27.5" diameter - approximately 5240 in^3 volume, with 1.5 in^2 vent).
   - o Knee Restraint - Aluminum Honeycomb (1/4-5052-.0007) With 6061-TO Aluminum/vinyl Cover.
   - o Sensing Time - Approximately 15 msec.
2. Impact Configuration
   - o Impact Speed - 36 mph.
   - o Occupant Size - 50th Percentile Adult Male.
   - o Crash Pulse - DMC-12 Test No. 3120-1, Accelerometer No. 2.[1]

---

[1] Ibid., page 2-1.

3.2.1 Study Objective

The objective of this study was to evaluate the effects of component hardware design on restraint system performance, so that an intelligent selection of the component hardware could be made to achieve near optimum restraint system performance. The important design factors considered in this study were:

- Bag Geometry and Vent Size
- Inflator Flow Rate and Thermodynamic Characteristics
- Sensing Time
- Occupant Size
- Impact Speed

3.2.2 System Constraints

The system constraints imposed in this study are described in the following paragraphs:

<u>BAG GEOMETRY</u>

The shape of the bag when inflated was assumed to be an ellipsoid. The effects of bag size (volume) on restraint performance was evaluated, in DRACR, by "fixing" the bag shape (A/B = constant) and varying the major (A) and minor (B) radii. Using the baseline bag shape as the constant, we have:

$$A/B\big|_{baseline} = A_{baseline}/B_{baseline} \quad \ldots\ldots\ldots\ldots \quad (3\text{-}1)$$

$$= 12.5/8.0$$

$$= \underline{\underline{1.563}}$$

Three bag sizes were evaluated in this study. For the baseline design, a bag volume of approximately 5240 in^3 (A=12.5 in, B=8. in) was assumed. The other two sizes were determined as follows:

$\underline{VOL_{low} = 4500\ in^3 \quad (assumed)}$

$$VOL_{low} = 4/3\pi A_{low}^2\ B_{low} = 4500 \quad .... \quad (3\text{-}2)$$

But,

$$A_{low}/B_{low} = 1.563$$

$$\therefore \quad 4/3\pi(1.563B_{low})^2 B_{low} = 4500$$

or,

$$B_{low} = (4500(3)/(4\pi 1.563^2))^{\frac{1}{3}} = \underline{\underline{7.6}}\ in$$

and,

$$A_{low} = 1.563B_{low}$$
$$= 1.563(7.6) = \underline{\underline{11.89}}\ in$$

$\underline{VOL_{high} = 6000\ in^3 \quad (assumed)}$

$$VOL_{high} = 4/3\pi A_{high}^2\ B_{high} = 6000 \quad .... \quad (3\text{-}3)$$

But,

$$A_{high}/B_{high} = 1.563$$

$$\therefore \quad 4/3\pi(1.563B_{high})^2 B_{high} = 6000$$

or,

$$B_{high} = (6000(3)/(4\pi 1.563^2))^{\frac{1}{3}} = \underline{\underline{8.37}}\ in$$

and,

$$A_{high} = 1.563B_{high} = 1.563(8.37) = \underline{\underline{13.1}}\ in$$

INFLATOR CHARACTERISTICS

Four inflator designs were selected for evaluation in this study. These designs were:

- Thiokol/Mercedes Part No. IU92520-04 (Baseline design)
- Talley Part No. CB-1640 (Driver Type - 111.1 gms)
- Talley Part No. CU-1605 (Passenger Type - 168.6 gms)
- Bayer Chemie[1]

Figure 3-1 compares the flow rate history curves for these inflators (the flow rate history curves were determined from tank test data).

SENSING TIME

The effects of sensing time were evaluated using sensing times of 10, 15 (baseline) and 20 msec (i.e., time scale for inflator flow rate history curve translated + and - 5 msec from the baseline).

OCCUPANT GEOMETRY, MASS AND STIFFNESS

For the baseline impact condition, a 50th percentile adult male occupant was assumed. The geometry and mass characteristics for this occupant size are discussed in Section 2.1.2. The neck stiffness for this occupant size is shown in Figure 2-7. To evaluate the effects of occupant size on restraint performance, two additional sizes of occupants were considered, a 5th percentile adult female and a 95th percentile adult male. Because of the scarcity of biomechanic, geometry and mass data for these occupant sizes, various assumptions were made

---

[1] Data not available in time for this analysis.

NO. 340-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.

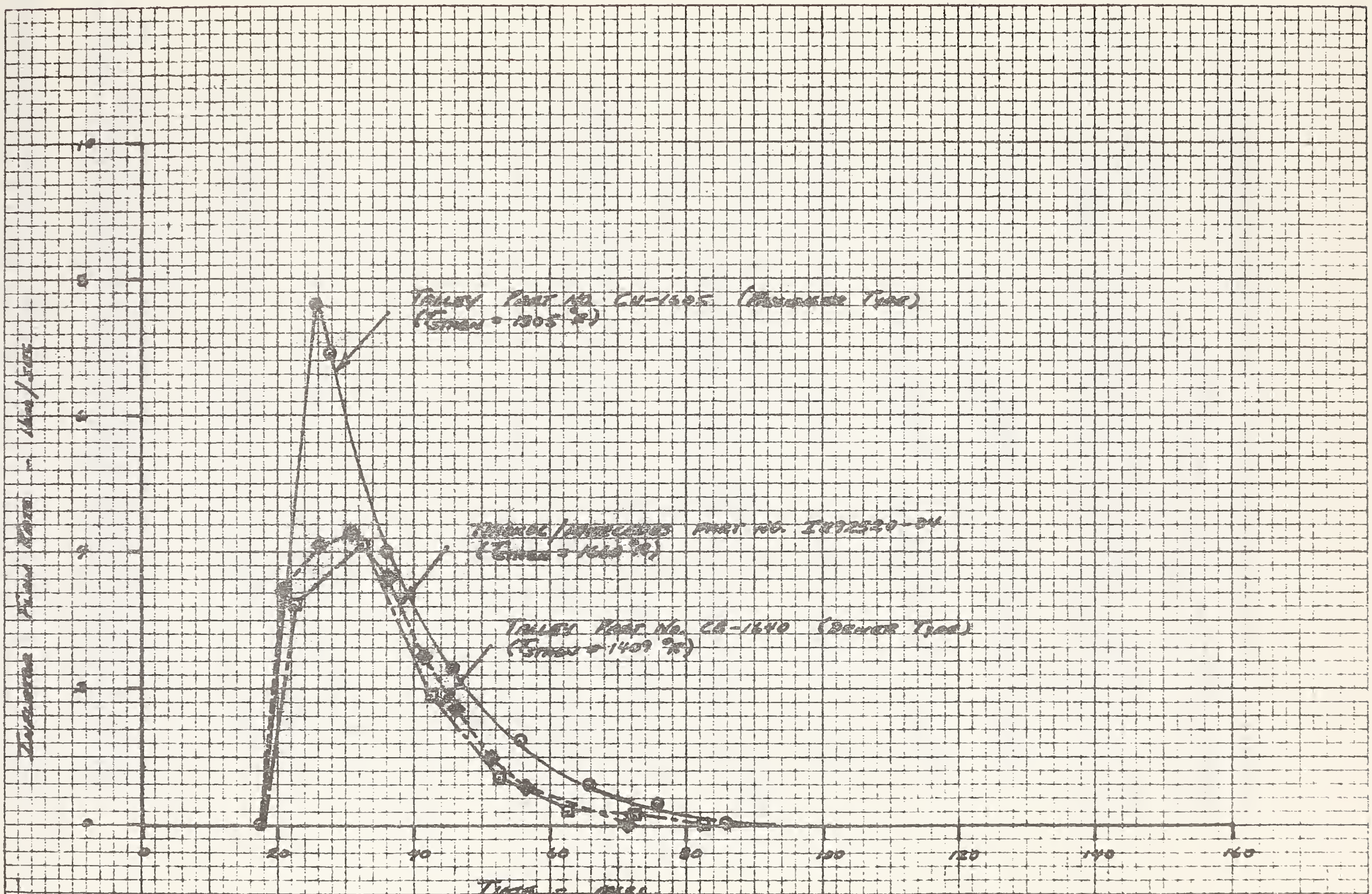


Figure 3-1. Comparison of Flow Rate History Curves For Several Inflator Designs.

L.S.F. 1/11/82

in generating the required data input for the DRACR simulations.[1] The assumptions made here are discussed below:

Mass Distribution: The mass distribution for the 5th percentile female and the 95th percentile male occupant sizes were estimated as follows:

$$M_{head_i} = (M_{tot_i}/M_{tot_{50th}}) \cdot M_{head_{50th}} \quad \ldots\ldots\ldots \quad (3\text{-}4)$$

$$M_{torso_i} = (M_{tot_i}/M_{tot_{50th}}) \cdot M_{torso_{50th}} \quad \ldots\ldots\ldots \quad (3\text{-}5)$$

$$M_{hip_i} = (M_{tot_i}/M_{tot_{50th}}) \cdot M_{hip_{50th}} \quad \ldots\ldots\ldots \quad (3\text{-}6)$$

where,

i = ith percentile occupant size (5th, 95th)

From dummy data[2] we have,

- o $M_{tot_{5th}}$ = 102 lbs
- o $M_{tot_{50th}}$ = 164 lbs
- o $M_{tot_{95th}}$ = 215 lbs

From Figure 2-3,

- o $M_{head_{50th}}$ = 11.2 lbs
- o $M_{torso_{50th}}$ = 57.9 lbs
- o $M_{hip_{50th}}$ = 72.7 lbs

---

1 Plans are being made for additional research work in this area. The objective of this future work will be to generate a more accurate data set, applicable for various occupant sizes, for use in future DRACR and PAC simulation work.

2 Ltr from Mr. A.J. Slechter, Jr. (DOT), to Mr. W. Rup (AMF inc.), 31 Aug. 1970, "Preliminary Dimensions for 5th % F and 95th % M dummies" (Appendix F).

Using Equation 3-4,

$$M_{head_{5th}} = (102/164)(11.2) = \underline{\underline{6.97}} \text{ lbs}$$

$$M_{head_{95th}} = (215/164)(11.2) = \underline{\underline{14.68}} \text{ lbs}$$

Using Equation 3-5,

$$M_{torso_{5th}} = (102/164)(57.9) = \underline{\underline{36.0}} \text{ lbs}$$

$$M_{torso_{95th}} = (215/164)(57.9) = \underline{\underline{75.9}} \text{ lbs}$$

Using Equation 3-6,

$$M_{hip_{5th}} = (102/164)(72.7) = \underline{\underline{45.2}} \text{ lbs}$$

$$M_{hip_{95th}} = (215/164)(72.7) = \underline{\underline{95.2}} \text{ lbs}$$

Parameter (RTOPH): The parameter RTOPH, for the 5th percentile and 95th percentile occupants, was estimated from dummy data (see Appendix F)[1]. Using the nomenclature in Appendix F,

RTOPH[2] $= U - .737\,Q - 4.$ .... (3-7)

for the 5th percentile female,

$$RTOPH_{5th} = 30.9 - .737(4.1) - 4. = \underline{\underline{23.9}} \text{ in}$$

$$RTOPH_{95th} = 38.0 - .737(6.9) - 4 = \underline{\underline{28.9}} \text{ in}$$

---

1 Ibid., page 3-8.

2 See definition of RTOPH in Figure 2-3.

PARAMETER (R_H): For definition of R_H see Figure 2-3. The assumption was made here that R_H is proportional to the parameter RTOPH. Thus,

$$R_{H_i} = (RTOPH_i \ / \ RTOPH_{50th})(R_{H_{50th}}) \quad .... \quad (3\text{-}8)$$

where,

i = ith percentile occupant size

Therefore,

$$R_{H_{5th}} = (23.9/27.2)(6.5) = \underline{\underline{5.71}} \text{ in}$$

$$R_{H_{95th}} = (28.9/27.2)(6.5) = \underline{\underline{6.91}} \text{ in}$$

PARAMETER (R_N): This parameter was estimated from data by McFarland and Stoudt[1], using the following formula:

$$R_{N_i} = C_i - .737 \, E_i \quad .... \quad (3\text{-}9)$$

where,

i = ith percentile occupant size

C = Shoulder height (seated occupant - Table 3-1)

E = Thigh Height (seated occupant - Table 3-1)

Using Equation 3-9,

$$R_{N_{50th}} = 23.3 - .737(5.7) = \underline{\underline{19.1}} \text{ in}$$ [2]

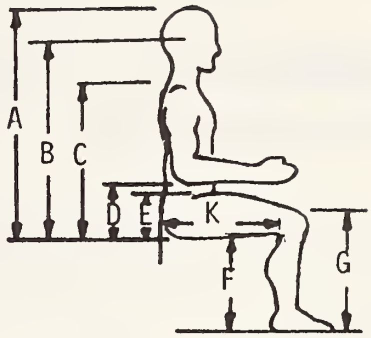
$$R_{N_{5th}} = 19.3 - .737(4.9) = \underline{\underline{15.7}} \text{ in}$$

---

1 R.A. McFarland and H.W. Stoudt, "Human Body Size and Passenger Vehicle Design", Harvard School of Public Health, SP-142A, SAE.

2 Good check, see Figure 2-3.

Table 3-1. Human Body Measurements.



Body Measurement		PERCENTILES 5th F	50th M	95th M
	Stature	59.5	68.4	72.6
	Weight (lbs)	105.	166.	216.
A.	Sitting Height	31.6	36.0	38.2
B.	Eye Height	27.2	31.6	33.7
C.	Shoulder Height	19.3	23.3	25.2
D.	Elbow Height	8.2	9.3	10.9
E.	Thigh Height	4.9	5.7	6.8
F.	Popliteal Height	13.9	16.9	18.1
G.	Knee Height	17.9	21.6	23.5
K.	Buttock-Popliteal Length	16.8	18.9	20.8

Ref. R.A. McFarland and H.W. Stoudt. "Human Body Size and Passenger Vehicle Design", SP-142A.

$$R_{N_{95th}} = 25.2-.737\ (6.8) = \underline{\underline{20.2}}\text{ in}$$

<u>PARAMETER (R_T):</u> It was assumed that the parameter R_T is proportional to the parameter RTOPH. Thus,

$$R_{T_i} = (RTOPH_i\ /RTOPH_{50th}) \cdot R_{T_{50th}} \quad \ldots\ldots\ldots\ldots \quad (3\text{-}10)$$

where,

i = ith percentile occupant size

Thus,

$$R_{T_{5th}} = (23.9/27.2)(13.7)^1 = \underline{\underline{12.0}}\text{ in}$$

$$R_{T_{95th}} = (28.9/27.2)(13.7)^1 = \underline{\underline{14.6}}\text{ in}$$

<u>PARAMETER (L_F):</u> The femur length (L_F) was determined from the following formulas and from dummy data[2].

$$L_{F_{5th}} = L_{F_{50th}} - (P_{50th} - P_{5th}) \quad \ldots\ldots\ldots\ldots\ldots \quad (3\text{-}11)$$

$$L_{F_{95th}} = L_{F_{50th}} - (P_{95th} - P_{50th}) \quad \ldots\ldots\ldots\ldots\ldots \quad (3\text{-}12)$$

Using these formulas we have,

$$L_{F_{5th}} = 18. - (23.3-20.4) = \underline{\underline{15.1}}\text{ in}$$

$$L_{F_{95th}} = 18. - (25.2-23.3) = \underline{\underline{19.9}}\text{ in}$$

---

1 See Figure 2-3.

2 Ibid., page 3-8

PARAMETER (WB): The effective width of the occupant's body (WB) was estimated as follows.

$$WB_{5th} = (RTOPH_{5th} / RTOPH_{50th}) \cdot WB_{50th} \quad \ldots\ldots\ldots\ldots \quad (3\text{-}13)$$

$$= (23.9/27.2)(15) = \underline{\underline{13.2}} \text{ in}$$

$$WB_{95th} = (RTOPH_{95th} / RTOPH_{50th}) \cdot WB_{50th} \quad \ldots\ldots\ldots\ldots \quad (3\text{-}14)$$

$$= (28.9/27.2)(15) = \underline{\underline{15.9}} \text{ in}$$

PARAMETER (WH): The effective width of the occupant's head (WH) was defined as,

$$WH_{5th} = \underline{\underline{4.4}} \text{ in}$$

$$WH_{50th} = \underline{\underline{7.0}} \text{ in}$$

$$WH_{95th} = \underline{\underline{7.0}} \text{ in}$$

PARAMETER (L_{flesh}): The parameter L_{flesh} (see Figure 2-3) was defined as the following,

$$L_{flesh_{5th}} = \underline{\underline{2.8}} \text{ in}$$

$$L_{flesh_{95th}} = \underline{\underline{4.0}} \text{ in}$$

NECK STIFFNESS: It was assumed here that the neck stiffness does not vary with dummy size.[1] Figure 2-7 shows the characteristics assumed here.

---

[1] Plans are being made for a future study in which physical measurements of neck stiffness (for various dummy sizes) will be made.

IMPACT SPEED

Three impact speeds were evaluated for their effect on restraint performance. The impact speeds were 30 mph, 36 mph and 40.6 mph. The acceleration pulses for the 36 mph and the 40.6 mph impact speeds were determined from actual barrier impact tests of the Delorean Sports Car.[1] For the 30 mph case, the acceleration pulse was determined as follows:

$$a(t)_{30} = (30./36.) \cdot a(t)_{36} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3\text{-}15)$$

In addition, two sensing effects were included. First, it was assumed that the baseline sensing time of 15 msec applied to all of the impact speeds (i.e., sensing time independent of impact speed). Next, it was assumed that the sensing time varied with impact speed in the following manner:

Impact Speed	Sensing Time
30 mph	20 msec
36 mph	15 msec (baseline)
40.6 mph	12 msec

STEERING WHEEL CRUSH CHARACTERISTICS

The crush characteristics assumed for the steering wheel are those shown in Figure 2-6.

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[1] Ibid., page 2-1.

STEERING COLUMN CRUSH (STROKING) CHARACTERISTICS

The characteristics assumed for steering column crush are those shown in Figure 3-2.

SEAT FRICTION AND KNEE RESTRAINT RESISTANCE

Figure 3-3 shows the characteristics assumed for seat friction and knee restraint resistance.

3.2.3 Simulation Results - Driver System

DRACR simulations were conducted to evaluate the following effects on restraint system performance:

EFFECT OF INFLATOR DESIGN

Three inflator designs were evaluated here.[1] These designs were,

1. Thiokol/Mercedes Part No. IU92520-04 (baseline)
2. Talley Part No. CB-1640 (Driver Type - 111.1 gms)
3. Talley Part No. CU-1605 (Passenger Type - 168.6 gms).

DRACR simulations for the Thiokol/Mercedes inflator are summarized in Figure 3-4. In these simulations, the bag vent area was varied to determine the "near-optimum" operating condition for the inflator. Other parameters were "fixed" at the baseline values (see page 3-1).

DRACR simulations for the Talley Part No. CB-1640 inflator indicated that this inflator does not put out enough gas for the baseline crash

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[1] Inflator by Bayer Chemie not evaluated because data was not available for this study.

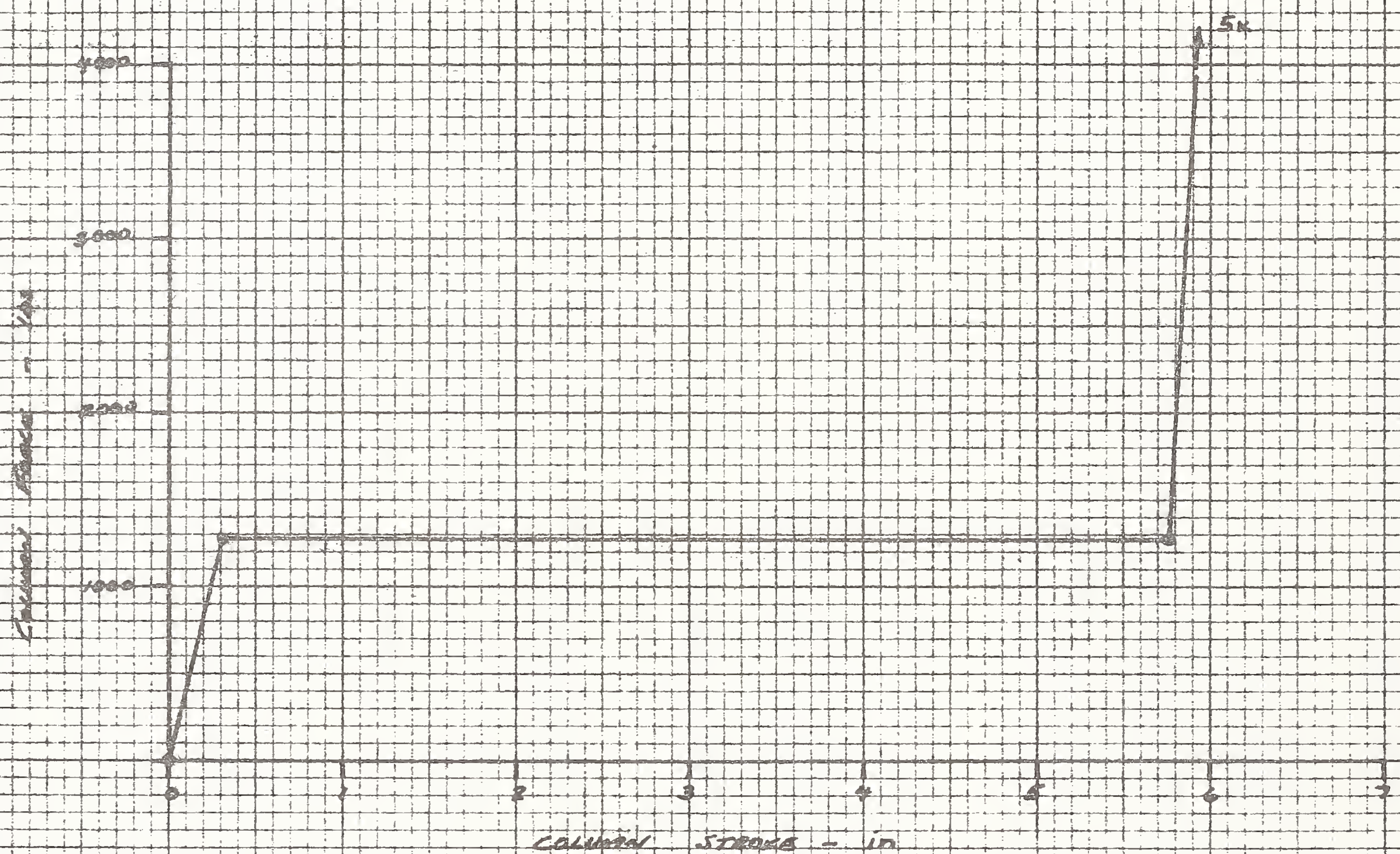

Figure 3-2. Steering Column Force v.s. Stroking Distance.

LSP 1/18/82

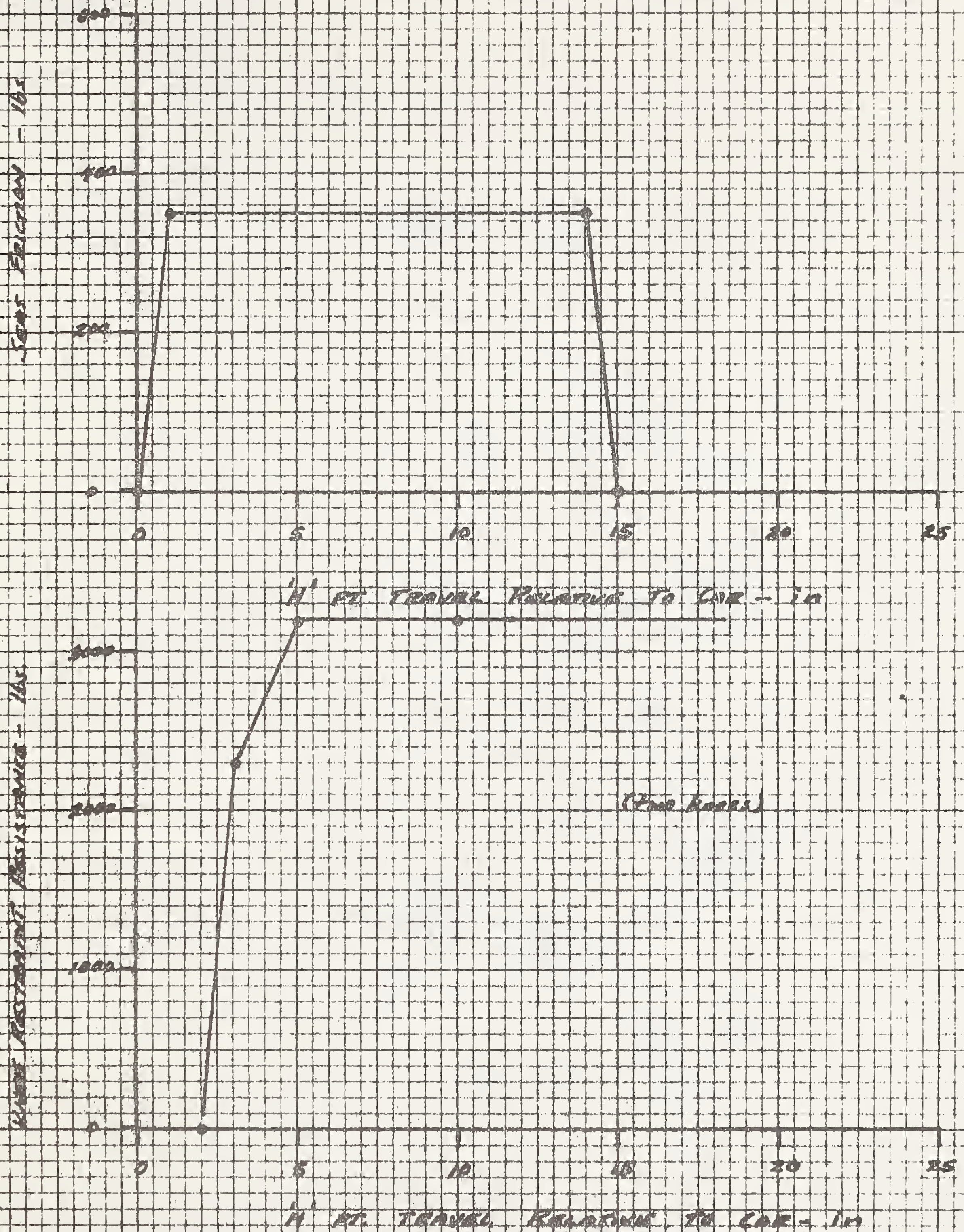

Figure 3-3. Seat Friction and Knee Restraint Resistance.

LSP 1/15/82

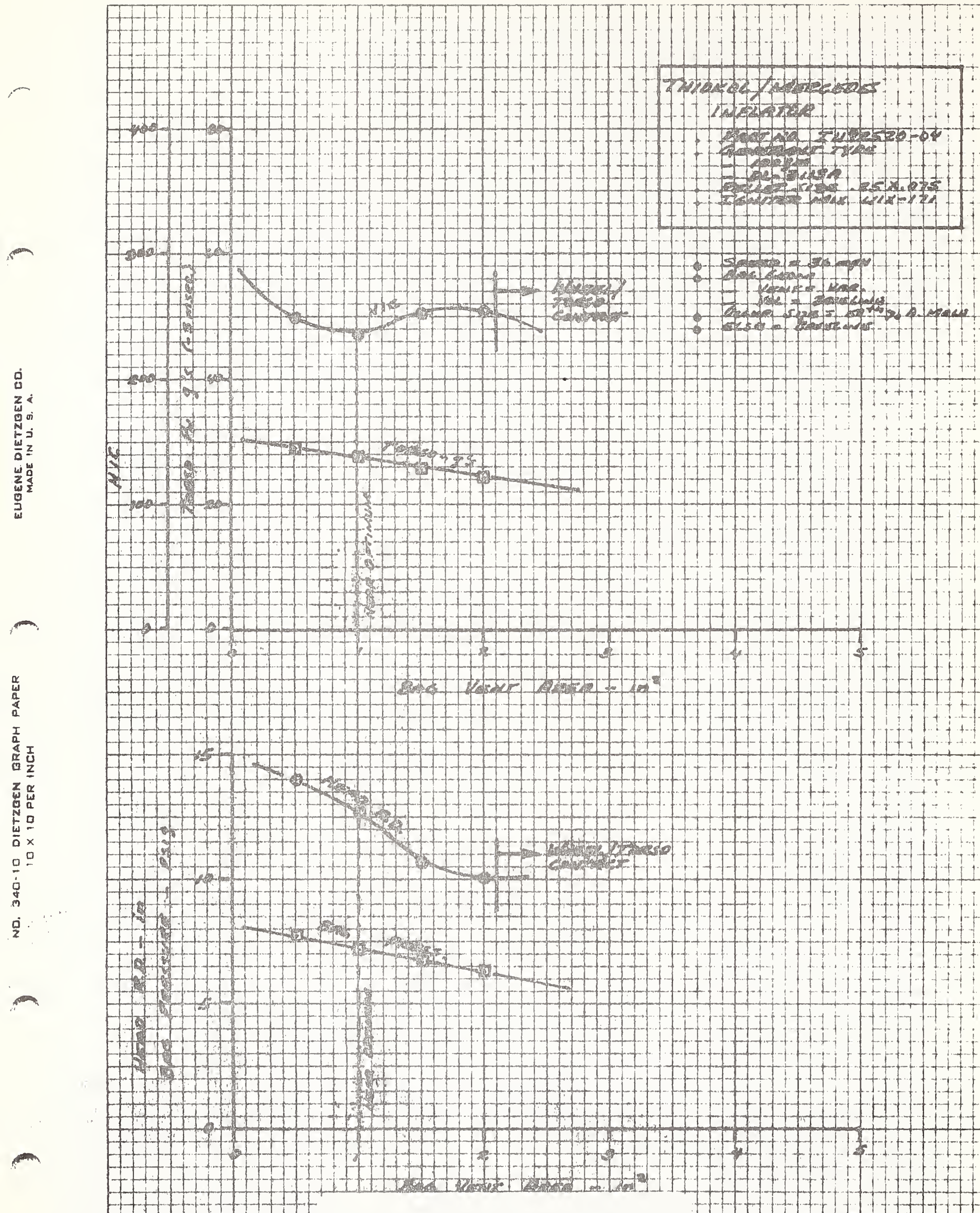

Figure 3-4. Restraint System Performance, Thiokol/Mercedes Inflator.

conditions. This inflator was, therefore, removed from further consideration.

Figure 3-5 summarizes the DRACR results for the Talley Part No. CU-1605 inflator. Comparing these results with those summarized in Figure 3-4 we see that at the near optimum conditions, both the Talley and the Thiokol/Mercedes inflators give about the same level of restraint system performance (measured in terms of HIC, peak torso g's, head relative displacement, and peak bag pressure).

In selecting the primary inflator design, for the remaining parts of this study, several factors (other than restraint performance) were considered. First, was the availability of the inflators. The Thiokol/Mercedes inflator is an off-the-shelf design which has been produced on a mass basis by Thiokol. This part appears to be readily available at a reasonable cost. The Talley inflator also has a production line set-up, however its increased size might make it hard to package in the Volvo wheel. This second factor was considered in making sure the inflator selected would fit within the DMC. The Thiokol/Mercedes inflator has a proven track record here[1] while the Talley inflator may require some steering wheel modification for its application as a "driver" inflator in the DMC.

All things being considered, the Thiokol/Mercedes inflator appears to be the best selection for the "primary" inflator design in the remaining parts of this study. The Talley inflator (Part No. CU-1605) is considered to be a back-up design. Since these two inflators give about the same restraint performance, it is believed that the simulation

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[1] Ibid., page 2-1.

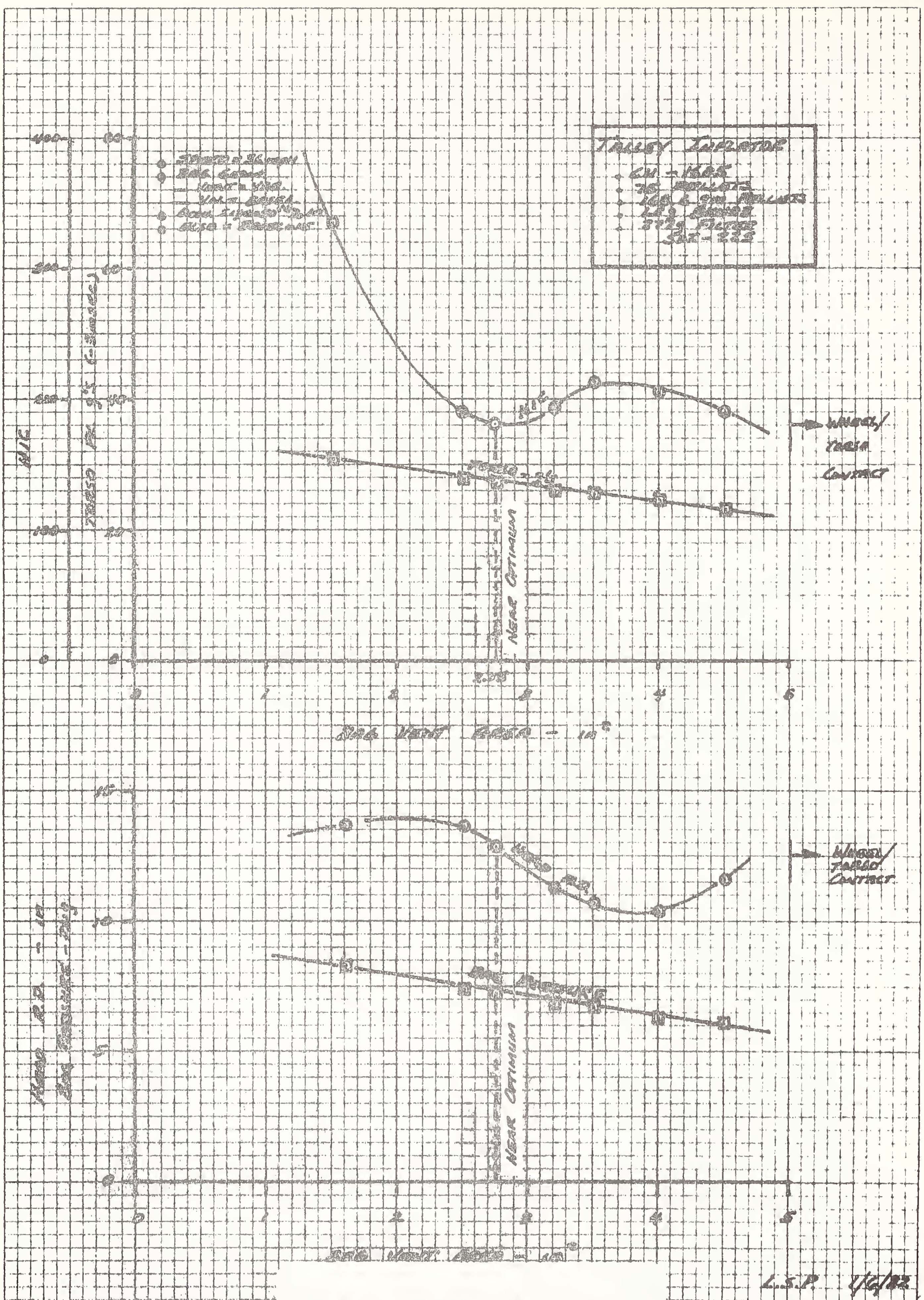

Figure 3-5. Restraint System Performance, Talley Inflator.

results in the remaining parts of this study, applicable to the Thiokol/ Mercedes inflator, will be approximately the same for the Talley inflator.

EFFECT OF BAG VOLUME

In determining the effect of bag volume on restraint system performance, the following conditions were assumed in DRACR:

. Inflator - Thiokol/Mercedes

. Bag Volume - Variable

. Bag Vent Area - 1.0 in^2 (near optimum, see Figure 3-4)

. Remaining Parameters - Baseline (see page 3-1)

Figure 3-6 summarizes the results of the DRACR simulations. The results indicate that the baseline bag volume (approximately 5240 in^3) gives near-optimum restraint performance.

EFFECT OF OCCUPANT SIZE

In determining the effect of occupant size on restraint system performance, the following conditions were assumed in DRACR:

. Inflator - Thiokol/Mercedes

. Bag Volume - Baseline (approximately 5240 in^3)

. Bag Vent Area - 1.0 in^2 (near optimum, see Figure 3-4)

. Occupant Size - 5th Percentile Female, 50th Percentile Male, 95th Percentile Male

. Remaining Parameters - Baseline (see page 3-3)

Figure 3-7 summarizes the results of the DRACR simulations. The results show that the injury criteria (HIC $\leq$ 1000, peak torso g's $\leq$ 60 g's) are satisfied for all of the occupant sizes considered. The only marginal

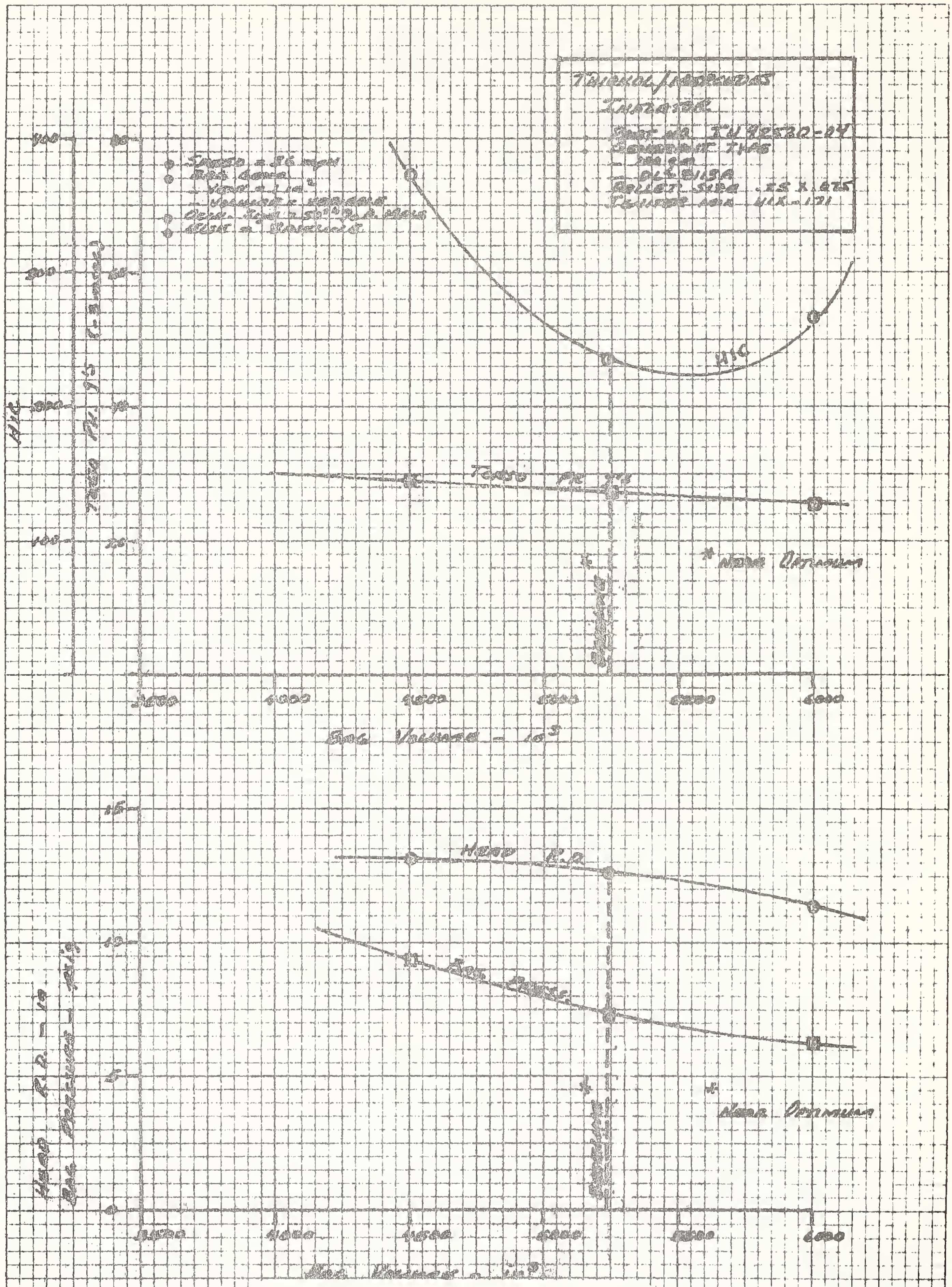

Figure 3-6. Effect of Bag Volume On Restraint System Performance.

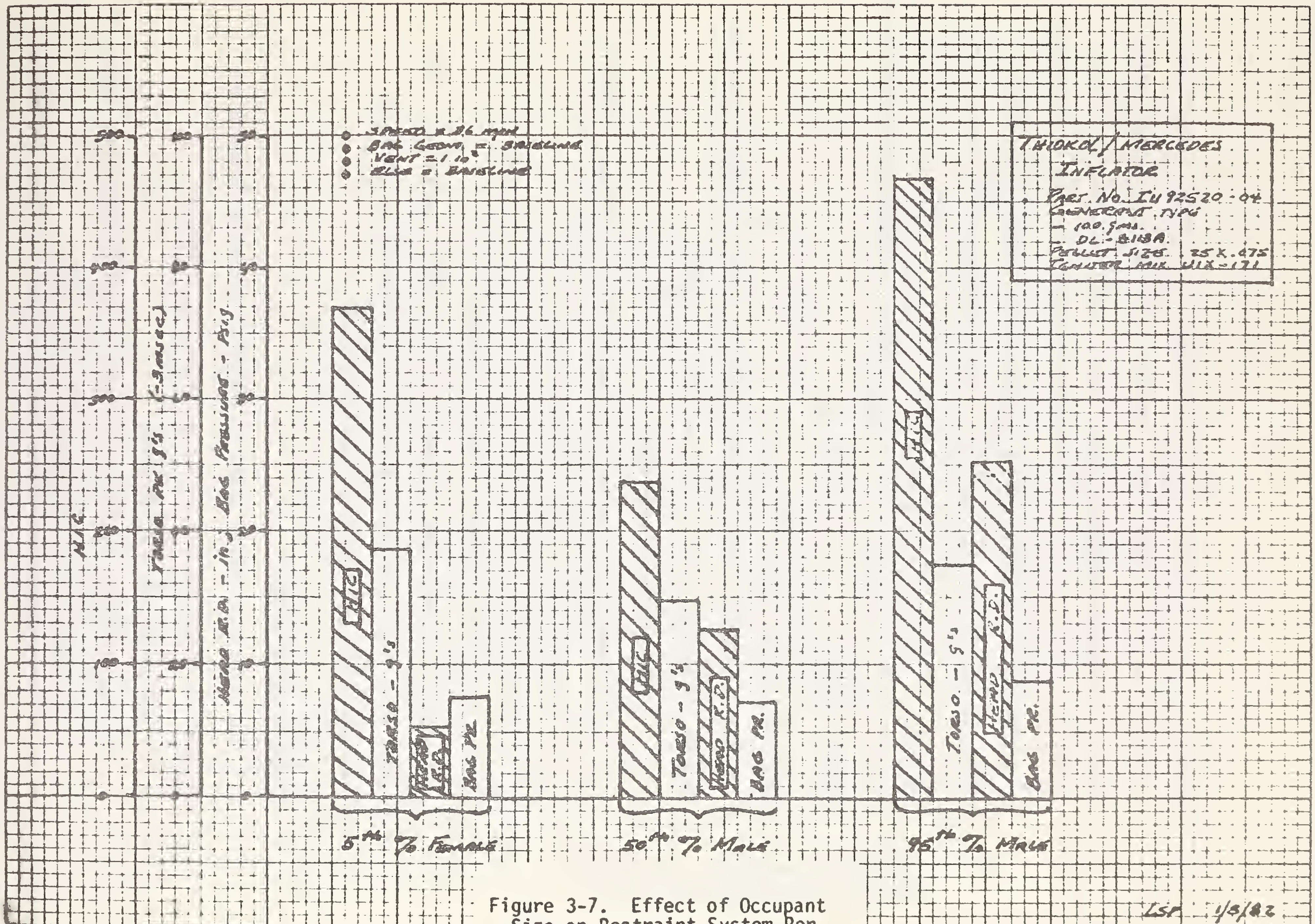

Figure 3-7. Effect of Occupant Size on Restraint System Permance.

condition that is indicated is head containment. The DRACR results give a head displacement (relative to passenger compartment) of approximately 25 inches, for the 95th percentile adult male. Figure 3-8 compares the configuration of the occupants at maximum bag penetration. The head excursion, calculated for the 95th percentile male occupant, exceeds the "safe" envelope provided by the DMC interior. This indicates that the driver ACRS should be optimized for the 95th percentile male occupant, to minimize head excursion. This, of course, will result with a "harder" bag for the smaller occupant sizes.

EFFECT OF SENSING TIME

The effects of sensing time on restraint system performance was evaluated by enforcing the following conditions in DRACR:

- Inflator - Thiokol/Mercedes
- Bag Geometry - Baseline (see page 3-3) With Vent Area = 1.0 in^2
- Occupant Size - 50th Percentile Adult Male
- Sensing Time - Variable
- Remaining Parameters - Baseline (see page 3-3)

Figure 3-9 summarizes the results of the DRACR simulations. The results show that the baseline sensing time (approximately 15 msec) gives near-optimum restraint system performance.

EFFECT OF IMPACT SPEED

The effects of impact speed on restraint system performance was evaluated by enforcing the following conditions in DRACR:

- Inflator - Thiokol/Mercedes
- Bag Geometry - Baseline (see page 3-3) With Vent Area = 1.0 in^2
- Occupant Size - 50th Percentile Adult Male

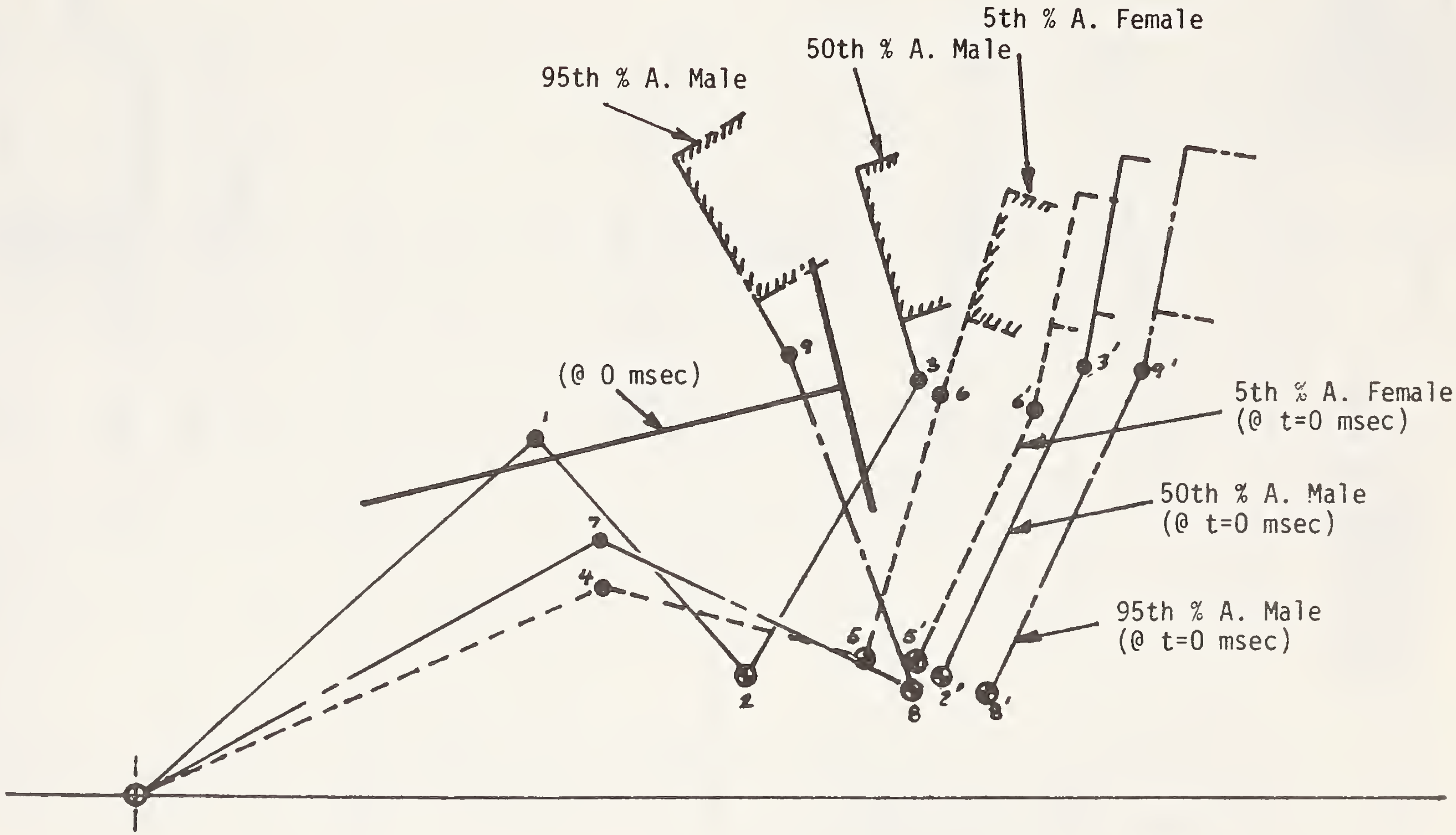

Figure 3-8. Occupant Configuration at Maximum Bag Penetration.

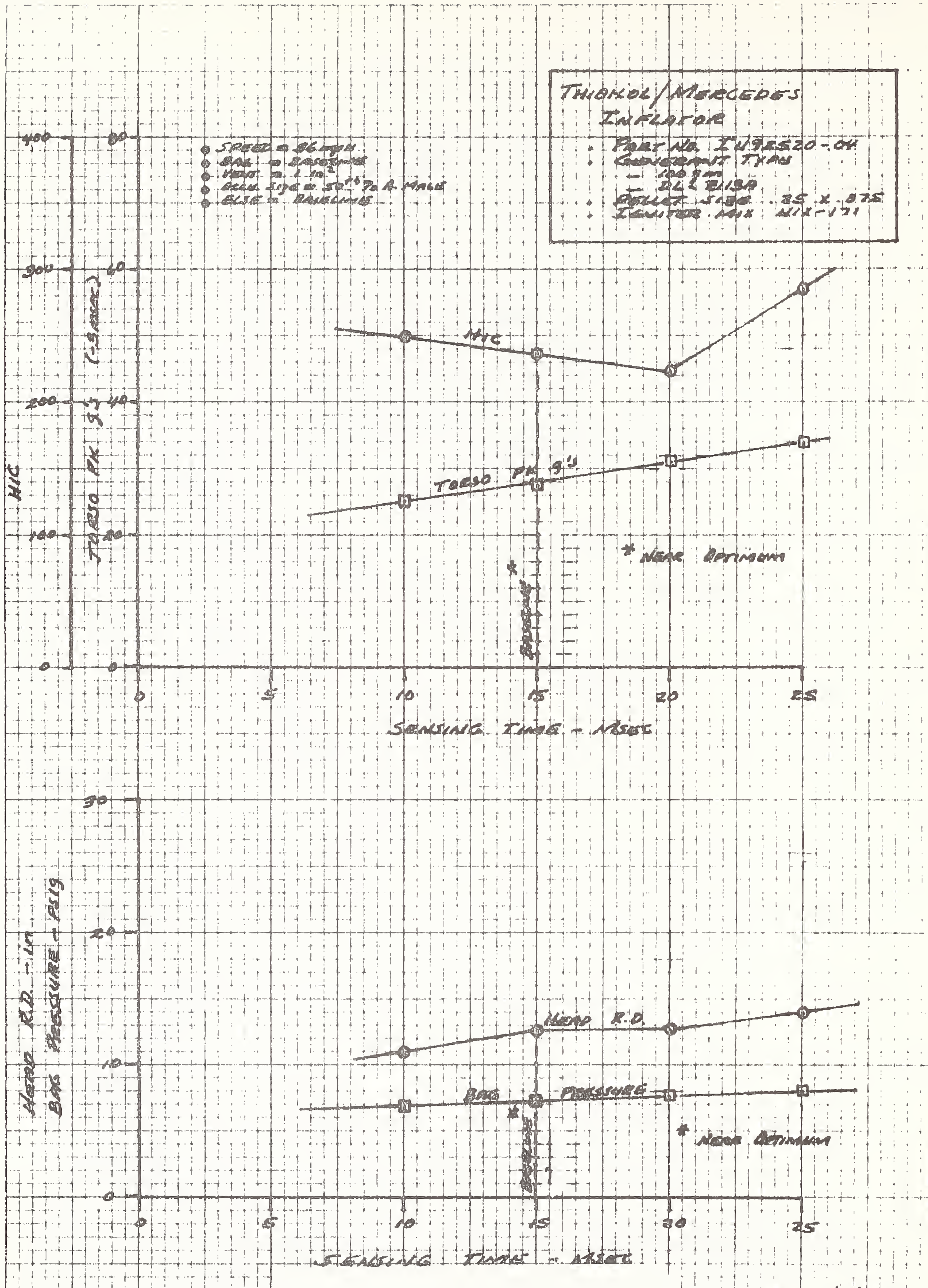

Figure 3-9. Effect of Sensing Time on Restraint System Performance.

- Impact Speed - Variable
- Sensing Time
  - Baseline (approximately 15 msec)
  - Varies With Impact Speed (see page 3-14)

Figure 3-10 summarizes the results of the DRACR simulations. The results show that for the 50th percentile adult male occupant, the injury criteria (i.e., HIC $\leq$ 1000 and peak torso g's $\leq$ 60 g's) is satisfied for the full impact velocity range considered. This holds true regardless of which sensing time assumptions (i.e., baseline or variable) are made. Furthermore, it appears that adequate head containment is provided by the ACRS for the full impact velocity range (head excursion less than 16 inches).

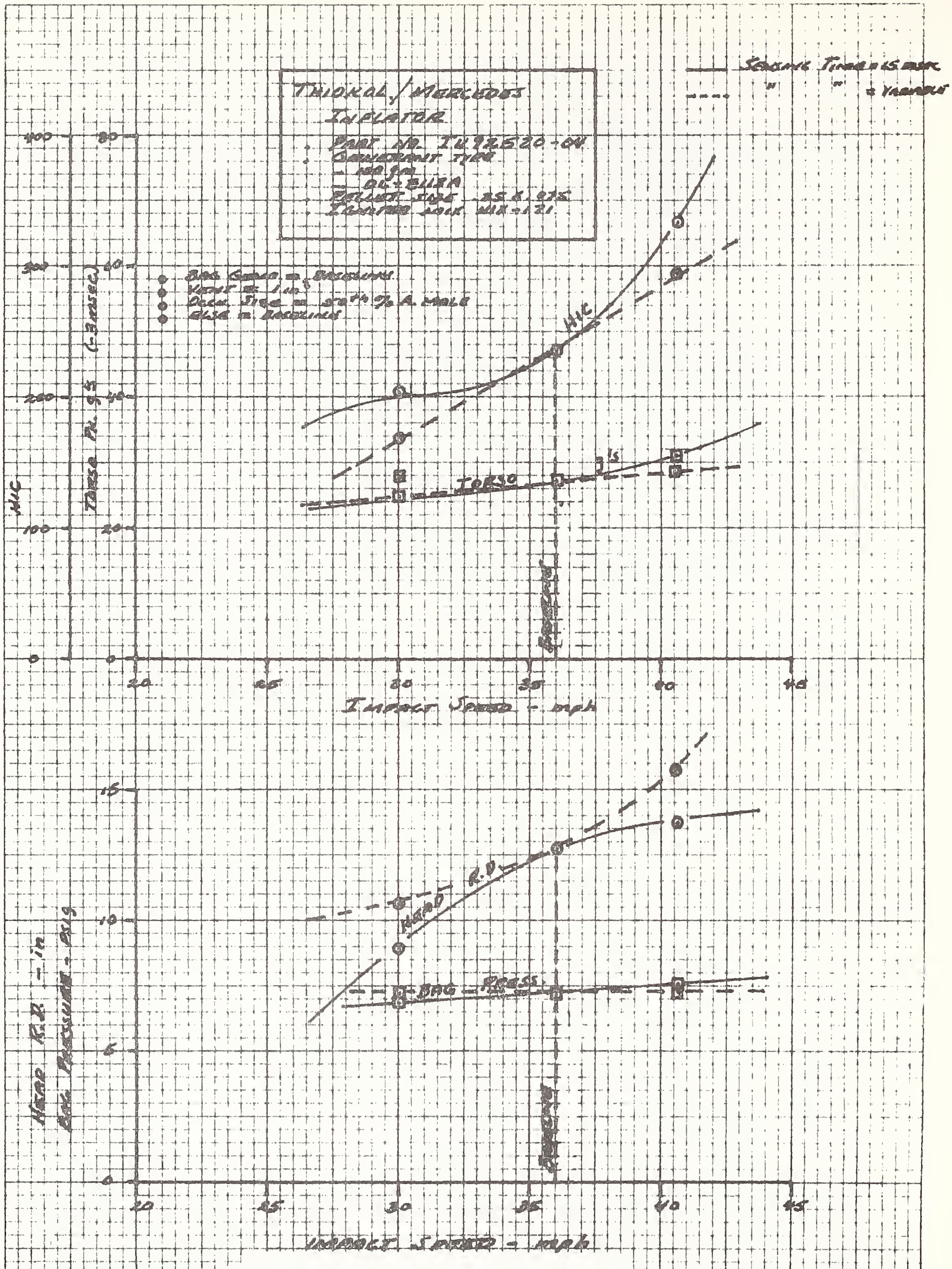

Figure 3-10. Effect of Impact Speed on Restraint System Performance.

3.3 RESULTS OF COMPUTER SIMULATION STUDY - PASSENGER SYSTEM

In this section, the results of the "parametric sensitivity study" for the passenger restraint system are discussed. Here, we will follow the same procedure as that followed in Section 3.2 for the driver restraint system. We will again assume that the baseline design is the one derived in Section 2.2 for the validation phase. To reiterate, the system derived in the validation phase (called here the "baseline" design) is composed of the ACRS components and crash conditions specified below:

1. ACRS Components
   - o Inflator - Two Thiokol/Mercedes Part No. IU 92520-4 inflators; staged in firing sequence by 7 msec.
   - o Air Bag - Circular cross section (19 inches wide - approxmately 5.7 cu. ft. total volume, with 5 sq. in. vent). See Figure 3-11.
   - o Knee Restraint - Aluminum honeycomb (Hexcel, 1/4 -5052-.0007) with aluminum casing and vinyl cover (Figure 3-12).
   - o Sensing Time - Approximately 15 msec (including squib burn-time) for first stage with second inflator ignited seven msec after the first.
2. Impact Configuration
   - o Impact Speed - 36 mph
   - o Passenger Size - 50th percentile adult male
   - o Crash Pulse - DeLorean crash test No. 3120-1, Accelerometer No. 3 (behind passenger, near "B" post).[1]

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[1] Ibid., page 2-1.

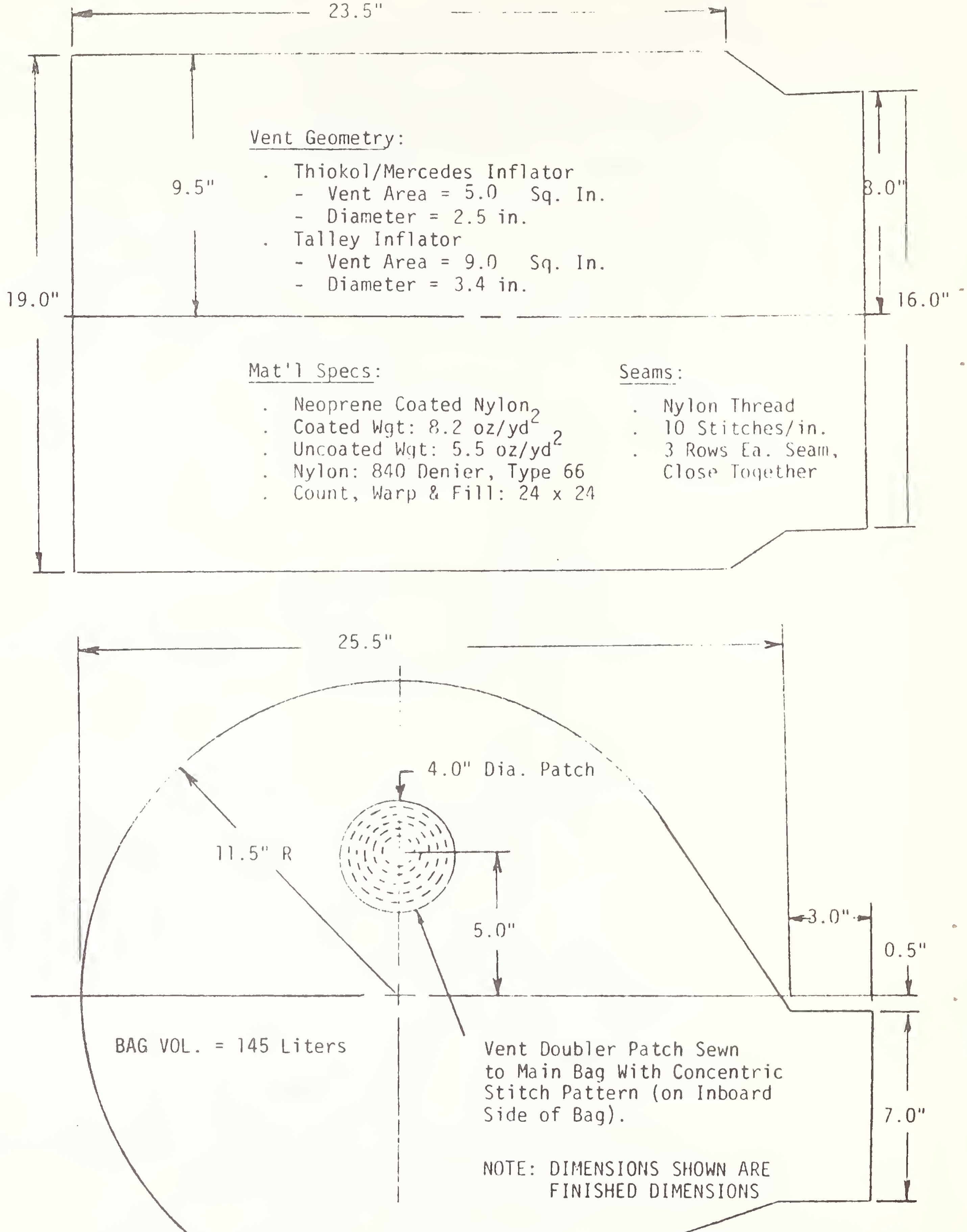

Figure 3-11. Bag Geometry, Passenger Restraint System.

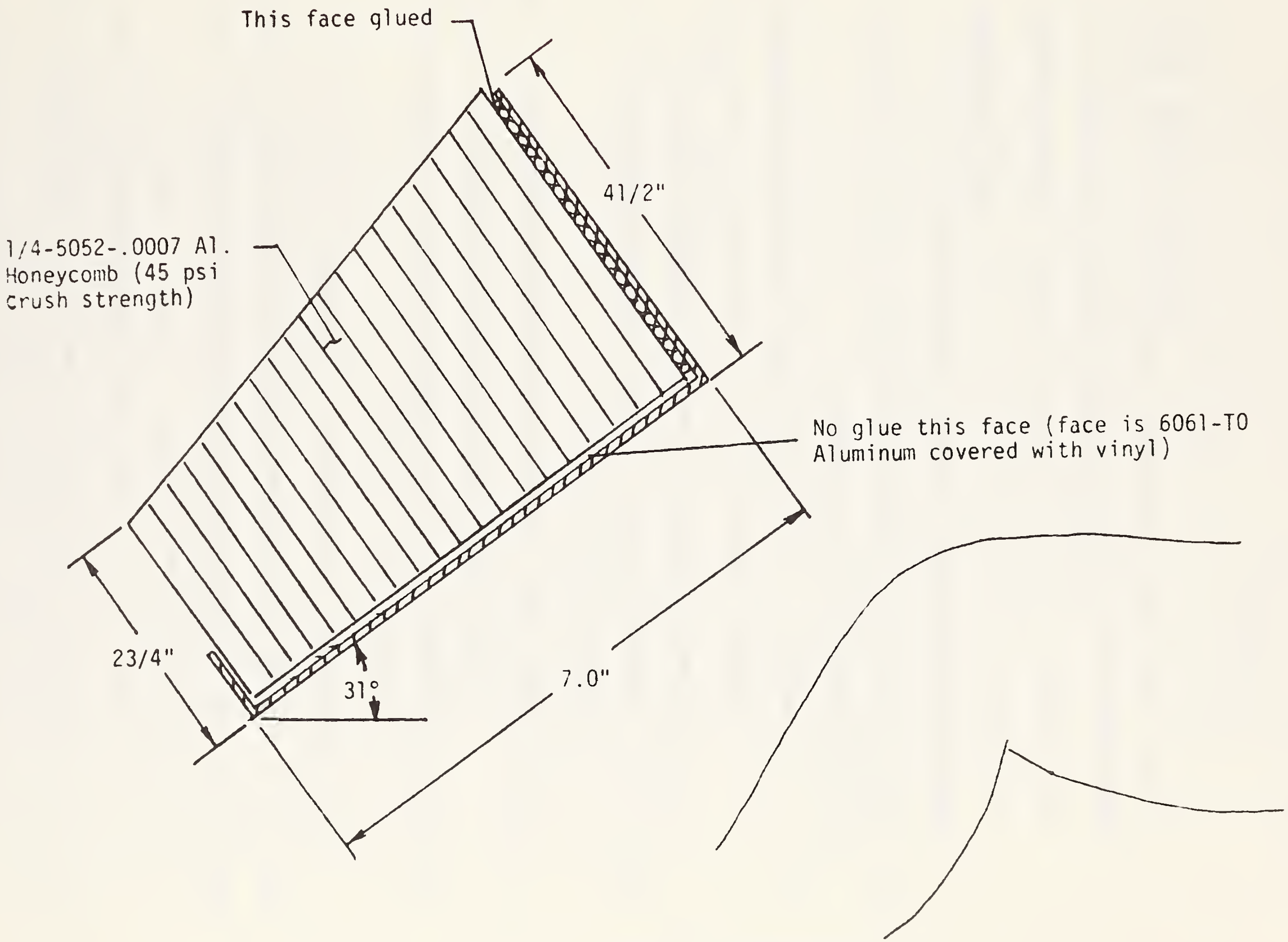

Figure 3-12. DeLorean Knee Restraint.

3.3.1 Study Objective

One objective of this phase of the study was to use the PAC computer program, described and validated in Section 2.2.2, to investigate the sensitivity of the passenger injury measures to variations in the air bag, passenger inflator and sensing parameters over the practical range of interest. A second objective was to choose, again via computer simulation, the combination of hardware components that are predicted to give near optimum restraint system performance. The design factors considered in this portion of the study were:

- Inflator - Selection of the inflator (or gas generator) that promises to best meet the program objectives of near optimum restraint performance and "off-the-shelf" availability.
- Staging Time (i.e., the time duration between ignition of the first and second inflators).
- Sensor Type - To determine whether the sensor trigger levels (first and second stage) should be triggered by the vehicle undergoing a specified change in velocity or a specified elapsed time from "bumper contact".
- Passenger Size Variation - To determine the near optimum selection of the above parameters considering the protective requirements of both the forward positioned child and the potential size range of normally seated adults.
- Impact Speed - To, again, select the restraint system parameters that, based upon computer simulations, promise maximum protection over a range of potential impact speeds.
- Child Positions - To verify that the hardware components selected

in this study will not be overly agressive to a small child seated in various forward positioned configurations.

3.3.2 System Constraints

The system constraints imposed upon this part of the study are described below:

INFLATOR DESIGN

Four separate inflator designs were considered for evaluation in this part of the study; However, when the preliminary screening factors such as projected cost, availability and production capability were applied, only three gas generators were still considered viable candidates. They were:

- o Thiokol/Mercedes - Part No. IU 92520-04 with 100 grams of propellant each (2 inflators required per bag). This was the inflator used in the two crash tests discussed earlier. The production line for this inflator is set up and available (subject to vehicle manufacturer permission).
- o Talley - Part No. CU-1605 with 168.6 grams of propellant each (2 inflators required per bag). The production line is set up and available (subject to vehicle manufacturer permission).
- o Bayer Chemie - This German firm has a production inflator which we wanted to include in this study; However, as the report went to press, we had not received the information required to include this inflator in our study.

The fourth inflator type we considered was an aspirated inflator manufactured by Hamill Mfg. Co. (Part No. SK-902-01129). This particular inflator was not of the "driver shape" as the three discussed above were. This inflator is cylindrical in shape with the longitudinal axis of the cylinder in the vehicle transverse direction. This inflator was not included in this study for the following reasons:

- o Cost was judged to be higher than for the other types
- o Availability in mass quantities was somewhat doubtful since the assembly line has been dismantled.
- o The relatively large size of the inflator package means that the glove box in the DeLorean sports car would be lost as its space would be needed to house the inflator.
- o This inflator is slightly heavier than the other designs.
- o A separate design would be required for the driver and passenger systems since this inflator is designed only for the passenger system. The other inflator candidates considered in this study have the potential of being used for both the driver and passenger systems.

Although the Hamill inflator is not included in this study, it was evaluated earlier in the preliminary computer design phase of Contract No. DTNH22-81-C-07330 and it was found to be a technically viable candidate. However, in light of the points mentioned above it was decided, after consultation with both DeLorean and NHTSA, to proceed with the study without the Hamill inflator. However, a stipulation was made that if at some future time more gas would be needed to implement a knee bag or needed for some other reason, or if some of the factors given above appeared less crucial, the Hamill inflator would be reconsidered and could then become predominate in future evaluations.

Figure 3-1 compares the flow rate history for the Thiokol and Talley inflators considered in this study. These plots are based upon actual controlled tests by the respective manufacturers.

STAGING TIME

Staging time, as defined here, is the time duration between ignition of the first and second inflators. Five staging times covering the practical range of potential staging were selected for evaluation in this study. They were:

1. Zero milliseconds (both inflators firing simultaneously)
2. Four milliseconds
3. Seven milliseconds (baseline - as used in the two crash tests)
4. Twelve milliseconds
5. Twenty milliseconds

Thirteen to fifteen milliseconds was used in this study as the sensing time (time at which the first of the two gas generators was ignited).

SENSOR TYPE

The two most prevalent types of sensors are the "elapsed time" sensor, which triggers the bag firing based upon a certain time elapsing after bumper contact and/or between firing stages, and the "Delta V" (change in vehicle velocity) type, which triggers the bag firing when a specified vehicle change in velocity has occurred. Both types were considered in this study and the rationale for selecting one of these two types for the DeLorean is given in Section 3.3.3.

OCCUPANT GEOMETRY, MASS AND STIFFNESS

For the baseline impact condition, a 50th percentile adult male was assumed for the driver and passenger. The geometry and mass characteristics assumed for this size of occupant are those discussed in Section 2.1.2. For other adult occupant sizes, the geometry and mass characteristics are those derived in Section 3.2.1.

For the out-of-position child simulations, the following parameters (based upon dummy measurement) were used (refer to Figure 2-3 for nomenclature):

- Head Weight = 5.8 lbs
- Torso Weight = 16.5 lbs
- Lower Body Weight = 11.0 lbs
- Sternal Weight = 2.5 lbs
- R_H = 3.5 in
- R_T = 8.5 in
- R_N = 14.0 in
- R_{TOPH} = 21.0 in
- W_H = 4.75 in
- W_B = 6.75 in
- L_F = 9.0 in

Figure 3-13 shows the chest and sternal properties used for the 3 year old child in the PAC simulations.

IMPACT SPEED

Three impact speeds were evaluated in this study. The speeds were the same as those chosen for the driver study (i.e., 30, 36, and 40.6 mph). These are the only three speeds for which crash test information was available.[1]

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1 In the driver study, the crash pulse for the 30 mph case was derived (see page 3-14). However, subsequent to the driver analysis the results of a 30 mph crash test, at the Motor Industries Research association (MIRA) in Great Britain, were obtained.

Sternal and Chest Force vs Deflection Properties

3 Year Old Child Dummy

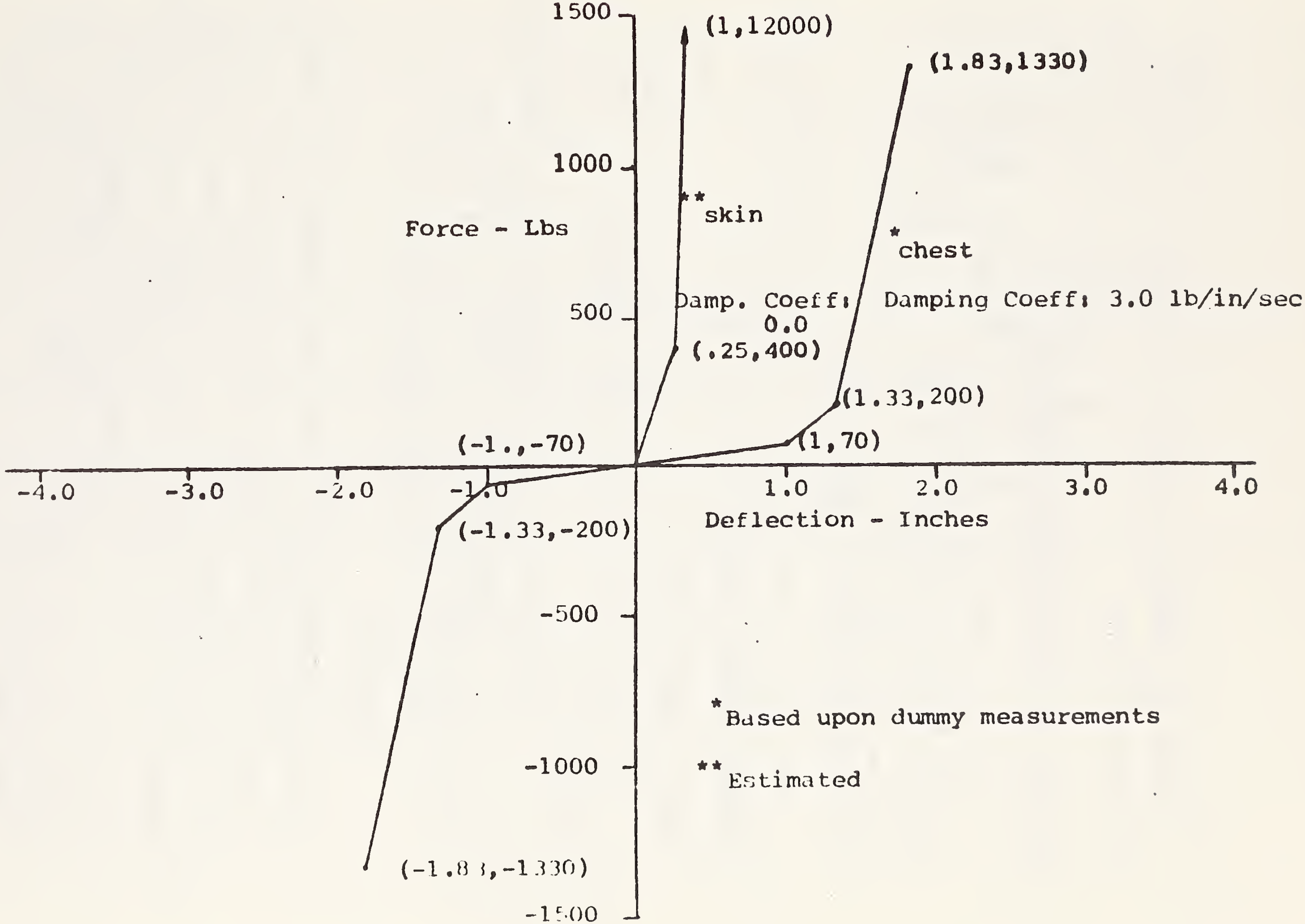

Figure 3-13

Figure 3-14 shows the crash pulses assumed in this study for the three test speeds.

SEAT FRICTION AND KNEE RESTRAINT PROPERTIES

Figure 2-22 shows the characteristics assumed for seat friction and knee restraint resistance.

3.3.3 Simulation Results - Passenger System

PAC simulations were conducted to evaluate the following previously mentioned effects on restraint system performance.

EFFECT OF INFLATOR DESIGN

Two inflator designs were evaluated in this portion the study. These designs were:

1. Thiokol/Mercedes Part No. IU 92520-04 (baseline, used in crash tests)[1], 100 gms propellant, 1200 ^{o}F gas temperature.

2. Talley Part No. CU-1605, 168.6 gms propellant, 845 ^{o}F gas temperature.

In order to best evaluate these two gas generators over a variety of conditions, two other parameters were introduced into this portion of the study. They were occupant size (both the normally seated 50th percentile adult male and the forward positioned child were investigated), and staging time. The staging time variation was introduced into this portion of the study since how the two generators are phased in their

[1] Ibid., page 2-1.

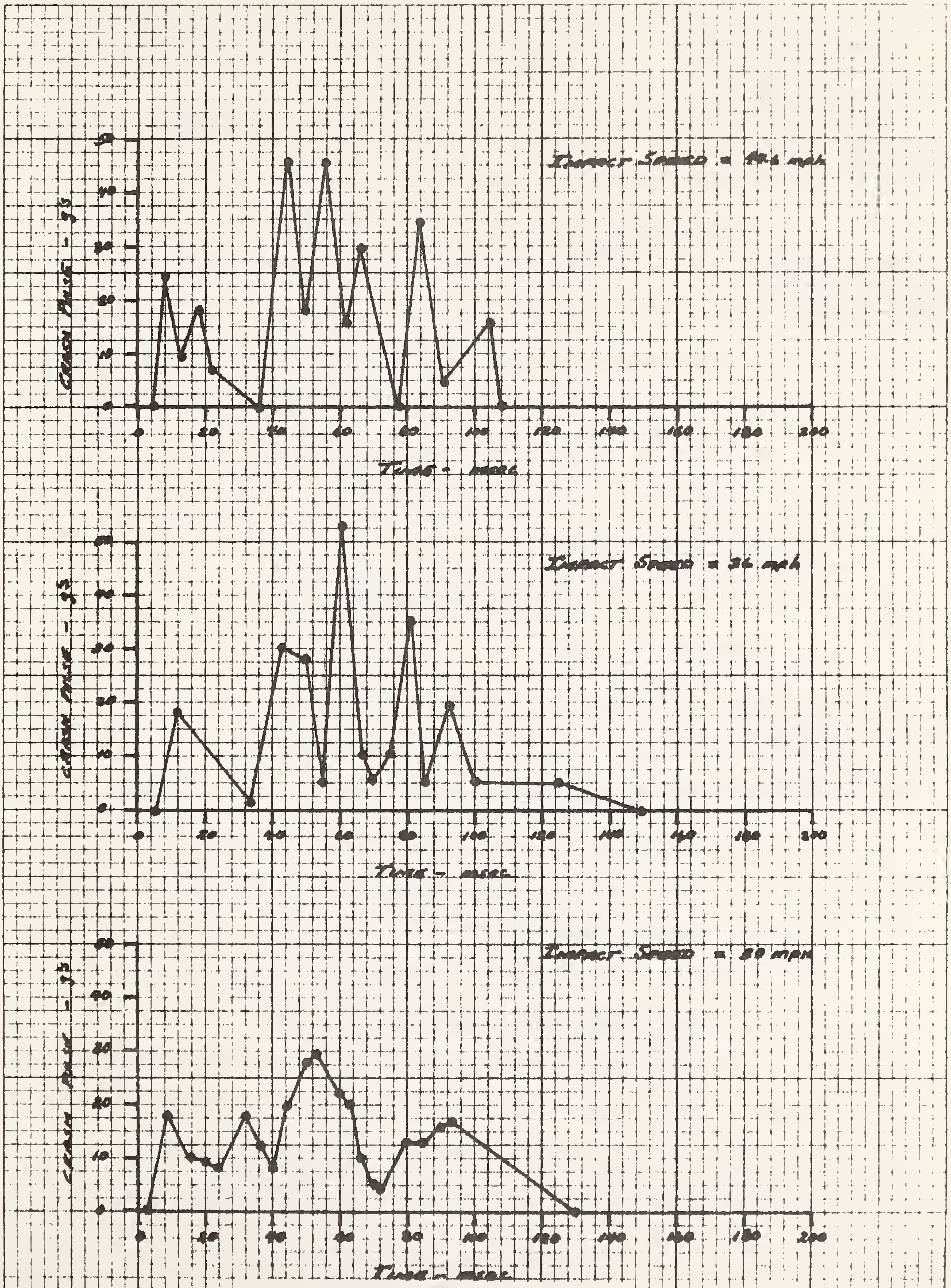

Figure 3-14. DeLorean Crash Pulses.

firing sequence will affect the injury measures and, therefore, play a part in determining which inflator will be selected.

The methodology of selecting the air bag vent area (for the PAC simulations) was as follows. First, for the baseline case (36 mph crash test, using the Thiokol inflator - see Section 2.2.2) the vent area was approximately five square inches. In order to derive an equivalent vent area to be used for the Talley inflator (with the same air bag design as the baseline case) it was decided to vary the vent area in the "Talley" bag until the same maximum H-point translation was obtained as with the Thiokol system. This "equivalent" vent area for the Talley system turned out to be 9 square inches.

<u>Thiokol/Mercedes Inflator</u>

First, the Thiokol/Mercedes inflator was simulated. Figures 3-15, 3-16 and 3-17 show the effects of staging time on the injury measures for three separate passenger/crash environments (i.e., the 50th percentile adult male seated normally undergoing a crash at the baseline speed of 36 mph; the 3 year old child seated forward, 6 inches from the dash, with the vehicle not moving at the time of air bag deployment; and the 3 year old child seated forward, 6 inches from the dash, with the vehicle traveling at 30 mph at the time of bag deployment).

In deciding the "optimum" staging time for the Thiokol/Mercedes inflator, we must look at all three figures together. Figure 3-15a shows the predicted injury measures for the normally seated, 50th percentile male undergoing a 36 mph barrier crash. This figure shows that there

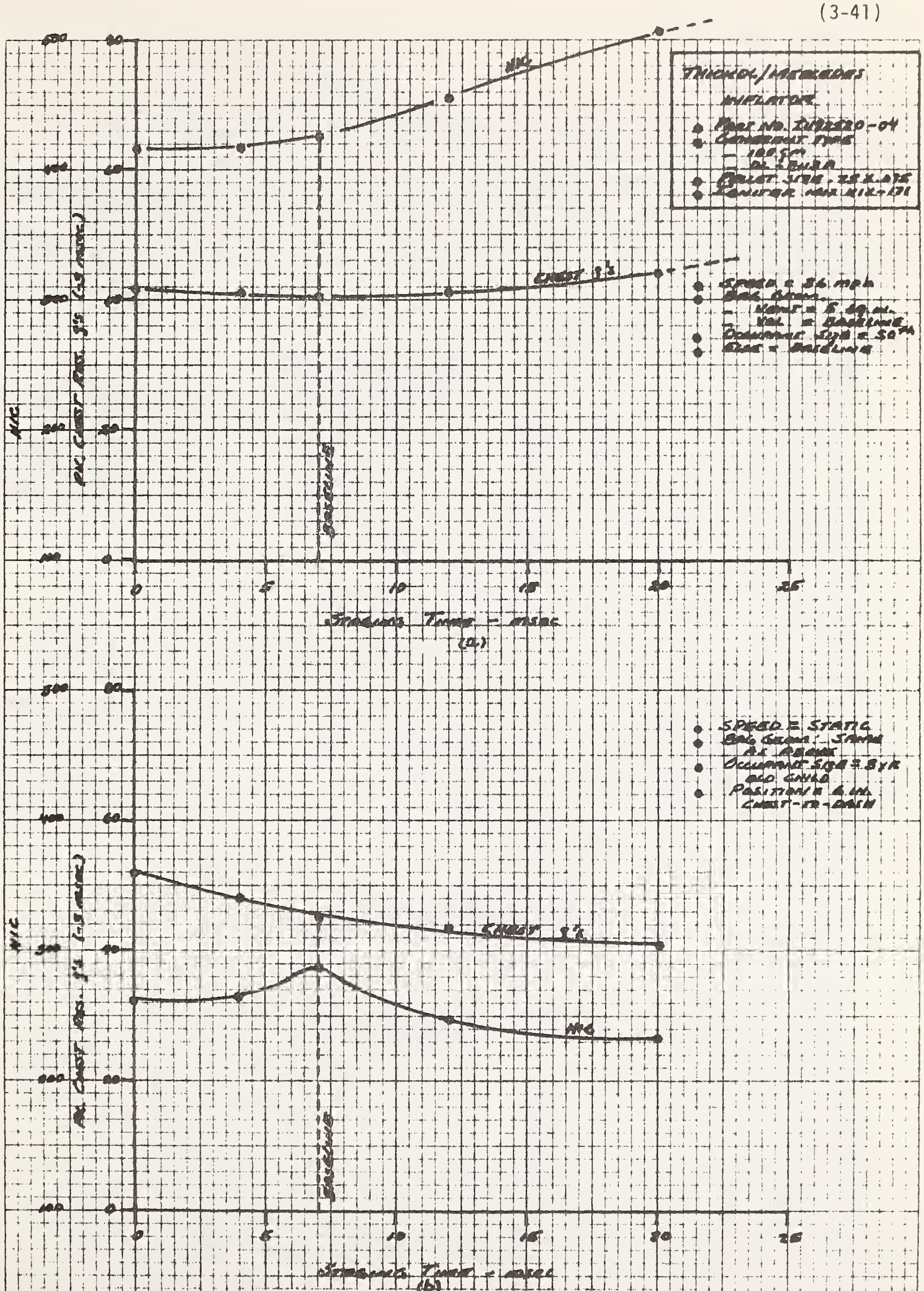

Figure 3-15. Restraint System Performance, Thiokol Inflator.

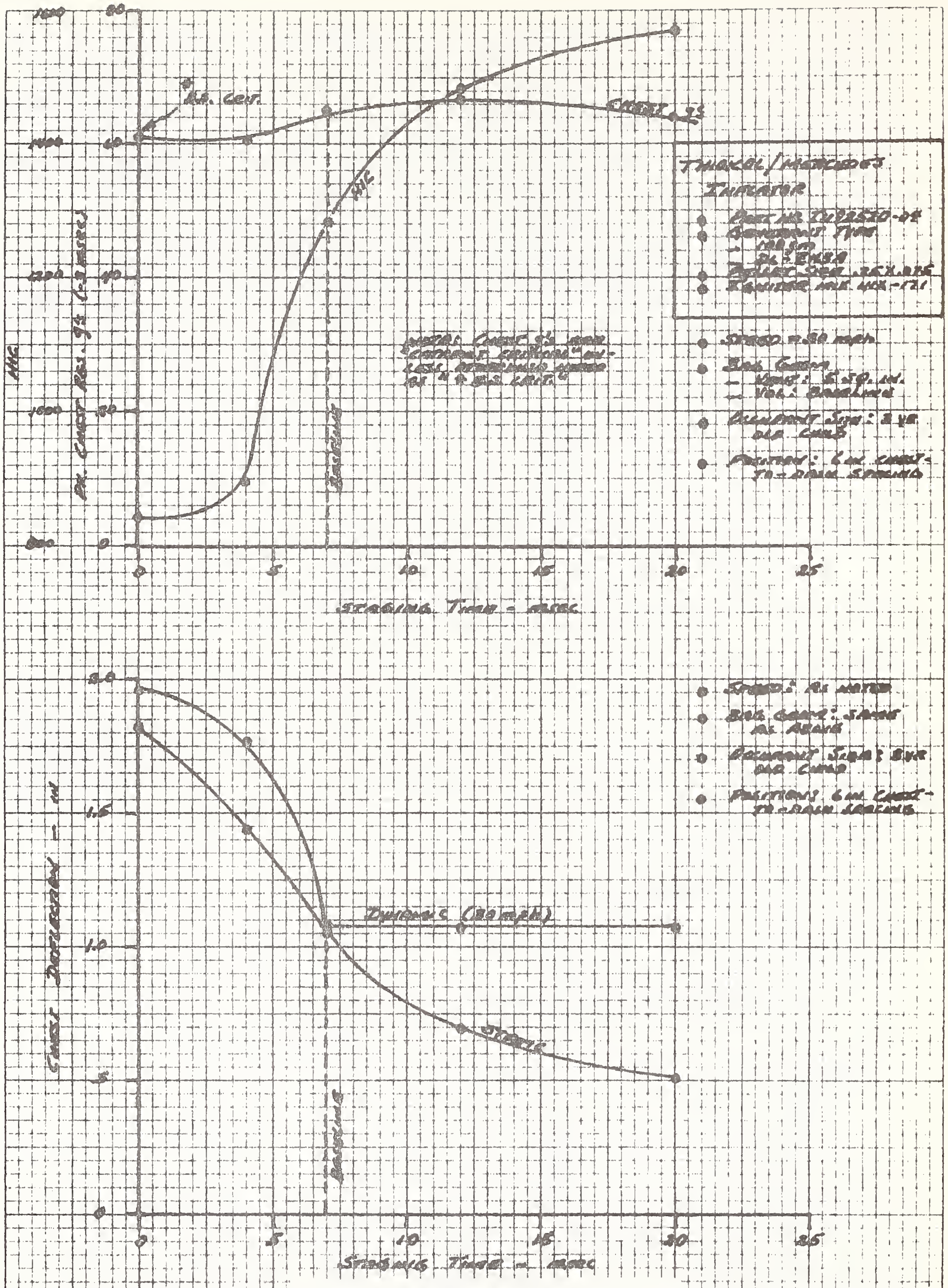

Figure 3-16. Restraint System Performance, Thiokol Inflator.

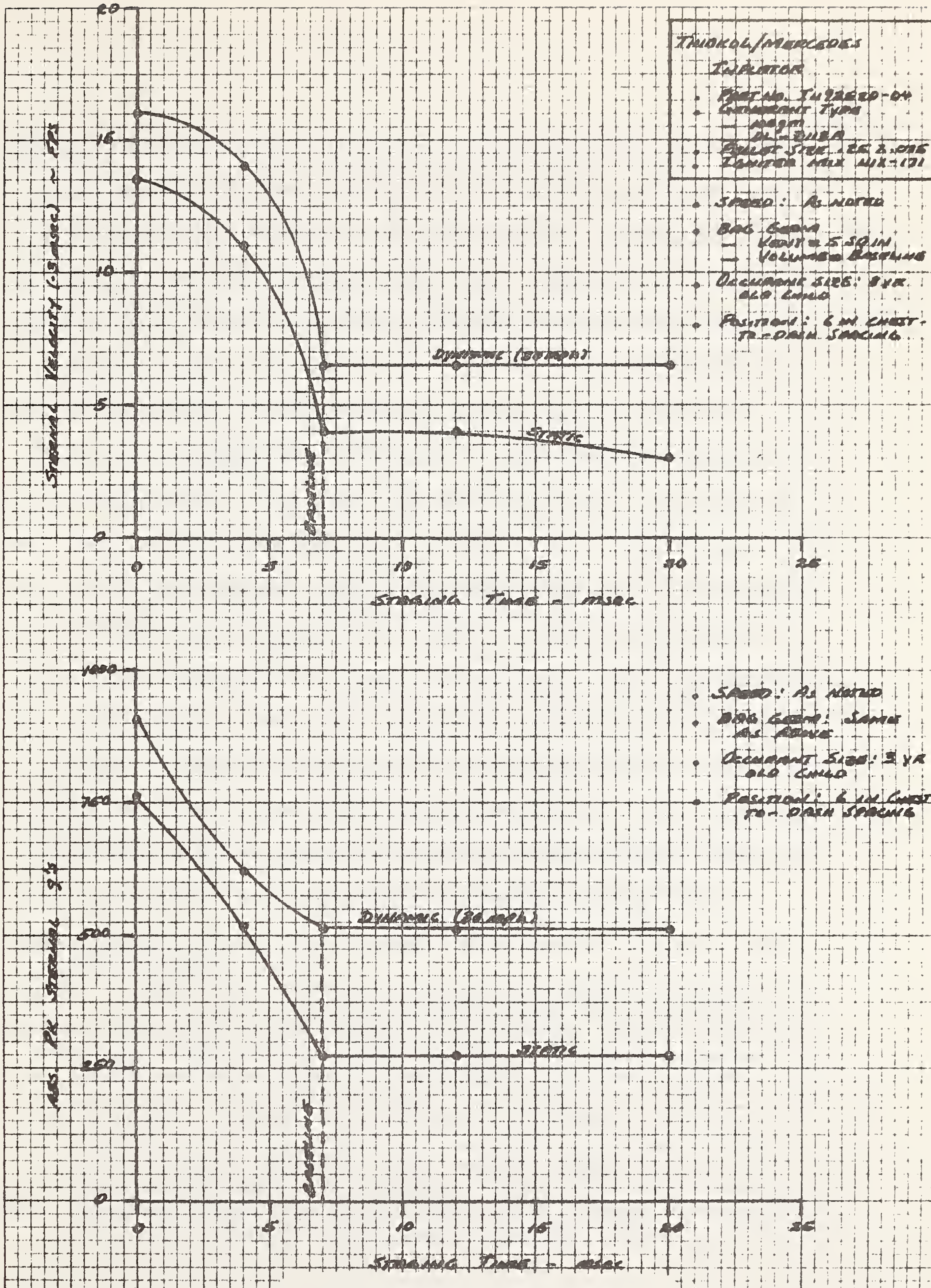

Figure 3-17. Restraint System Performance, Thiokol Inflator.

is not a great deal of variation in the injury measurements with staging time. Furthermore, for all staging times of interest, the injury measures are predicted to be much below the criteria limits of 1000 for HIC and 60 g's for the chest. What little variation there is, is primarily in the HIC which begins to increase slightly for staging times in excess of 7 milliseconds.

In Figures 3-16 and 3-17 we see that chest deflection, peak sternal g's and peak sternal velocity for the child are highest for the dynamic (30 mph) case. Figure 3-17 shows that these injury measures are the highest for the situation in which there is no staging (staging time = 0). These measures drop off rapidly with an increase in staging time until a seven millisecond staging time is reached. For staging times greater than seven milliseconds, these injury measures remain relatively constant. This is expected since the bagslap forces are highest for low staging times when the flow from both gas generators add together to produce the highest total gas flow rates. These higher total gas flow rates result in a faster bag deployment with concomitantly higher "g" response for the child's chest.

As the flow is more evenly distributed in time, as is the case for higher staging times (say up to seven milliseconds), the bag deployment velocities will be lower and, hence, the child's chest loads will be correspondingly lower. However, as the staging time is increased beyond seven milliseconds, the second inflator has no effect on bagslap because the bag impacts the chest before the second inflator ignites. We must be carefull in our evaluation, however, since the effects described above are only true in regard to peak sternal response and chest deflection. Looking at Figure 3-16 we see that for the child undergoing a 30 mph impact the HIC increases dramatically with staging time for staging times greater than about 4 milliseconds. The reason for this is that when the gas flow from the inflators are distributed over a longer period of time, the "catapult" forces, developed by the bag, begin to predominate so that bag pressures reach their maximum when the bag is fully deployed and fully enveloping the child (bagslap g's are relatively low for the Thiokol inflators even when both inflators fire simultaneously since these units produce comparatively little gas when compared to the pure pyro cylindrical units customarily used). Therefore, for the forward positioned child (in the dynamic case) the bagslap forces tend to be lowest for staging times greater than 4 to 7 msec, while the HIC is lowest for staging times less than 4 to 7 msec. This indicates that the optimum staging time will be 4-7 msec (the static forward positioned child case is not critcal since that case exhibits comparatively low injury measures).

Based on the above findings, we recommend a staging time of approximately 7 msec for the Thiokol inflators which, interestingly enough, is exactly what was used in the baseline crash test at 36 mph.

Talley Inflator

As it turned out, the qualitative trends discussed above for the Thiokol inflator may be equally applied to the Talley inflator. The performance of the Talley inflators are summarized in Figures 3-18, 3-19 and 3-20. Figure 3-18a shows that for the normally seated adult, the injury measures do not vary much with staging time. This is much like the Thiokol inflator. One difference, however, is that the Talley in-

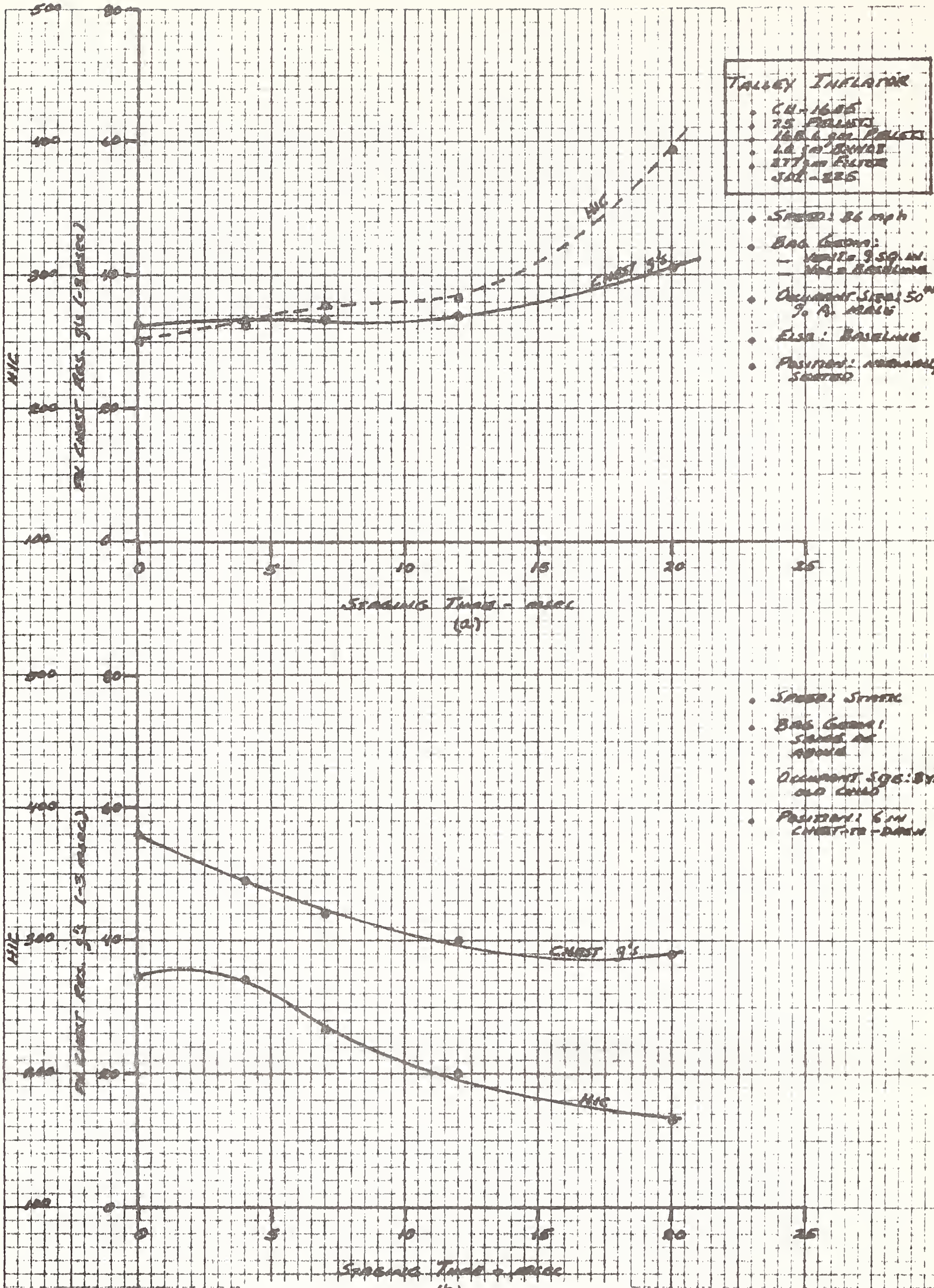

Figure 3-18. Restraint System Performance, Talley Inflator.

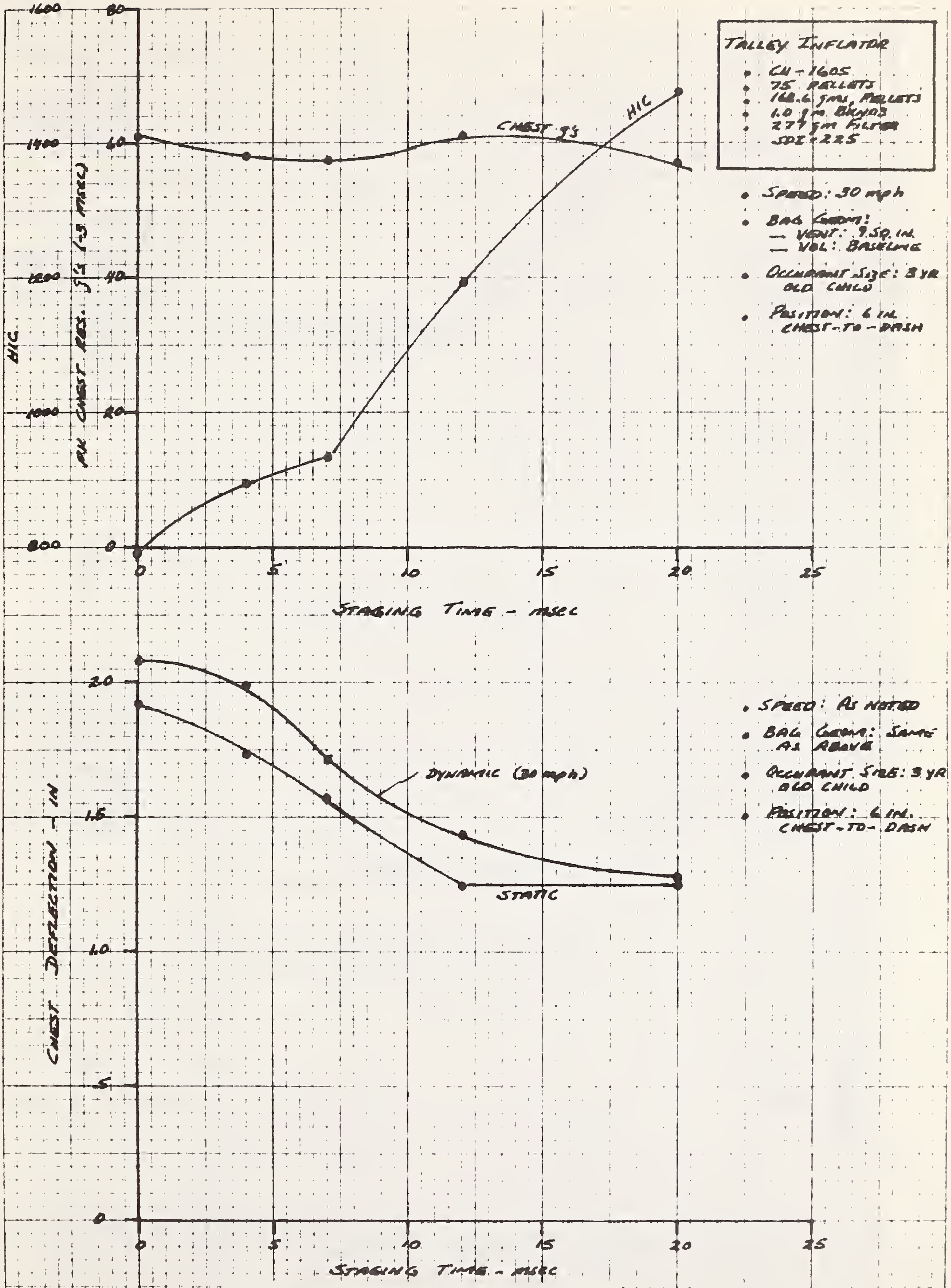

Figure 3-19. Restraint System Performance, Talley Inflator.

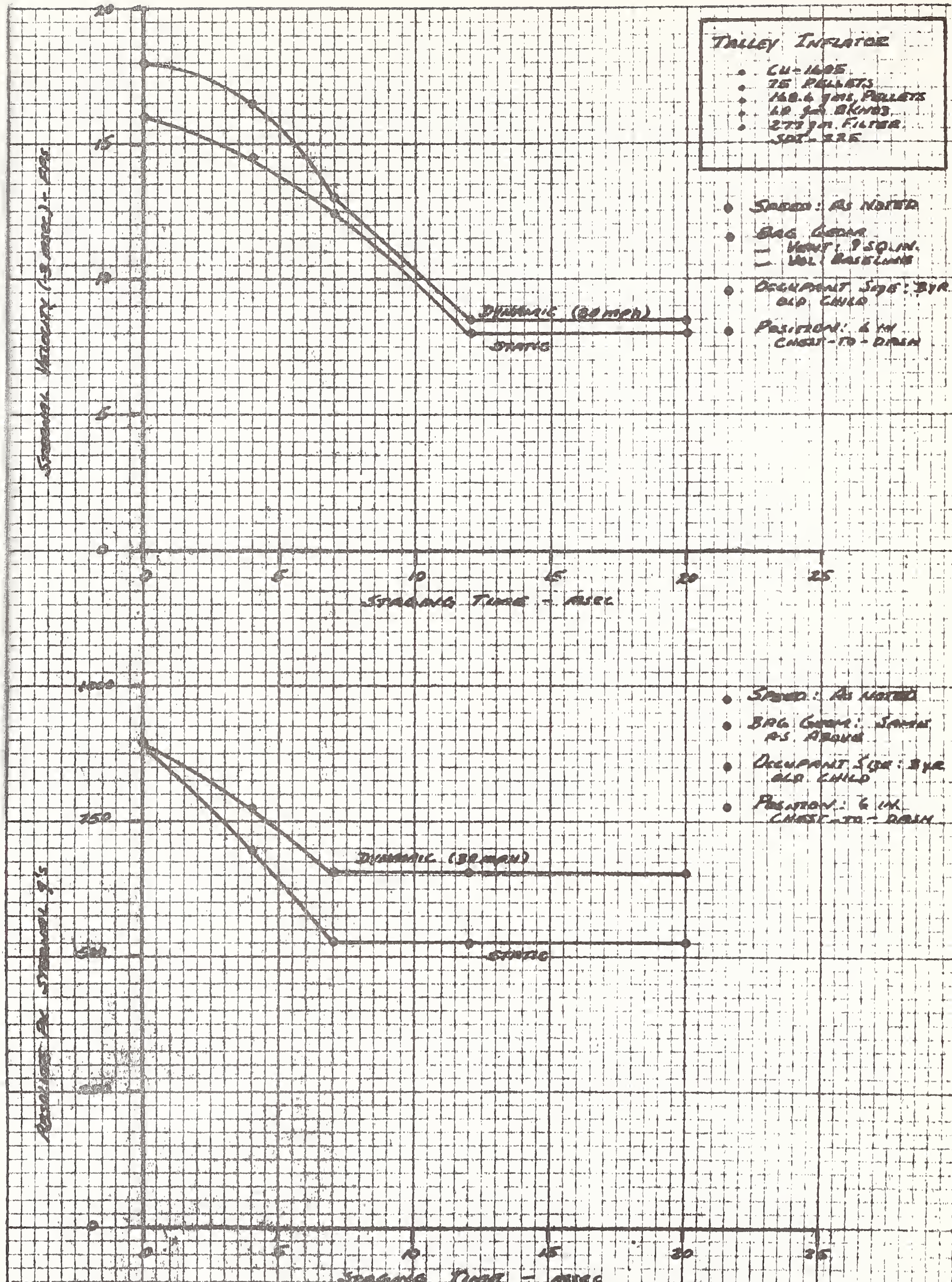

Figure 3-20. Restraint System Performance, Talley Inflator.

flator is predicted to better protect the adult than the Thiokol inflator. This is due to the greater amount of "ride-down" and more effective bag pumping achieved with the greater amount of available gas from the Talley inflator.

Regarding the child passenger, as it turned out the qualitative trends discussed above for the Thiokol inflator may be equally applied to the Talley inflator (see Figures 3-18b, 3-19 and 3-20). Here, again the forward positioned child experienced highest sternal response for low staging times and highest HIC values for the higher staging times. The reason for this is the same as that discussed for the Thiokol inflator. Not only were the qualitative conclusions the same for the child, but the injury measures predicted were also not much different from the values associated with the Thiokol inflator.

One minor problem with the Talley system, however, is the greater depth of the gas generator which, if used in the DeLorean, would almost certainly result in giving up the glove box to accommodate its larger size. Another slight drawback to the Talley inflator is that the cost is suspected to be somewhat greater than the Thiokol inflator (based on prices actually paid for equivalent inflators in the past). However, this fact has not been difinitely confirmed for production quantities.

Here again, as with the Thiokol inflator, a staging time of 7 msec seems to be optimum.

Therefore, based upon the results of the above computer simulations and other subjective considerations, we have concluded that both the Talley and the Thiokol inflators are extremely good candidates for the DeLorean restraint system. Both inflators are predicted to be able to protect the normally seated adult and the static, forward positioned child with injury measures substantially below the criteria limits of 1000 for HIC and 60 g's for the chest. For the forward positioned child, undergoing a 30 mph crash, we predict marginal restraint performance. However, we should state that the forward positioned child analysis is somewhat conservative and yields injury measures generally higher than those experienced in actual testing. The reason for this is that the computer analysis assumes all of the energy of the deploying air bag is absorbed by the chest. The air bag is assumed to continue deploying straight into the child. In an actual test, the bag commonly impacts the chest and then deploys in a downward direction until contact with the floor and seat is made. This change in deployment direction and floor/seat interference usually attenuates the injury measures.

Since both inflators perform very well with the normally seated, 50th percentile adult male and about equally well for the forward positioned child, we decided to carry both inflators through most of the remaining parts of this analysis.

EFFECT OF SENSOR TYPE

There are basically two types of sensors available. One type is the accelerometer/velocity type which uses solid state circuitry to record the g-time profile of a given crash signature and then operate on it to affect the desired sensing. The second type is the mechanical equivalent of a spring mass system with a built in time-reponse lag to switch closure from initial actuation.

Since the first type of sensor is a solid state device with inherently fast response time, and since both the elements of elapsed time and acceleration are measured, recorded, and operated on in real time extremely quickly, we have the option of choosing either elapsed time or change in velocity as the parameter which triggers initial sensing and then the staging of the gas generator flow. For the Electro-mechanical type of sensing device, we are limited in our option and are usually forced to accept the inherent response time of the device for the given crash environment. Therefore, the question boils down to this: "Do we choose elapsed time or vehicle change in velocity as the means of actuating the gas flow from the inflators?".

Perhaps the best way to answer this question is to study Figure 3-21. This figure shows the vehicle change in velocity as a function of time from bumper contact, for different impact velocities. From the figure, two things are readily evident. First, there is very little difference between the three curves over the range of interest (i.e., from zero to 35 msec - recall that this is the range over which our sensing time study was conducted for 13-15 millisecond primary sensing and up to 20 milliseconds staging). It would have been informative to have one crash pulse of, say, 12 mph so that the entire range of velocities, over which the air bags would inflate, could be studied. However, such data was not available. The second thing which is evident from Figure 3-21 is that the variation in vehicle "delta V" with time is fairly constant over the range (i.e., the slopes of the lines are not changing much). In fact, from 10 msec until 40 msec the vehicle change in velocity is only about 9.7 fps. Since the accelerometer type of sensor must already count each time increment (to be used in the integration process required to calculate "delta - V") and since there is virtually no difference between the

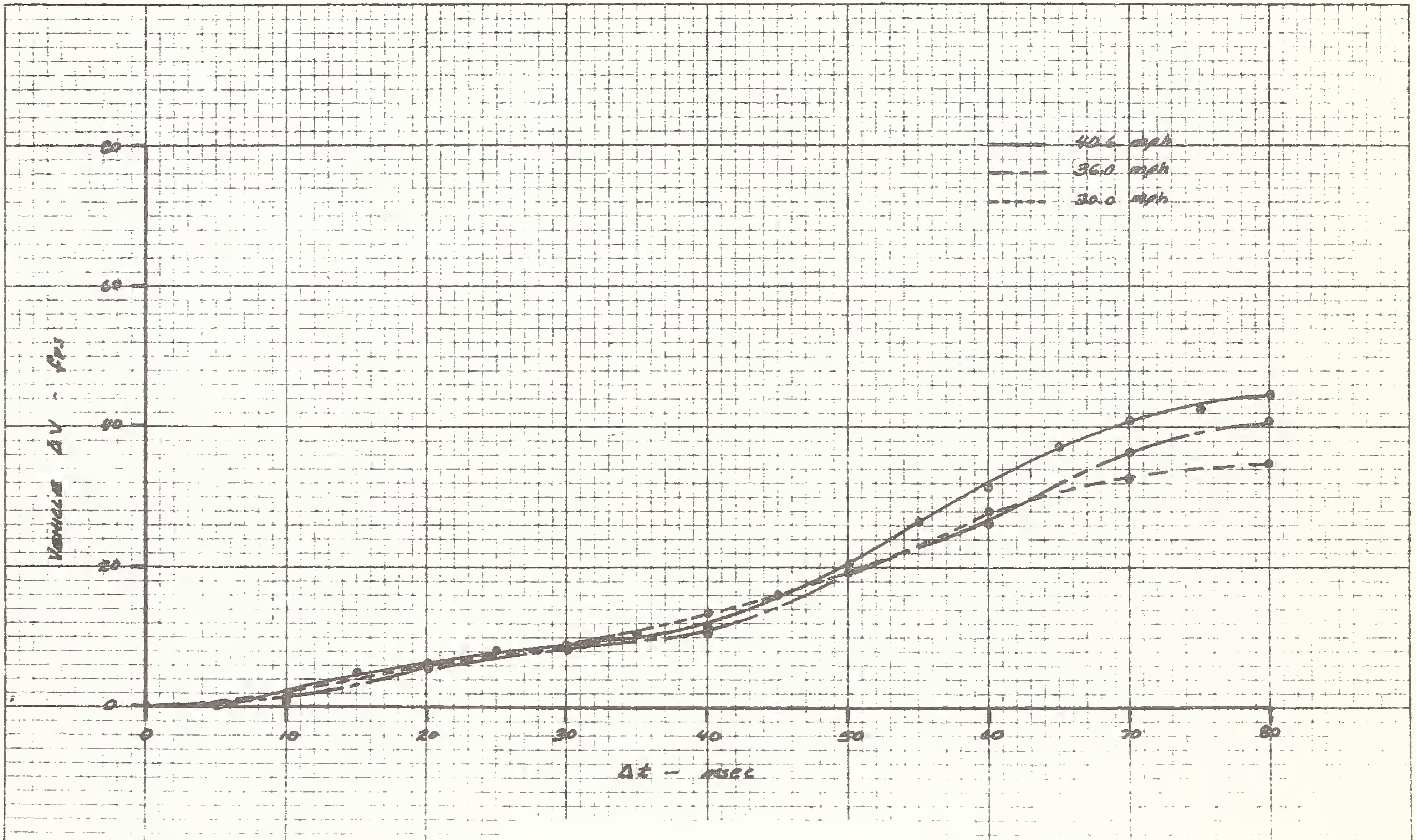

Figure 3-21. DeLorean Speed v.s. Time.

curves for the three impact speeds, we feel that elapsed time would be the most dependable and most responsive "trigger" for the sensor firing circuit.

EFFECT OF PASSENGER SIZE VARIATION

Up until this point in the study we have demonstrated that for the baseline air bag design used in the crash testing (see Figure 3-11), both the Talley and Thiokol inflators will perform well for the following crash conditions which have been investigated (by performing "well" we mean that the injury measures are well below the injury critera limits for HIC and chest g's for both inflator designs):

1. Normally seated 50th percentile adult male, 36 mph impact speed for all staging times of interest.
2. Forward positioned child (6 inches from dash, seated with vertical torso) for static bag firing for all staging times of interest.

Injury measures received by the forward positioned child in a 30 mph crash were found to be marginal (for both inflators). However, as pointed out earlier, the analysis was a "worst case" analysis that may not be too realistic.

It was also determined that a seven millisecond staging time was most nearly "optimum" for the range of conditions investigated. This became the staging time used in the remainder of the study.

To investigate how well the two gas generators will perform for other sizes of normally seated passengers, we selected the 5th percentile adult female to represent the smallest passenger size and the 95th percentile adult male to represent the largest. Figures 3-22 and 3-23 show the results of this portion of the study. It is obvious from studying the two figures that the Talley inflator, with its greater total gas production, promises to do a better job than the Thyiokol unit in protecting the large passenger. For the small passenger, both units perform about the same. Again, however, both inflators should do a good job in protecting the entire size range of normally seated adult passengers up to and beyond the 36 mph impact speed.

EFFECT OF IMPACT SPEED

In order to gain information on how the 50th percentile passenger injury measures vary with impact speed, we ran a series of several more computer runs for each of the two gas generators. Figure 3-24 shows the results of these runs. In Figure 3-24a, we have plotted the computer predicted results for the three impact speeds chosen for the Thiokol/Mercedes inflator (i.e., 30, 36, and 40.6 mph - the latter two being the crash test speeds). As may be seen from the curve, the agreement between the actual test data and the PAC predictions is not too good. The reason for this is that in the actual test (at the higher impact speeds) the windshield and dash caused the bag to take a shape that is not very close to the right elliptical cylinder assumed in the simulations. Thus, bottoming effects become important. These effects are not included in the PAC model. Because of this, we are limited in the conclusions we may draw from this portion of the study. We may, however, state that the injury measures for the 50th percentile male will be well below the criteria limits since we know from actual testing that the

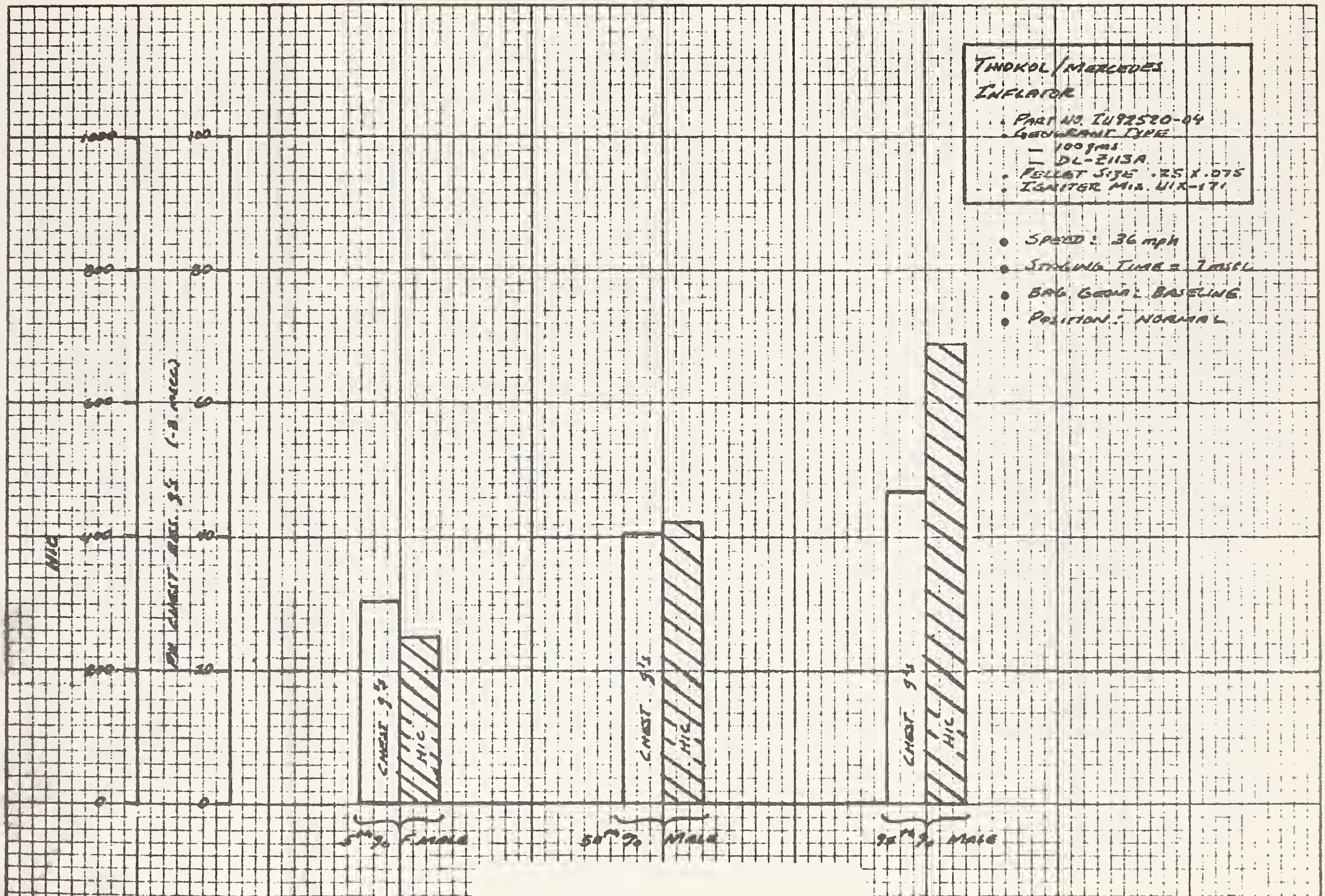

Figure 3-22. Injury Measures v.s. Occupant Size.

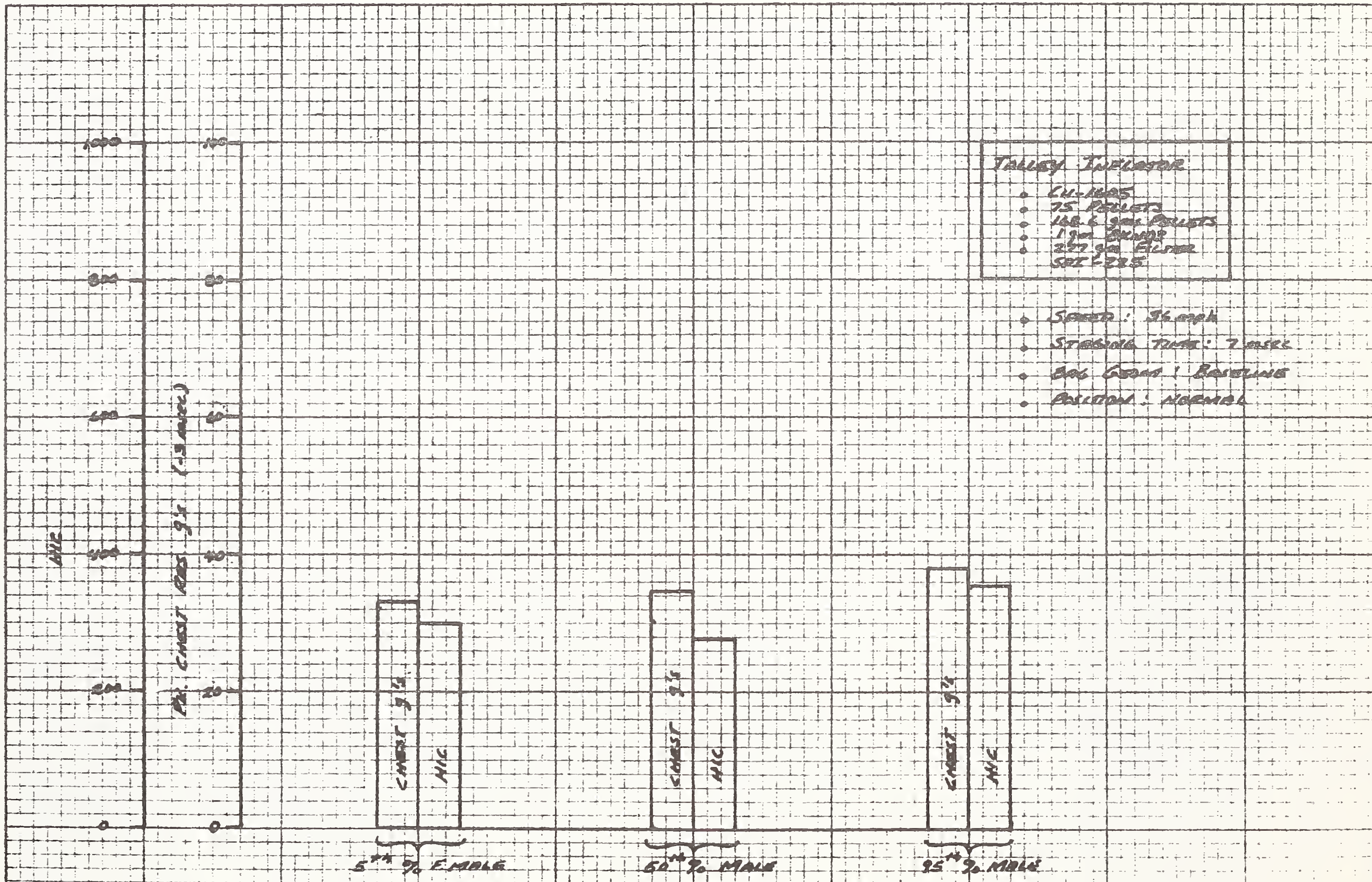

Figure 3-23. Injury Measures v.s. Occupant Size.

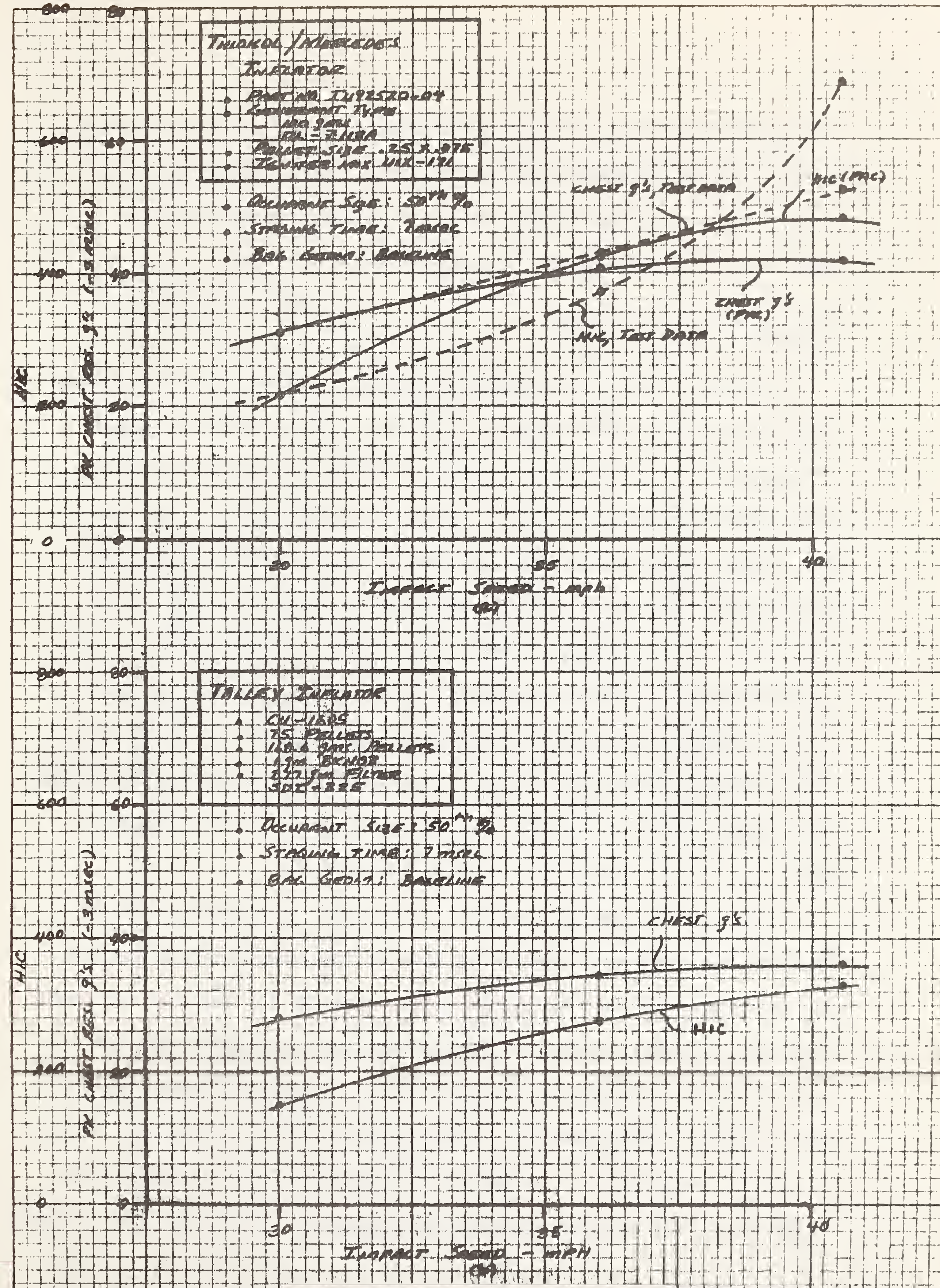

Figure 3-24. Effect of Impact Velocity on Restraint Performance.

Thiokol/Mercedes inflator performs within the injury criteria limits, even at the most severe crash condition (40.6 mph). Based upon the results shown in Figure 3-24b, the Talley inflator should perform even slightly better due to its greater gas production.

EFFECTS OF CHILD POSITION

The 3 year old child was investigated in several positions in the fore-aft direction with respect to the dash. These positions ranged from the child's chest being 3 inches from the dash to the normally seated position with his chest 26 inches from the dash. In all cases the child's chest was vertical as shown in Figure 3-25. The study was conducted for the most critical condition, as derived earlier in this study, which is the 30 mph impact case. Since both the Talley inflator and the Thiokol inflator gave almost identical results for the child, in the staging time portion of the study, we suspected that there would not be much difference here also. Consequently, we arbitrarily selected the Thiokol inflator for this part of the study with the supposition that the Talley inflator will perform similarly.

Figure 3-26 shows the results of this part of the study. Notice that the most critical position is the six inch chest-to-dash spacing. As can be seen in the figure, the injury measures for the head and chest are lower for chest-to-dash distances less than or greater than the six inch spacing. One might well wonder what is so special about the six inch spacing. The reason for it being critical is the following. First, all things being equal, the deeper the penetration into the bag by the child (i.e., the less the chest-to-dash spacing), the greater the catapult

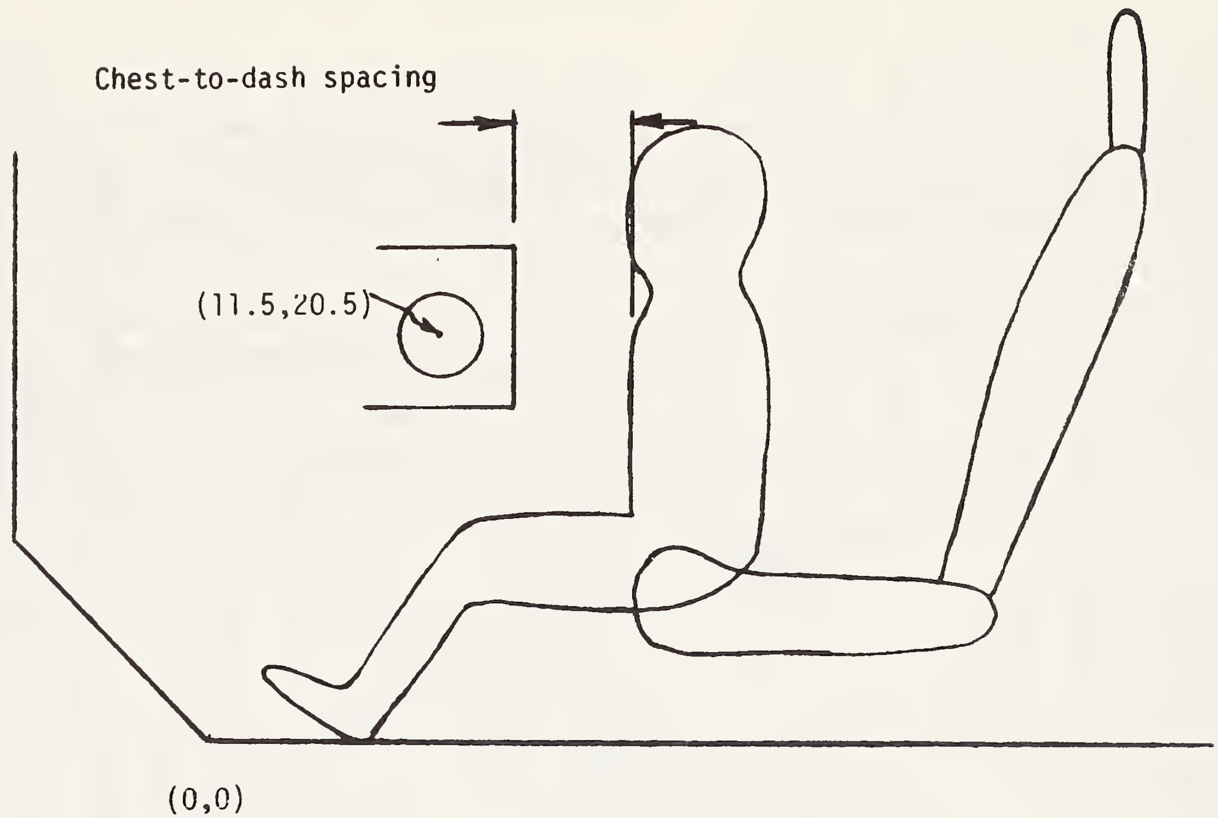

Figure 3-25. Forward Positioned Child Configuration.

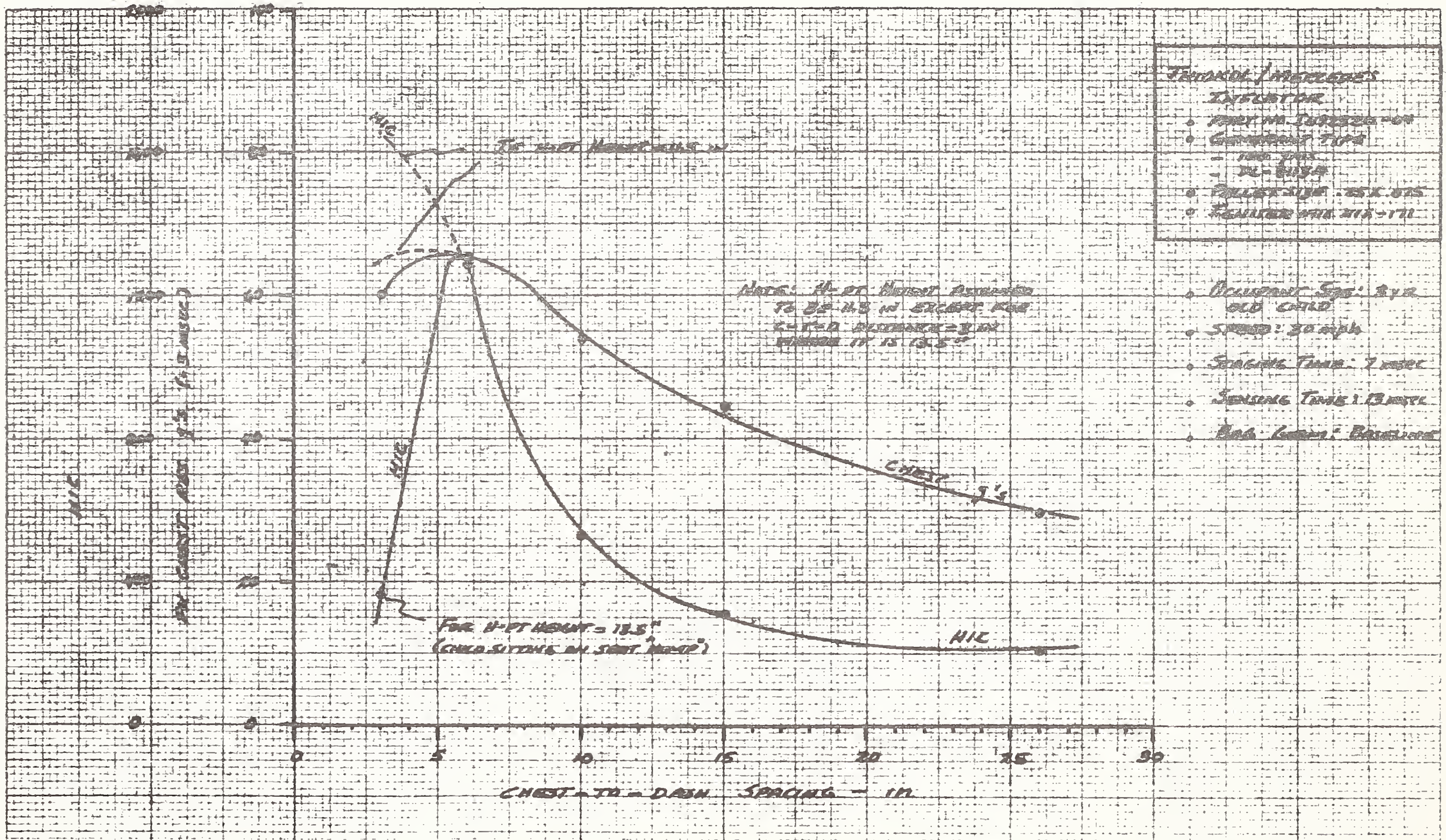

Figure 3-26. Predicted Injury Measures v.s. Chest-to-Dash Spacing.

g-levels for the chest and head (catapult g's predominate over bagslap g's for both the Thiokol and Talley generators with the 7 millisecond staging). However, and this is a strong factor, the injury measures are extremely sensitive to the vertical H-point dimension (the higher the H-point, the lower the injury measures since the bag impacts the child further down on the chest so there is less body articulation. Conversely, the lower the H-point the higher the injury measures since the bag is impacting the child higher up causing high rotational g-levels). In the case of the DeLorean seat design, when the child is seated very close to the dash (as in the 3 inch chest-to-dash spacing), his H-point is relatively high off the floor since the seat has a hump on the forward edge which boosts his H-point in the vertical direction. The lower injury measures that result from this effect more than offset the higher injury measures associated with his forward position (this point is illustrated in Figure 3-26 - note the two points plotted at the 3 inch chest-to-dash spacing representing the effects of the hump). However, as the child's position moves rearward and drops down off of the seat hump the injury measures go up, more than offsetting the normal lessening one might expect due to his more rearward seat location. As the child moves progressively further back on the seat, his H-point vertical dimension remains about the same so that now the reduced catapult g-effect due to the more rearward position controls and the injury measures begin to fall again.

The point we are attempting to make here is not that the six inch chest-to-dash spacing has any special significance, but rather that the two different factors (i.e., chest-to-dash spacing and vertical H-point height off the floor) both influence the degree of injury received by the child. Whether the child's H-point drops to the point where injury becomes critical at 6 inches or 12 inches from the dash is beside the point. The point is that one should be careful in designing the air bag system so that during deployment, bag contact with the child remains as low as possible, thereby minimizing the child's injury measures for any seat spacing relative to the dash. In upcoming sled tests, we will endeavor to position and fold the bag relative to the child so as to obtain as low a bag deployment as possible consistent with maintaining proper deployment for the normally seated adult.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 DRIVER RESTRAINT SYSTEM

The following conclusions and recommendations are based on the results of the DRACR simulations discussed in Sections 2.1 and 3.2 and the impact test data discussed in Section 2.1.3:

1. Knee Restraint - Design modification of the driver knee restraint is needed to eliminate the oscillatory knee force characteristic shown in Figures 2-12 and 2-13. Ideally, the knee force trace should be trapezoidal (like the knee force traces for the passenger - see Figures 2-27 and 2-28). One possible design solution here is to increase the angle of the knee padding (see Figure 2-10 for definition of knee padding angle). This will make the knee loading less sensitive to the upward movement of the knee padding during impact.

2. Inflator Design - The Thiokol/Mercedes Part No. IU92520-04 provides good restraint performance for the full range of design variables considered herein (the only exception is head containment for the 95th percentile adult male occupant - a marginal condition exists here). based on these results, the availability and cost of the inflator, and its adaptability to the DeLorean sports car, it is recommended that this inflator be selected as the primary inflator design for the DeLorean sport car application. The Talley (Part No. CU-1605) inflator may be used as a back-up design since it gives good performance as well.

3. DRACR Results for Head Containment (95th % Male) - The DRACR simulation results indicate a marginal condition concerning head containment for the 95th percentile adult male occupant (a head excursion of approximately 25 inches was calculated for the 36 mph impact condition). It should be noted, however, that stroking performance data for the steering column (a DeLorean design) was not available for this analysis and idealized characteristics had to be assumed (see Figure 3-2). The stroking characteristics of the steering column can have a significant effect on the head excursion calculations.

   It is recommended that static testing of the DeLorean steering column be conducted to determine its stroking and rotational resistance, for future DRACR simulation work.

4. Figure 4-1 shows the recommended bag design for use in the "DeLorean" driver ACRS. This design is basically the same as that derived for the baseline crash test studies.[1]

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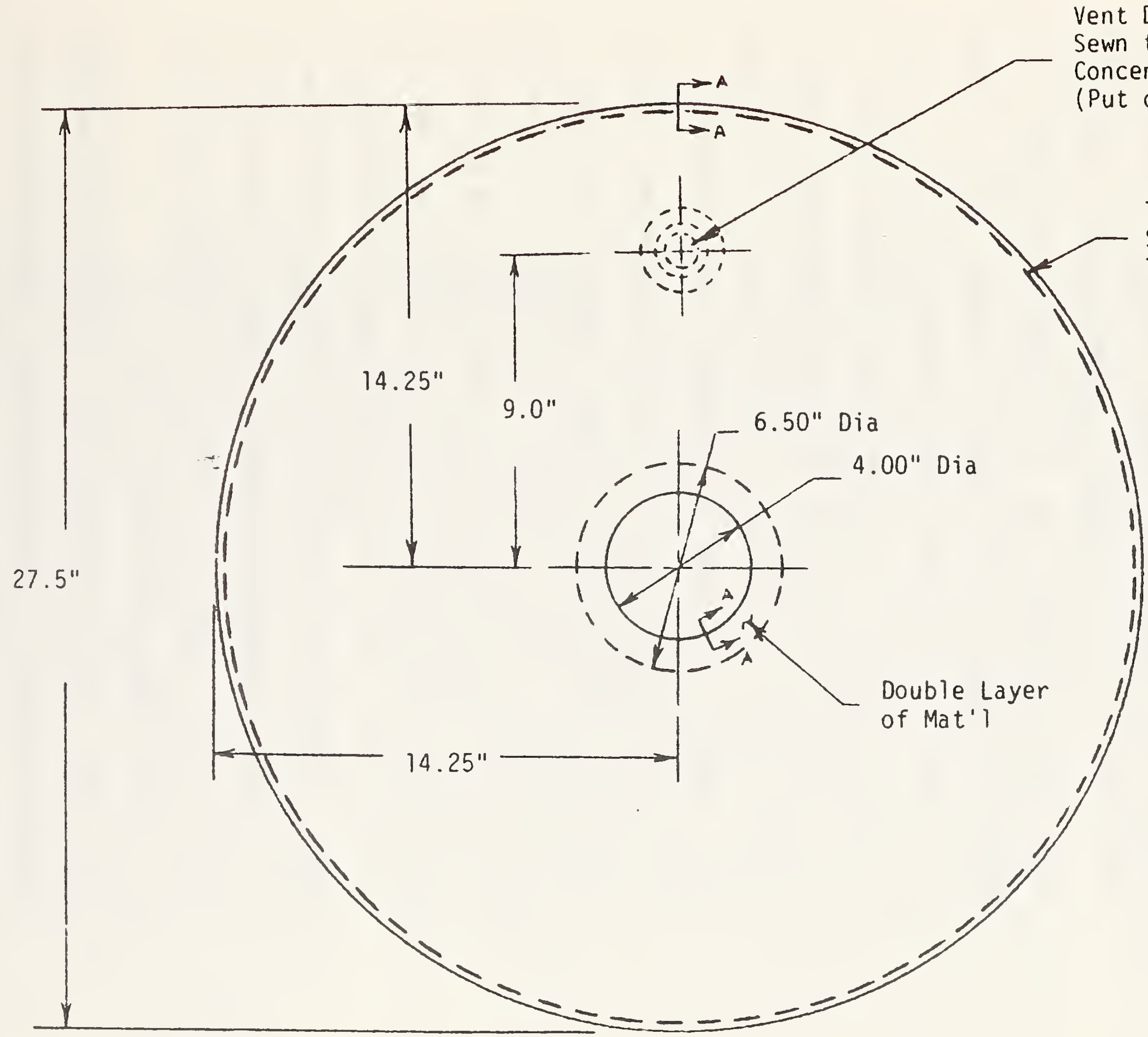
[1] Ibid., page 2-1.



Mat'l Specs:

- . Neoprene Coated Nylon
- . Coated Wgt: 8.2 oz/yd^2
- . Uncoated Wgt: 5.5 oz/yd^2
- . Nylon, Type 66, 840 Denier
- . Count, Warp & Fill 24x24

Seams:

- . Nylon Thread
- . 10 Stitches/in
- . 3 Rows Ea. Seam, Close Together

Vent Geometry:

- . Thiokol/Mercedes Inflat.
  - Vent Area = 1.0 in^2
  - Diameter = 1.128 in
- . Talley Part No. CU-1605
  - Vent Area = 2.75 in^2
  - Diameter = 1.871 in

NOTE: DIMENSIONS SHOWN ARE FINISHED DIMENSIONS

Figure 4-1. Driver ACRS Bag Design.

4.2 PASSENGER RESTRAINT SYSTEM

The following conclusions and recommendations are based upon the results of the PAC simulations discussed in Sections 2.2 and 3.3 and the crash test information presented in Section 2.2.3.

1. Inflator Design - According to computer prediction, the overall performances of both the Thiokol/Mercedes Part No. IU92520-04 design and the Talley Part No. CU-1605 design show them to be excellent candidates as the passenger restraint system inflator for the DeLorean sports car. One advantage the Thiokol system has, however, is that its performance has also been verified in two very satisfactory crash tests with the DeLorean vehicle. A further plus for this design is that the size is small enough that it appears that it may be sandwiched into the knee restraint area immediately aft of the glove box whereas, with the Talley unit, some glove box volume may have to be sacrificed.
2. Air Bag Design - Figure 3-11 shows the passenger air bag design which performed very well in the two crash tests and which was used in the computer study in this report. Based upon the very good crash test results with the 50th percentile male and also based upon the very satisfactory performance of this same air bag design throughout the computer study for the various crash and design conditions presented in this report, we recommend that the design remain just as it is.
3. Sensor Type - In the 36 mph crash test conducted on the DeLorean at Dynamic Science, the accelerometer type Bosche sensor (that was used in the test) indicated a sensing time of 13 milliseconds.

This is approximately the same sensing time used in this computer study. Either a "delta-V" or "elapsed time" sensor that results in this approximate sensing time over the range of speeds investigated herein will be satisfactory as the first stage sensor for the DeLorean. This first sensing stage will initiate the driver inflator and the first of the two passenger inflators.

However, for the second stage (where the second passenger inflator is initiated) we recommend (for the reasons cited in Section 3.3.3) that a sensor that utilizes elapsed time be used. Since the Bosche sensor is designed to have more than one level of crash sensing if desired, we believe that the Bosche unit lends itself to this scenario. The first level of sensing at say 13 msec from bumper contact, should be used to initiate the driver and first passenger inflator as well as to start a time counter. After the preprogrammed elapsed time (the staging time) has elapsed, the second sensing stage is reached and as the switch closes the second passenger inflator is "fired". Again, we believe that the present design of the Bosche sensor lends itself to this application.

4. Staging Time - Staging time as defined in this report is the time which elapses from the initiation of the first passenger inflator until initiation of the second. After studying possible staging times from zero to 20 milliseconds, under a variety of crash conditions, and potential passenger sizes and positions, we have determined that approximately seven milliseconds results with the best all around performance. We, therefore, recommend that the

second stage of the crash sensor be programmed to "fire" approximately seven milliseconds after the first stage (assuming a first stage "fire" of approximately 13 milliseconds for a 36 mph impact velocity - some increase in the 13 msec time will be satisfactory at lower impact speeds).

5. Passenger Size - Both inflator designs investigated (Thiokol and Talley) perform almost equally well for the range in potential passenger sizes from the 3 year old child to the 95th percentile adult male. Further, all passenger sizes from the 5th percentile female to the 95th percentile male are predicted to receive injury measures substantially below the criteria limits, at impact speeds up to and beyond 36 mph.

   The foreward positioned 3 year old child receives very low injury measures (for both the Thiokol and Talley inflators) for the static (vehicle not in in a crash) case, where the air bag is inadvertently deployed. However, for the dynamic (30 mph) case, where the child is positioned close to the dash, our analysis shows that the child will receive injury measures close to the criteria limits. We must point out, however, that our analysis is somewhat consevative and very much a "worst case" analysis for the child for the reasons stated in the body of this report. Sled tests which are scheduled in Contract DTNH22-82-07132 will help us to determine if this latter area is really a problem. As the child is positioned back toward his normally seated position (chest-to-dash spacing of 26 in.) the injury measures of the child drop to values substantially below the criteria limits, as indicated in Figure 3-26.

6. Impact Speed - The effects of impact speed on restraint system performance was evaluated in this study. The results of this evaluation shows that both the Thiokol and the Talley inflators are capable of protecting the passenger in barrier crashes in excess of 40 mph. In this portion of the study, we used the 50th percentile male anatomical properties. However, according to our analysis, regarding the effects of passenger size on restraint performance (where we learned that passengers smaller than the 50th percentile male receives even a greater amount of protection from the restraint system), we may conclude that the full range from the 3 year old child to the 50th percentile male (in the normally seated position) will receive injury measures below the criteria limits, for speeds up to and even beyond 40 mph.

For the 95th percentile male, the results are not so clear. There is very little headroom in the DeLorean sports car and we suspect that some head/windshield or header contact may take place at the higher impact speeds. This will be further investigated in the sled tests scheduled for February, 1982.

FINAL COMMENT

This completes the analysis, satisfying the objectives stated at the beginning of this report. As a closing remark, we would like to comment on an interesting observation we made concerning the analytical/experimental approach followed in this study. This observation supports our belief that a balanced analytical/experimental approach for ACRS optimization offers the greatest insight into the design optimization process. To illustrate, in a previous ACRS development effort, involving sled impact tests with an out-of-position 3 year old child dummy, we observed that the injury measures experienced by the dummy increased progressively during the sled test series, even when the test conditions remained about the same. Because of the cost of these sled tests, it was impossible to isolate the source (or sources) of this effect. However, in the current study, with the aid of computer simulations, we have gained a tremendous amount of insight into the crash dynamics of the 3 year old out-of-position child dummy and are now able to reflect back to the earlier sled tests and identify the key factor responsible for the noted increase in the injury measures. We have learned, in the current study, that the injury measures of the 3 year old child dummy are extremely sensitive to the vertical H-point dimension (see Figure 3-26). The results herein show that the higher the H-point the lower the injury measures since the bag impacts the child further down on the chest so that there is less body articulation. The converse is also true, the lower the H-point the higher the injury measures. Relating this now to the referenced sled test series, it appears that the reported increase in the injury measures was caused by the "breaking down" of the seat cushion material and the yielding of the seat structure as the test series progressed. This caused a decrease in the dummy's vertical H-point dimension and the corresponding increase in the injury measures as the test series progressed. This sort of insight can be gained only thru the use of computer simulations.

APPENDIX A: SAE J963

ANTHROPOMORPHIC TEST DEVICE FOR DYNAMIC TESTING—SAE J963

SAE Recommended Practice

Report of Automotive Safety Committee approved June 1968.

1. Scope—This SAE Recommended Practice describes and defines a standard anthropomorphic test device for use in both actual and simulated vehicle crash impact tests. This test device is designed to be used in the evaluation of vehicle interiors and restraint systems for vehicle occupants during various impact conditions. The structural characteristics of this device simulate the basic human body components only in size, shape, mass, and kinematics. The device has no capability to simulate human physiological functions or to measure simulated physiological responses.

This report establishes the basic design criteria for component weights, weight distribution, dimensions, and motion capabilities of the device. Specific performance requirements for the device are given only where data are available. This SAE Recommended Practice reflects the current state-of-the-art in this regard. Additional sizes of

TABLE 1—50th PERCENTILE MALE-BODY CENTERS OF GRAVITY, WEIGHTS AND DIMENSIONS (SEE FIG. 1)

Letter Designation	Title	Value	Reference
	Centers of Gravity	**in.**	
A	Head (forward from backline of body)	4.0	1
B	Head (below top of head)	4.7	1
C	Shoulders (forward of backline)	3.8	1
D	Shoulders (below top of head)	14.1	1
E	Abdomen (forward of backline)	4.9	1
F	Abdomen (below top of head)	20.8	1
G	Buttocks (forward of backline)	5.3	1
H	Buttocks (below top of head)	31.2	1
	Head and trunk whole (forward of backline)	4.7	1
	Head and trunk whole (below top of head)	22.7	1
	Segment Weights	**lb**	
	Head	11.2	1
	Shoulders and Upper Thorax	17.3	1
	Lower Thorax and Upper Abdomen	23.0	1
	Lower Abdomen, Buttocks, and Upper Thighs	37.5	1
	Upper Arm—each	5.4	1
	Forearm—each	3.4	1
	Hand—each	1.4	1
	Upper Leg—each	17.6	1
	Lower Leg—each	6.9	1
	Foot—each	2.8	1
	Total Test Device Weight	164 ± 3	

Letter Designation	Title	Value	Reference
	Segment Section Lines	**in.**	
AB	Head	9.3	1
AC	Shoulders	16.9	1
AD	Abdomen	25.1	1
K	Buttocks	10.0	1
I	Shoulder—Elbow Length	14.1 ± 0.3	4
J	Ėlbow Rest Height (erect)	9.5 ± 0.5	3
L	Popliteal Height	17.3 ± 0.2	3
M	Knee Height (sitting)	21.4 ± 0.3	3
N	Buttock Popliteal Length	19.5 ± 0.3	3
O	Chest Depth	9.0 ± 0.4	2
P	Buttock Knee Length	23.3 ± 0.3	3
Q	Thigh Clearance	5.7 ± 0.3	3
R	Elbow-Finger Tip Length	18.7 ± 0.5	4
S	Foot Length	10.5 ± 0.2	2
T	Heoo Length	7.7 ± 0.2	2
U	Sitting Height (erect)	35.7 ± 0.5	3
V	Shoulder Breadth	17.9 ± 0.4	2
W	Foot Breadth	3.8 ± 0.3	2
X	Head Circumference	22.5 ± 0.5	2
Y	Chest Circumference	37.7 ± 1.0	4
Z	Waist Circumference (sitting)	33.0 ± 1.0	4
AA	Head Breadth	6.1 ± 0.2	2

1. Experimental data submitted to the SAE Crash Test Dummy Task Force in a report by Alderson Research Laboratories, Inc., and reported in the minutes of April 1, 1968 meeting.
2. H. T. E. Hertzberg, E. Churchill, and G. S. Daniels, "Anthropometry of Flying Personnel, 1950." WADC Technical Report T. R. 52-321, Wright Air Development Center, September 1954.
3. "Weight, Height and Selected Body Dimensions of Adults—United States, 1960-1962." Report Series 11 Number 8, National Center for Health Statistics, Public Health Service, U. S. Department of Health, Education and Welfare.
4. H. T. E. Hertzberg, Robert M. White, and the Crash Dummy Task Force of SAE Human Factors Subcommittee as reported in the Task Force minutes of Dec. 5, 1967 meeting. These values were developed utilizing adjusted military data on a judgment basis in the absence of existing published data on the civilian population.
5. Newman and White, "Reference Anthropometry of Army Men." Report 180, 1951.

TABLE 2—50th PERCENTILE MALE RANGES OF MOTIONS AND TERMINOLOGY

NOTE: The movements are described and measured from a referenced "anatomical position," which is defined as: "An erect standing posture with the palm surfaces of the hands positioned anteriorly (in supination)."

There are some movements described in this list that may be best achieved mechanically by not duplicating the normal anatomical relationships of the skeletal components.

Letter Designation	Title	Angle, Deg
	Head with Respect to Torso	
B	Flexion	60 + 10
A	Hyperextension	60 + 45
C	Lateral Flexion	±40 ± 10
D	Rotation	±70 ± 10
	Shoulder Girdle with Respect to Torso	
E	Anterior-Posterior Excursion	± 10
F	Elevation	20 + 10
AG	Depression	10 + 10
	Upper Arm at Shoulder	
G	Adduction	0 } +10
H	Abduction	135 }
I	Medial Rotation	90 } +10
J	Lateral Rotation	0 }
K	Flexion	180 } +10
L	Hyperextension	60 }
	Forearm at Elbow	
M	Flexion	135 min
	Hand at Wrist	
P	Palmar Flexion	90 + 10
Q	Dorsiflexion	60 + 10
O	Pronation	} 180 ± 10
N	Supination	}

Letter Designation	Title	Angle, Deg
	Thigh at Hip	
R	Flexion	120 min
S	Hyperextension	45 + 10
U	Medial Rotation	50 } +10
T	Lateral Rotation	50 }
W	Adduction	10 } +10
V	Abduction	50 }
	Lower Leg at Knee	
X	Flexion	135 min
	Foot at Ankle	
Z	Plantar Flexion	45 } +10
Y	Dorsiflexion	30 }
AB	Inversion	20 } −5
AA	Eversion	20 }
	Long Axis of Torso	
AC	Flexion	40 min
AE	Hyperextension	30 + 5
AD	Lateral Flexion	35 + 10
AF	Rotation	35 + 10

References:
1. Reference 4, Table 1.
2. Glanville and Kreezer, "The Maximum Amplitude and Velocity of Joint Movements in Normal Male Adults." Human Biology Vol. 9, 1937, pp 197-211.

anthropomorphic test devices are under development. It is intended that the content of this report will be subject to continuing review and will be revised as additional data, experience, and new technology warrant.

Other dynamic anthropomorphic test devices are described in the SAE J944 and SAE J984.

2. *Purpose*—The test device described herein is for use in the following evaluation programs:

2.1 Design developments of the vehicle interiors for energy absorption during impacts.

2.2 Correlation of data obtained from various types of test programs and facilities and from different testing agencies.

3. *General Description*—The standard anthropomorphic test device shall have 50th percentile component size and weight characteristics appropriate to the adult male as defined in Tables 1 and 2 and Figs. 1-3.

The test device(s) shall be capable of receiving instrumentation, and when so equipped shall have a range of component kinematic patterns similar to those of an adult human male as defined in Table 2 and Figs. 2 and 3. The head, torso, arm, and leg components of the test device shall have characteristics to respond kinematically during impact. These shall include the functional mechanical equivalents of the spinal column, rib cage and sternum, pelvis, joint articulations at the neck, shoulder, elbow, wrist, hip, knee, and ankle, and exterior component coverings.

4. *Component or Segment Requirements*

4.1 Head—The head shall consist of composite structures that are geometrically similar to the human head. The basic structure shall have an accessible internal ballast and instrumentation cavity and a pliable external covering with appropriate surface contours. The connecting and supporting structure for the head shall have the capability of maintaining an erect head position up to a horizontal acceleration of 2g.

4.2 Torso—The connecting and supporting structures shall allow the test device to maintain a simulated sitting position similar to that of a human occupant of a vehicle. The design of these connecting and supporting structures shall be such that during acceleration, the lap belt restrained test device will develop a forward jackknifing motion.

4.2.1 Torso: Shoulder Sections—The shoulder structures shall be geometrically and functionally similar to the human shoulder complex.

4.2.2 Thorax: Spring Rate—The thorax dynamic impact load—deflection spring rate shall be 900 ± 100 lb/in. This spring rate is determined by dividing the force applied to the thorax by the deflection within the range of 0.75-1.0 in.

4.2.2.1 Determination of Thorax Spring Rate—The dynamic spring rate of the thorax may be determined using a complete test device with the thorax assembly only. When the complete test device is evaluated, a simulated forward impact of a seated occupant is used. When only the thorax assembly is used, its weight along with mounting fixture shall be 45 ± 5 lb.

4.2.2.2 Impact Target—The impact target shall be 6 in. in diameter with an optional 0.5 in. covering of padding material. The target shall be fixed to a stationary load cell.

4.2.2.3 Location of Center of Target—The center of impact on the sternum shall be on the vertical centerline at a point located 18 ± 0.5 in. from the top of the head of an erect test device.

4.2.2.4 Alignment of Impact Target—The impact target and load cell assembly shall be aligned so that the major force axis is normal to

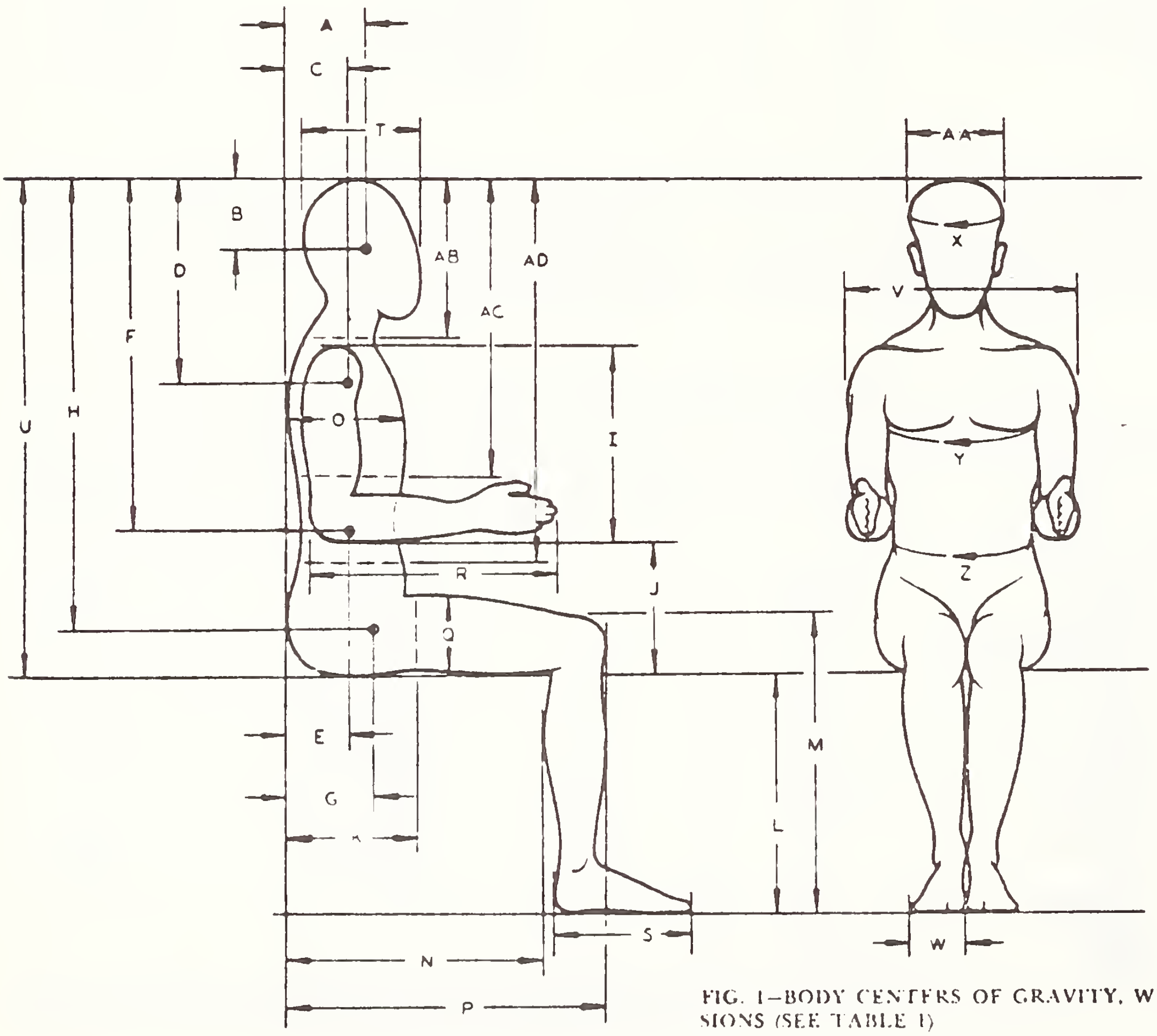


FIG. 1—BODY CENTERS OF GRAVITY, WEIGHTS, AND DIMENSIONS (SEE TABLE 1)

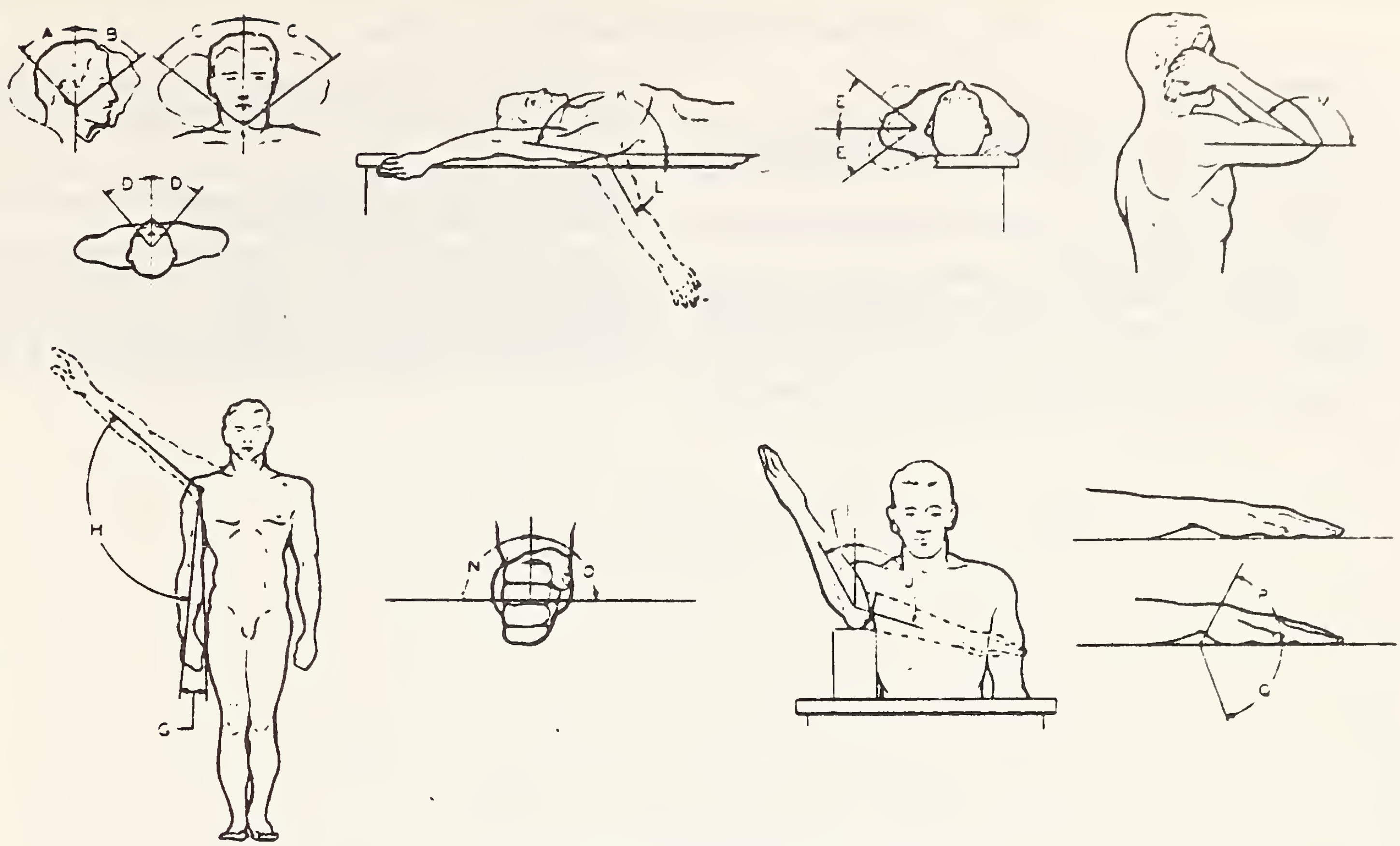


FIG. 2—RANGES OF MOTION (SEE TABLE 2)

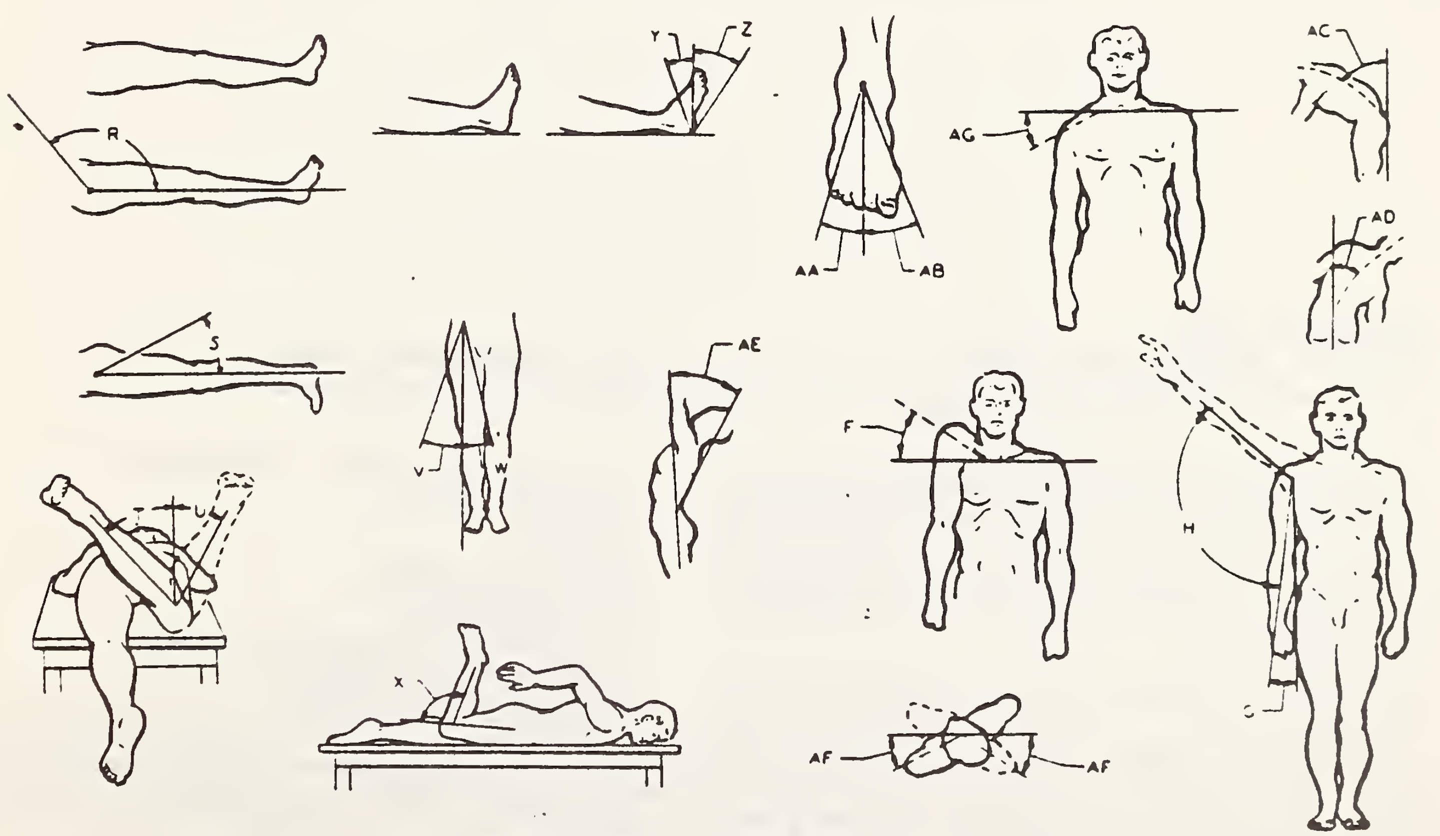


FIG. 3—RANGES OF MOTION (SEE TABLE 2)

the impacting sternum.

4.2.2.5 Impact Velocity—Impact velocity is 22 ± 7 ft/sec.

4.2.2.6 Sternum Deflection Measurement—The measured deflection shall be a measure of sternum movement relative to the spine only.

4.2.3 Torso: Abdominal Section—The simulated abdominal structure shall be soft and pliable.

4.2.4 Torso: Pelvic Section—The pelvic structure shall be geometrically similar to the human pelvis.

4.3 Arm and Leg Kinematics—The range of motion of each extremity component is defined in Table 2 and Figs. 2 and 3. All joints shall have adjustment features which can be set to hold the test device components in any position against an acceleration of 2g in any direction.

5. External Covering—The external covering of the test device shall be soft, pliable, tear resistant, and elastic. The covering may be discontinuous as required for unrestricted motion, except at torso sections where restraint belts will be used with the test device during impact tests.

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

7. Instrumentation—There shall be provision for internal placement of instrumentation in the head and thorax and pelvic sections. All instrument cavities shall be readily accessible. They shall contain removable ballast to establish initially specified masses and centers of gravity. Care shall be taken when installing instrumentation to maintain masses and center of gravity specified in Table 2 and Figs. 2 and 3.

ROLL-OVER TESTS WITHOUT COLLISION—SAE J857

SAE Recommended Practice

Report of Automotive Safety Committee approved June 1963.

1. Scope—Roll-over tests are conducted to evaluate vehicle structure and occupant injury potential. This SAE Recommended Practice is intended to establish guidelines for conducting passenger car roll-over tests for the purpose of standardizing these tests, so that data obtained by various test facilities may be more readily compared. Methods and instrumentation are recommended for the study and evaluation of vehicle structures and occupant movement in simulated roll-over accidents without collision.

Procedures and equipment described will be subject to continuing review and will be revised as experience and improvements in the technology warrant.

2. Objectives—The objective of this test procedure is to produce vehicle and occupant dynamics corresponding to accidental vehicle roll-over without collision and to provide a uniform evaluation of passenger compartment performance during roll-over. Data gathered should include measurements of, and means for, identifying occupant and vehicle dynamics and violation of the passenger compartment by structural deformation, as well as penetration and separation of the various components of the vehicle. The following occupant and vehicle criteria are desirable in evaluating vehicle performance:

2.1 Triaxial Acceleration

2.1.1 Occupant

2.1.2 Vehicle

2.2 Occupant Movements

2.2.1 Conditions of restraint

2.2.2 Restraint loadings

2.3 Mechanisms of Accidental Door Unlatching

2.4 Physical Damage to Vehicle

2.5 Physical Damage to Occupants

3. Methodology—Studies of roll-over test techniques have indicated that no one technique is available that can obtain realistic results that are reproducible among test laboratories and between different types of passenger vehicles. Therefore, the methodology section is written to provide information on current techniques and will be modified as new data develops.

These general techniques are in use to produce test roll-overs:

Ground Level Roll-Over—In ground level roll-overs, a linear velocity is applied to the test vehicle and the roll is induced by a turn-

APPENDIX B: LISTING OF DRACR INPUT AND RESULTS

```
INPUT FILE NAME?DMCLP12

ENTER 1 IF COLUMN IS SUPPORTED AT THE FIREWALL; OTHERWISE ENTER 2?1



INPUT VALUES -- INPUT UNITS( MSEC, MPH, DEGREES, INCHES, LBS, FT-LBS, G'S)
INITIAL VELOCITY:         36.0
INITIAL HEAD ANGLE:        -11.0
INITIAL TORSO ANGLE:        -26.0
      MLEG     MTORSO     MHEAD       RT        RN        RH       RTOPH
      73.0      57.9      11.2      13.7      19.1      6.50      27.2
     NPTS NECK  NPTS KR  NPTS VEH  NPTS SEAT NPTS GAS  NPTS COL  NPTS WHC
         9         5        12         6        12         5         8
     NP WRP    NP WRN    NP CRP    NP CRN
         2         2         6         6
     SL SEAT   SL KR
 0.500E+04 0.500E+04
GAS FLOW TIME - MSEC
        0.      17.5      20.5      26.0      31.0      36.0      41.0      46.0
  51.0      56.0
GAS FLOW TIME - MSEC
      71.0      100.
GAS FLOW - LB/SEC
        0.        0.      3.40      4.09      4.26      3.60      2.45      1.63
 0.980     0.490
GAS FLOW - LB/SEC
        0.        0.
COLUMN STROKE - INCHES
     -10.0        0.     0.100      1.00      20.0
COLUMN FORCE - LBS
        0.        0. 0.100E+05 0.200E+05 0.200E+05
SEAT FRICTION DISPLACEMENT - INCHES
     -50.0        0.      1.00      14.0      15.0      50.0
SEAT FRICTION FORCE - LBS
        0.        0.      350.      350.        0.        0.
NECK ANGLE - DEG
     -85.0     -75.0     -60.0     -22.5      15.0      16.0      45.0      60.0
  70.0
NECK TORQUE - FT-LBS
      50.0      35.0      22.5      22.5        0.     -45.0     -45.0     -65.0
 -140.
VEH. PULSE TIME - MSEC
        0.      14.0      37.0      43.0      55.0      60.0      67.0      77.5
  81.0      85.0
VEH. PULSE TIME - MSEC
      110.      120.
VEH. PULSE DECELERATION - G'S
        0.      17.0        0.      37.0      12.0      56.0      17.0      9.00
  42.0      15.0
VEH. PULSE DECELERATION - G'S
        0.        0.
```

```
KNEE DISPLACEMENT - INCHES
    -50.0      2.00      3.10      10.0      15.0
KNEE FORCE - LBS
       0.        0. 0.180E+04 0.120E+04      200.
WHEEL STROKE - INCHES
    -10.0        0.     0.400      1.40      2.40      3.00      4.00      6.00
WHEEL FORCE - LBS
       0.        0. 0.120E+04 0.120E+04 0.370E+04 0.370E+04 0.370E+04 0.370E+04
WHEEL ANGLE, POS. - DEG
       0.      90.0
WHEEL TORQUE, POS. - IN-LBS
 0.500E+05 0.500E+05
WHEEL ANGLE, NEG. - DEG
       0.      90.0
WHEEL TORQUE, NEG. - IN-LBS
 0.500E+05 0.500E+05
COLUMN ANGLE, POS. - DEG
    -10.0        0.      1.00      12.0      40.0      50.0
COLUMN REACTION, POS. - IN-LBS IF 2; LBS IF 1
       0.        0. 0.500E+04 0.500E+04 0.500E+04 0.100E+05
COLUMN ANGLE, NEG. - DEG
    -10.0        0.      1.00      12.0      40.0      50.0
COLUMN REACTION, NEG. - IN-LBS IF 2; LBS IF 1
       0.        0. 0.500E+04 0.500E+04 0.500E+04 0.100E+05
    ATMOP       PG7       GTZ         U       PN1       PN2       PN3
     14.7     -14.7 0.166E+04      662.      1.40      1.40      1.40
      VC1       VC2        AV        SA        SC       X1Z       Y1Z
    0.700     0.700      1.50      12.5      8.00      40.0      23.4
   THETAC        MU      LSCZ      LFWZ      LBAZ      LBFZ        WC
     14.0        0.      11.0      16.5      15.0      19.0      7.00
       LF      THFO      THLO
     18.0      20.0      25.0
      XWH       YWH    RIMRAD       X2Z       Y2Z        WB        WH
    -6.00        0.      7.38      44.9      6.75      15.0      7.00
   THETAW       RIP       WWH       WIP      RCOL       DCN
     14.0      2.50      3.00      2.00      15.0     0.690
```

Note: Please see Appendix E for modifications to the head force routine in DRACR.

TIME (MS)	VEH G'S (G'S)	VEH VEL (MPH)	VEH DISP (INCHES)	BODY G'S (G'S)	COL DISP (INCHES)	BAG PRESS (PSIG)
0.	0.	36.03	0.	-0.37	0.	-14.70
5.00	6.07	35.70	3.16	-0.49	0.	-14.70
10.00	12.14	34.70	6.26	-0.50	0.	-14.70
15.00	16.26	33.05	9.25	-0.54	0.	-14.70
20.00	12.57	31.47	12.08	-0.60	0.	-13.62
25.00	8.67	30.30	14.80	-0.66	0.	-9.63
30.00	5.17	29.53	17.43	-0.63	0.	-5.07
35.00	1.48	29.16	20.01	-0.63	0.	-0.55
40.00	18.50	28.53	22.56	-9.65	0.	2.57
45.00	32.83	25.16	24.94	-17.18	0.02	4.74
50.00	22.42	22.13	27.01	-22.49	0.02	6.08
55.00	12.00	20.24	28.87	-25.20	0.02	6.73
60.00	56.00	16.53	30.52	-25.39	0.02	6.78
65.00	28.14	11.89	31.75	-25.15	0.02	6.94
70.00	14.71	9.87	32.69	-24.29	0.02	6.92
75.00	10.90	8.46	33.50	-23.67	0.02	6.68
80.00	32.57	6.77	34.19	-21.44	0.02	6.29
85.00	15.00	3.42	34.61	-19.04	0.02	5.85
90.00	12.00	1.95	34.85	-16.54	0.02	5.35
95.00	9.00	0.80	34.97	-13.94	0.02	4.80
100.00	6.00	-0.02	35.00	-11.57	0.02	4.20
105.00	3.00	-0.52	34.97	-9.43	0.02	3.59
110.00	0.	-0.68	34.92	-7.45	0.02	2.98
115.00	0.	-0.68	34.86	-5.50	0.02	2.40
120.00	0.	-0.68	34.80	-4.57	0.02	1.87

TIME (MS)	FEM ANGLE (DEG)	H-P VEL (MPH)	H-P ACC (G'S)	FEM FORCE (LBS)	SEAT FR. (LBS)	H-P R.D. (INCHES)
0.	20.00	36.03	0.	0.	0.	0.
5.00	20.00	36.06	-0.27	0.	3.87	0.01
10.00	20.00	36.08	0.00	0.	29.12	0.08
15.00	20.00	36.05	0.74	0.	95.27	0.27
20.00	21.18	35.90	2.05	0.	210.96	0.60
25.00	22.83	35.59	3.65	0.	350.00	1.03
30.00	24.60	35.18	3.70	0.	350.00	1.52
35.00	26.33	34.78	3.72	0.	350.00	2.02
40.00	27.95	34.30	4.58	0.	350.00	2.51
45.00	29.93	33.81	4.27	0.	350.00	3.13
50.00	32.61	33.21	8.75	175.92	350.00	4.01
55.00	35.51	31.77	17.80	502.58	350.00	5.02
60.00	38.36	29.38	24.26	700.28	350.00	6.06
65.00	41.61	26.77	23.19	648.67	350.00	7.30
70.00	44.87	24.28	22.07	596.51	350.00	8.60
75.00	47.85	21.89	21.38	548.78	350.00	9.83
80.00	50.55	19.59	20.53	505.95	350.00	10.96
85.00	53.34	17.38	19.71	462.21	350.00	12.16
90.00	56.10	15.27	18.93	419.80	350.00	13.36
95.00	58.69	13.27	16.64	381.00	175.59	14.50
100.00	61.10	11.61	14.46	345.80	0.	15.56
105.00	63.32	10.05	14.02	314.21	0.	16.54
110.00	65.31	8.53	13.60	286.70	0.	17.41
115.00	67.02	7.07	13.21	263.64	0.	18.16
120.00	68.45	5.64	12.75	244.81	0.	18.77

TIME (MS)	TORSO DISP (INCHES)	TORSO ANG (DEG)	TORSO VEL (D/SEC)	TORSO ACC (D/SEC**2)	TORSO R.D. (INCHES)	TORSO R.V. (MPH)
0.	0.00	-26.00	0.	-594.75	0.00	0.
5.00	3.17	-26.01	-5.87	-1184.69	0.01	0.29
10.00	6.33	-26.06	-11.11	-810.28	0.07	1.25
15.00	9.49	-26.12	-13.10	196.10	0.25	2.84
20.00	12.65	-26.18	-8.17	1988.84	0.56	4.33
25.00	15.79	-26.18	7.20	4219.96	1.00	5.38
30.00	18.93	-26.09	28.80	4345.86	1.50	6.01
35.00	22.05	-25.90	50.62	4386.22	2.04	6.23
40.00	25.15	-25.62	49.40	-8917.01	2.59	6.37
45.00	28.16	-25.53	-25.43	-21516.51	3.23	8.33
50.00	31.03	-25.95	-145.14	-23612.60	4.02	9.31
55.00	33.68	-26.94	-244.96	-15070.72	4.82	8.56
60.00	36.09	-28.31	-294.38	-6508.52	5.57	9.32
65.00	38.23	-29.87	-331.37	-8136.90	6.48	10.97
70.00	40.11	-31.64	-374.41	-8888.19	7.42	10.08
75.00	41.74	-33.63	-423.02	-9475.32	8.24	8.64
80.00	43.13	-35.86	-466.66	-7759.30	8.94	7.69
85.00	44.29	-38.28	-500.84	-5757.80	9.68	8.62
90.00	45.26	-40.85	-524.59	-3581.34	10.41	7.92
95.00	46.04	-43.51	-538.92	-3011.77	11.07	7.16
100.00	46.67	-46.24	-555.21	-2532.35	11.67	6.41
105.00	47.17	-49.04	-562.69	-378.86	12.20	5.55
110.00	47.56	-51.85	-560.00	1539.39	12.64	4.52
115.00	47.85	-54.63	-547.84	3467.78	12.99	3.44
120.00	48.05	-57.32	-527.69	3742.28	13.25	2.45

TIME (MS)	HEAD DISP (INCHES)	HEAD ANG (DEG)	HEAD VEL (D/SEC)	HEAD ACC (D/SEC**2)	HEAD R.D. (INCHES)	HEAD R.ANG (DEG)
0.	0.00	-11.00	0.	-649.29	0.00	15.00
5.00	3.17	-10.98	7.94	1823.93	0.01	15.03
10.00	6.34	-10.92	17.16	1784.26	0.07	15.14
15.00	9.51	-10.81	26.01	1559.56	0.26	15.31
20.00	12.67	-10.66	33.29	1013.40	0.59	15.51
25.00	15.84	-10.48	37.18	23.76	1.04	15.70
30.00	19.00	-10.30	35.12	-502.43	1.57	15.79
35.00	22.15	-10.13	32.49	-567.17	2.15	15.76
40.00	25.30	-9.95	48.19	12438.66	2.74	15.67
45.00	28.35	-9.68	57.04	4083.76	3.41	15.85
50.00	31.22	-9.34	78.78	357.66	4.21	16.61
55.00	33.82	-9.00	47.93	-10529.88	4.96	17.94
60.00	36.13	-8.87	7.23	-12461.05	5.61	19.45
65.00	38.12	-9.09	-117.45	-38186.01	6.37	20.78
70.00	39.73	-10.22	-340.09	-46752.91	7.04	21.42
75.00	40.97	-12.30	-468.82	-20553.78	7.48	21.33
80.00	41.90	-14.91	-579.17	-23258.32	7.72	20.94
85.00	42.54	-18.11	-701.70	-25693.90	7.92	20.17
90.00	42.90	-21.95	-834.77	-27321.40	8.05	18.90
95.00	43.03	-26.47	-975.50	-28810.66	8.07	17.04
100.00	42.96	-31.70	-1117.66	-27470.55	7.96	14.54
105.00	42.73	-37.63	-1251.20	-25694.11	7.76	11.41
110.00	42.39	-44.19	-1370.62	-21608.73	7.47	7.66
115.00	41.98	-51.29	-1460.05	-13366.00	7.12	3.34
120.00	41.55	-58.70	-1492.97	928.03	6.76	-1.39

TIME (MS)	WH AX FOR (LBS)	WH N FOR (LBS)	WH MOMENT (IN-LBS)	WH RESIST (LBS)	WH STROKE (INCHES)	WH ST VEL (IN/SEC)
=======	=======	=======	=======	=======	=======	=======
0.	0.	0.	0.	0.	0.	0.
5.00	0.	0.	0.	0.	0.	0.
10.00	0.	0.	0.	0.	0.	0.
15.00	0.	0.	0.	0.	0.	0.
20.00	0.	0.	0.	0.	0.	0.
25.00	0.	0.	0.	0.	0.	0.
30.00	0.	0.	0.	0.	0.	0.
35.00	0.	0.	0.	0.	0.	0.
40.00	556.23	413.23	-537.52	1.00	0.	0.
45.00	1052.85	782.87	-1056.99	705.01	0.34	215.94
50.00	1319.15	1019.96	-1349.09	1200.00	0.62	23.04
55.00	1426.67	1151.68	-1405.68	1200.00	1.04	153.33
60.00	1527.97	1211.80	-1176.05	1862.11	1.66	0.
65.00	1470.96	1258.47	-1189.47	1862.11	1.66	0.
70.00	1366.83	1245.08	-1151.29	1862.11	1.66	0.
75.00	1224.24	1181.62	-1056.37	1862.11	1.66	0.
80.00	1132.89	1111.05	-939.70	1862.11	1.66	0.
85.00	923.93	997.45	-835.44	1862.11	1.66	0.
90.00	759.43	883.78	-733.83	1862.11	1.66	0.
95.00	603.20	764.86	-626.69	1862.11	1.66	0.
100.00	459.19	645.50	-513.85	1862.11	1.66	0.
105.00	328.75	527.10	-397.96	1862.11	1.66	0.
110.00	211.33	406.01	-284.81	1862.11	1.66	0.
115.00	113.78	270.74	-180.65	1862.11	1.66	0.
120.00	51.13	161.74	-102.19	1862.11	1.66	0.

TIME (MS)	COL AX FOR (LBS)	COL N FOR (LBS)	COL MOMENT (IN-LBS)	COL RESIST (LBS)	COL STROKE (INCHES)	COL ST VEL (IN/SEC)
=======	=======	=======	=======	=======	=======	=======
0.	0.	0.	0.	0.	0.	0.
5.00	0.	0.	0.	0.	0.	0.
10.00	0.	0.	0.	0.	0.	0.
15.00	0.	0.	0.	0.	0.	0.
20.00	0.	0.	0.	0.	0.	0.
25.00	0.	0.	0.	0.	0.	0.
30.00	0.	0.	0.	0.	0.	0.
35.00	0.	0.	0.	0.	0.	0.
40.00	681.84	410.94	-537.52	1.00	0.	0.
45.00	1275.27	768.82	-1056.99	1854.35	0.02	0.
50.00	1470.70	954.59	-1349.09	1854.35	0.02	0.
55.00	1507.49	1039.08	-1405.68	1854.35	0.02	0.
60.00	1907.18	1167.71	-1176.05	1893.80	0.02	1.95
65.00	1660.90	1132.73	-1189.47	1981.93	0.02	0.
70.00	1465.74	1085.28	-1151.29	1981.93	0.02	0.
75.00	1297.36	1024.02	-1056.37	1981.93	0.02	0.
80.00	1352.96	1008.53	-939.70	1981.93	0.02	0.
85.00	1024.94	885.69	-835.44	1981.93	0.02	0.
90.00	840.17	791.71	-733.83	1981.93	0.02	0.
95.00	663.68	694.46	-626.69	1981.93	0.02	0.
100.00	499.40	596.33	-513.85	1981.93	0.02	0.
105.00	348.69	496.42	-397.96	1981.93	0.02	0.
110.00	211.01	389.25	-284.81	1981.93	0.02	0.
115.00	113.56	266.75	-180.65	1981.93	0.02	0.
120.00	51.00	162.55	-102.19	1981.93	0.02	0.

TIME (MS)	WH AP MOM (IN-LBS)	WH RES MOM (IN-LBS)	WH ANGLE (DEG)	WH ANG VEL (DEG/SEC)		
0.	0.	0.	14.00	0.		
5.00	0.	0.	14.00	0.		
10.00	0.	0.	14.00	0.		
15.00	0.	0.	14.00	0.		
20.00	0.	0.	14.00	0.		
25.00	0.	0.	14.00	0.		
30.00	0.	0.	14.00	0.		
35.00	0.	0.	14.00	0.		
40.00	-537.52	50000.00	14.12	0.		
45.00	-1056.99	50000.00	14.19	0.		
50.00	-1349.09	50000.00	14.22	0.		
55.00	-1405.68	50000.00	14.22	0.		
60.00	-1176.05	50000.00	14.25	0.		
65.00	-1189.47	50000.00	14.36	0.		
70.00	-1151.29	50000.00	14.36	0.		
75.00	-1056.37	50000.00	14.36	0.		
80.00	-939.70	50000.00	14.36	0.		
85.00	-835.44	50000.00	14.36	0.		
90.00	-733.83	50000.00	14.36	0.		
95.00	-626.69	50000.00	14.36	0.		
100.00	-513.85	50000.00	14.36	0.		
105.00	-397.96	50000.00	14.36	0.		
110.00	-284.81	50000.00	14.36	0.		
115.00	-180.65	50000.00	14.36	0.		
120.00	-102.19	50000.00	14.36	0.		

TIME (MS)	COL AP MOM (IN-LBS)	COL RES MOM (IN-LBS)	COL ANGLE (DEG)	COL ANG VEL (DEG/SEC)		
0.	0.	0.	14.00	0.		
5.00	0.	0.	14.00	0.		
10.00	0.	0.	14.00	0.		
15.00	0.	0.	14.00	0.		
20.00	0.	0.	14.00	0.		
25.00	0.	0.	14.00	0.		
30.00	0.	0.	14.00	0.		
35.00	0.	0.	14.00	0.		
40.00	10763.28	-7244.49	14.12	65.17		
45.00	20071.33	-17970.45	14.22	0.		
50.00	24884.43	-20504.61	14.25	0.		
55.00	27149.62	-20504.61	14.25	0.		
60.00	30913.73	-25091.85	14.29	0.		
65.00	29938.24	-33212.13	14.40	0.		
70.00	28672.41	-33212.13	14.40	0.		
75.00	27083.91	-33212.13	14.40	0.		
80.00	26774.85	-33212.13	14.40	0.		
85.00	23503.59	-33212.13	14.40	0.		
90.00	21022.55	-33212.13	14.40	0.		
95.00	18457.07	-33212.13	14.40	0.		
100.00	15873.40	-33212.13	14.40	0.		
105.00	13243.67	-33212.13	14.40	0.		
110.00	10411.98	-33212.13	14.40	0.		
115.00	7149.63	-33212.13	14.40	0.		
120.00	4364.79	-33212.13	14.40	0.		

TIME (MS)	BAG PEN. (INCHES)	BAG VOL. (CU.IN.)	BAG PRESS. (PSIG)	W/A FORCE (LBS)	P. FORCE (LBS)
0.	3.34	5232.35	-14.70	0.	0.
5.00	3.35	5231.64	-14.70	0.	0.
10.00	3.40	5225.61	-14.70	0.	0.
15.00	3.56	5208.22	-14.70	0.	0.
20.00	3.85	5175.51	-13.62	0.	0.
25.00	4.24	5129.11	-9.63	0.	0.
30.00	4.69	5071.56	-5.07	0.	0.
35.00	5.18	5005.84	-0.55	0.	0.
40.00	5.67	5038.30	2.57	22.99	456.63
45.00	6.02	5004.89	4.74	51.06	833.09
50.00	6.42	4967.02	6.08	74.73	1054.00
55.00	6.81	4935.21	6.73	89.27	1139.11
60.00	6.87	4934.56	6.78	87.53	1142.14
65.00	7.53	4886.86	6.94	96.26	1090.74
70.00	8.16	4836.92	6.92	97.26	1003.66
75.00	8.60	4807.15	6.68	90.01	886.20
80.00	8.84	4801.03	6.29	79.10	762.31
85.00	8.96	4805.59	5.85	67.37	636.29
90.00	8.91	4823.80	5.35	55.64	514.01
95.00	8.62	4857.02	4.80	44.66	402.28
100.00	8.08	4903.05	4.20	34.71	304.20
105.00	7.26	4959.63	3.59	25.50	221.19
110.00	6.20	5023.50	2.98	16.28	154.18
115.00	4.99	5091.11	2.40	5.86	102.55
120.00	3.74	5158.57	1.87	0.	64.38

TIME (MS)	CHEST AP (G'S)	CHEST SI (G'S)	HEAD AP (G'S)	HEAD SI (G'S)
0.	-0.37	0.	-0.69	0.13
5.00	-0.49	0.12	-0.18	0.32
10.00	-0.50	-0.00	-0.15	0.19
15.00	-0.54	-0.32	-0.11	-0.18
20.00	-0.60	-0.90	-0.06	-0.83
25.00	-0.66	-1.61	-0.07	-1.64
30.00	-0.63	-1.62	-0.18	-1.67
35.00	-0.63	-1.60	-0.17	-1.64
40.00	-9.65	-1.95	-8.26	1.33
45.00	-17.18	-1.83	-20.88	4.38
50.00	-22.49	-3.60	-27.98	4.74
55.00	-25.20	-7.42	-32.78	2.10
60.00	-25.39	-10.57	-32.50	-0.64
65.00	-25.15	-10.37	-40.11	0.45
70.00	-24.29	-10.06	-41.83	1.45
75.00	-23.67	-9.90	-33.57	2.06
80.00	-21.44	-9.67	-31.75	1.90
85.00	-19.04	-9.50	-29.64	1.66
90.00	-16.54	-9.41	-27.17	1.42
95.00	-13.94	-8.32	-24.57	2.41
100.00	-11.57	-7.11	-21.33	3.85
105.00	-9.43	-7.17	-18.03	4.21
110.00	-7.45	-7.31	-14.16	4.66
115.00	-5.50	-7.53	-8.94	4.97
120.00	-4.57	-7.72	-3.22	4.81

TIME (MS)	EAWC (LBS)	EACC (LBS)	EAWR (LBS)	EACR (LBS)	EA (LBS)
0.	0.	0.	0.	0.	0.
5.00	0.	0.	0.	0.	0.
10.00	0.	0.	0.	0.	0.
15.00	0.	0.	0.	0.	0.
20.00	0.	0.	0.	0.	0.
25.00	0.	0.	0.	0.	0.
30.00	0.	0.	0.	0.	0.
35.00	0.	0.	0.	0.	0.
40.00	1.03	1.03	1000000.00	1382.87	1382.87
45.00	727.19	1000000.00	1000000.00	3399.56	727.19
50.00	1237.90	1000000.00	1000000.00	3877.16	1237.90
55.00	1237.90	1000000.00	1000000.00	3880.24	1237.90
60.00	1000000.00	1954.39	1000000.00	4725.80	1954.39
65.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00
70.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00
75.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00
80.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00
85.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00
90.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00
95.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00
100.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00
105.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00
110.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00
115.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00
120.00	1000000.00	1000000.00	1000000.00	1000000.00	1000000.00

ENTER 1 TO CALCULATE HIC?1

THE HIC IS 3.0872196E+02
T1= 4.5000000E-02
T2= 1.1000000E-01

APPENDIX C: LISTING OF PAC INPUT AND RESULTS

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CLLPPAC     10:52EST    12/28/81


INPUT FILE NAME?LPDMCP50

ENTER 1 IF YOU WANT FULL LIST OF OUTPUT; ENTER 2 IF YOU WANT ABBREVIATED LIST.?1



INPUT VALUES -- INPUT UNITS( MSEC, MPH, DEGREES, INCHES, LBS, FT-LBS, G'S)
INITIAL VELOCITY:          36.0
INITIAL HEAD ANGLE:          -11.0
INITIAL TORSO ANGLE:          -26.0
      MLEG       MTORSO     MSTERN      MHEAD        RT          RN          RH         RTOPH
      72.7        55.4       2.50        11.2        13.7        19.1        6.50        27.2
     NPTS NECK  NPTS KR  NPTS VEH  NPTS SEAT NPTS GAS SL.ST     SL.KR
        9          6         17          6          15 0.500E+04 0.240E+04
     NPTS STER NPTS CHST
        5          5
GAS FLOW TIME
        0.        15.0       17.0        22.0        23.5        26.5        30.0        33.2
  39.0       44.0
GAS FLOW TIME
      49.5        56.3       64.0        75.5        100.
GAS FLOW - LB/SEC
        0.         0.        3.00        4.00        6.50        7.90        8.20        7.90
  6.20       4.30
GAS FLOW - LB/SEC
      2.70        1.30      0.400         0.          0.
SEAT FRICTION DISPLACEMENT
     -50.0         0.        1.00        14.0        15.0        50.0
SEAT FRICTION FORCE - LBS
        0.         0.        350.        350.         0.          0.
NECK ANGLE
     -85.0       -75.0      -60.0       -22.5        15.0        20.0        45.0        60.0
  70.0
NECK TORQUE - FT-LBS
      50.0        35.0       22.5        22.5         0.        -45.0       -45.0       -65.0
 -140.
VEH. PULSE - TIME
        0.        5.00       12.0        35.0        43.0        50.0        55.0        61.0
  70.0       75.0
VEH. PULSE - TIME
      81.0        86.0       93.0        100.        125.        150.        160.
VEH. PULSE - DECELERATION
        0.         0.        18.0        1.00        30.0        28.0        5.00        53.0
  6.00       11.0
VEH. PULSE - DECELERATION
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      35.0      5.00      19.0      5.00      5.00        0.        0.
KNEE DISPLACEMENT
     -50.0      3.00      4.00      6.00      10.0      12.0
KNEE FORCE - LBS
        0.        0. 0.150E+04 0.240E+04 0.240E+04 0.240E+04
STERNUM DISPLACEMENT
     -50.0        0.     0.250      1.00      10.0
STERNUM FORCE - LBS
        0.        0.      400. 0.160E+04 0.250E+05
CHEST DISPLACEMENT
     -11.2     -1.25        0.      1.25      11.2
CHEST FORCE - LBS
-0.465E+04     -150.        0.      150. 0.465E+04
     ATMOP       PGZ       GTZ         U       PN1       PN2       PN3
      14.7        0. 0.166E+04      662.      1.40      1.40      1.40
       VC1       VC2        AV       FSA       FSB       FSC        X1        Y1
     0.700     0.700      5.00      11.8      2.00      11.8      11.5      24.5
        A0    THETAD    FABWGT    STDAMP     CDAMP       DMS      DINF     WSOCK
      9.50        0.      8.40        0.      3.00      6.00      4.00      13.0
        WH    DROLLZ       X2Z       Y2Z        WB        LF       DCN
      7.00      5.00      31.9      6.50      15.0      18.0     0.690
      THF0      THL0
      20.0      41.0
```

TIME (MS)	VEH G'S (G'S)	VEH VEL (FPS)	VEH DISP (INCHES)	CHEST BP (INCHES)	CWA FORCE (LBS)	CPR FORCE (LBS)
0.	0.	52.80	0.	0.	0.	0.
5.00	-0.00	52.80	3.17	0.	0.	0.
10.00	-12.86	51.77	6.32	0.	0.	0.
15.00	-15.78	49.14	9.34	0.	0.	0.
20.00	-12.09	46.90	12.22	0.	0.	0.
25.00	-8.39	45.25	14.98	0.	0.	0.
30.00	-4.70	44.19	17.66	0.	0.	0.
35.00	-1.00	43.74	20.30	0.	0.	0.
40.00	-19.12	42.12	22.89	0.	0.	0.
45.00	-29.43	37.83	25.30	0.	0.	0.
50.00	-28.00	33.21	27.43	1.74	5.72	62.88
55.00	-5.00	30.55	29.32	2.73	43.47	303.32
60.00	-45.00	26.53	31.06	3.74	97.39	496.37
65.00	-32.11	19.47	32.43	4.96	175.28	674.20
70.00	-6.00	16.40	33.48	6.32	280.39	845.39
75.00	-11.00	15.03	34.43	7.68	395.70	982.56
80.00	-31.00	11.65	35.25	9.00	512.18	1084.08
85.00	-11.00	7.62	35.81	10.37	636.91	1170.77
90.00	-13.00	6.21	36.23	11.59	737.91	1213.38
95.00	-15.00	3.57	36.52	12.57	793.06	1201.87
100.00	-5.00	1.96	36.68	13.28	794.36	1139.92
105.00	-5.00	1.15	36.77	13.61	731.35	1023.73
110.00	-5.00	0.35	36.82	13.57	613.97	862.23
115.00	-5.00	-0.46	36.81	13.19	464.89	671.46
120.00	-5.00	-1.26	36.76	12.56	309.89	470.21
125.00	-5.00	-2.07	36.66	11.77	171.63	277.75
130.00	-4.00	-2.79	36.51	10.94	63.27	110.17
135.00	-3.00	-3.36	36.33	10.13	0.	0.
140.00	-2.00	-3.76	36.12	9.38	0.	0.
145.00	-1.00	-4.00	35.88	8.67	0.	0.
150.00	-0.00	-4.08	35.64	8.00	0.	0.

TIME (MS)	H-P R.D. (INCHES)	H-P VEL (FPS)	SEAT FR. (LBS)	FEM FORCE (LBS)	FEM ANG (DEG)	TIB ANG (DEG)
0.	0.	52.80	0.	0.	20.00	41.00
5.00	0.00	52.80	0.03	0.	20.00	41.00
10.00	0.02	52.80	7.32	0.	20.00	41.00
15.00	0.16	52.75	55.70	0.	20.00	41.00
20.00	0.44	52.57	154.55	0.	20.04	41.05
25.00	0.82	52.16	288.19	0.	21.07	42.25
30.00	1.25	51.54	350.00	0.	22.18	43.57
35.00	1.69	50.88	350.00	0.	23.27	44.87
40.00	2.14	50.23	350.00	0.	24.32	46.16
45.00	2.72	49.56	350.00	0.	25.66	47.82
50.00	3.55	48.97	350.00	0.	27.45	50.08
55.00	4.57	48.08	350.00	209.02	29.50	52.79
60.00	5.64	45.37	350.00	653.04	31.51	55.54
65.00	6.88	41.22	350.00	801.65	33.65	58.64
70.00	8.15	36.14	350.00	948.76	35.67	61.76
75.00	9.20	30.42	350.00	955.79	37.20	64.30
80.00	10.03	24.57	350.00	941.19	38.34	66.31
85.00	10.77	18.66	350.00	928.74	39.29	68.09
90.00	11.29	12.72	350.00	920.26	39.92	69.35
95.00	11.58	6.83	350.00	915.66	40.27	70.05
100.00	11.66	0.95	319.47	910.20	40.35	70.24
105.00	11.47	-4.06	0.	777.03	40.13	69.77
110.00	11.06	-7.66	0.	498.64	39.65	68.79
115.00	10.54	-9.42	0.	138.81	39.00	67.54
120.00	10.02	-9.55	0.	0.	38.33	66.29
125.00	9.55	-9.57	0.	0.	37.69	65.15
130.00	9.12	-9.60	0.	0.	37.09	64.11
135.00	8.73	-9.64	0.	0.	36.53	63.16
140.00	8.36	-9.69	0.	0.	35.99	62.28
145.00	8.01	-9.74	0.	0.	35.46	61.43
150.00	7.67	-9.79	0.	0.	34.93	60.59

TIME (MS)	TORSO DISP (INCHES)	TORSO ANG (DEG)	TORSO VEL (D/SEC)	TORSO ACC (D/SEC**2)	TORSO R.D. (INCHES)	TORSO R.V. (FPS)
=======	=======	=======	=======	=======	=======	=======
0.	0.00	-26.00	0.	-0.00	0.00	0.
5.00	3.17	-26.00	-0.21	47.68	-0.00	-0.00
10.00	6.34	-26.00	0.05	183.64	0.02	1.04
15.00	9.50	-26.00	2.30	955.58	0.16	3.65
20.00	12.67	-25.97	10.57	2551.51	0.45	5.86
25.00	15.83	-25.88	28.13	4658.66	0.85	7.42
30.00	18.99	-25.67	54.55	5504.44	1.33	8.32
35.00	22.14	-25.33	81.50	5511.48	1.84	8.62
40.00	25.27	-24.85	109.21	5635.83	2.38	10.08
45.00	28.40	-24.24	137.39	5712.15	3.10	14.23
50.00	31.50	-23.55	131.09	4174.94	4.08	18.16
55.00	34.57	-22.68	137.72	3269.76	5.25	20.06
60.00	37.56	-22.10	184.46	15002.38	6.49	22.25
65.00	40.41	-20.99	260.84	15527.81	7.98	26.60
70.00	43.07	-19.49	339.70	15883.55	9.58	26.13
75.00	45.49	-17.60	408.53	10637.40	11.06	23.15
80.00	47.64	-15.45	447.05	4615.71	12.39	21.51
85.00	49.46	-13.18	453.99	-1960.89	13.65	19.84
90.00	50.92	-10.96	430.73	-8181.10	14.69	14.94
95.00	51.98	-8.93	381.78	-10495.54	15.46	10.78
100.00	52.64	-7.15	331.89	-9375.18	15.96	5.56
105.00	52.89	-5.65	259.98	-17627.97	16.12	-0.05
110.00	52.79	-4.59	158.79	-23524.61	15.97	-4.85
115.00	52.38	-4.12	20.86	-31886.33	15.56	-8.54
120.00	51.74	-4.41	-128.77	-24627.85	14.97	-10.85
125.00	50.95	-5.31	-223.64	-13467.76	14.28	-11.94
130.00	50.07	-6.56	-267.55	-4362.13	13.56	-12.11
135.00	49.17	-7.92	-272.40	1392.39	12.84	-11.66
140.00	48.28	-9.27	-265.65	1304.82	12.16	-11.16
145.00	47.38	-10.58	-259.34	1222.84	11.50	-10.82
150.00	46.50	-11.86	-253.41	1148.49	10.86	-10.65

TIME (MS)	HEAD DISP (INCHES)	HEAD ANG (DEG)	HEAD VEL (D/SEC)	HEAD ACC (D/SEC**2)	HEAD R.D. (INCHES)	HEAD R.ANG (DEG)
0.	0.00	-11.00	0.	0.00	0.00	15.00
5.00	3.17	-11.00	0.71	20.91	0.00	15.00
10.00	6.34	-10.99	0.47	-84.77	0.02	15.01
15.00	9.50	-10.99	-0.31	-318.33	0.16	15.00
20.00	12.67	-11.00	-3.35	-934.94	0.45	14.97
25.00	15.84	-11.03	-9.42	-1600.18	0.86	14.84
30.00	19.01	-11.10	-17.34	-1518.72	1.34	14.57
35.00	22.17	-11.20	-23.63	-1368.81	1.87	14.13
40.00	25.33	-11.34	-31.07	-1540.69	2.44	13.51
45.00	28.49	-11.51	-38.98	-1598.96	3.20	12.72
50.00	31.65	-11.55	40.53	677.68	4.23	12.01
55.00	34.81	-11.26	83.26	11380.61	5.49	11.62
60.00	37.92	-10.73	118.60	-498.24	6.86	11.37
65.00	40.93	-10.19	92.02	-7640.49	8.50	10.79
70.00	43.76	-9.83	48.55	-10405.32	10.28	9.65
75.00	46.37	-9.73	-6.53	-11069.36	11.94	7.87
80.00	48.69	-9.90	-61.48	-11037.08	13.44	5.55
85.00	50.67	-10.34	-116.18	-10840.57	14.86	2.84
90.00	52.25	-11.06	-170.81	-2000.87	16.03	-0.10
95.00	53.41	-11.92	-172.75	-786.81	16.89	-2.99
100.00	54.13	-12.80	-181.46	-2647.29	17.46	-5.65
105.00	54.4[illegible]	-13.71	-172.90	5689.96	17.66	-8.06
110.00	54.34	-14.48	-128.33	13218.33	17.52	-9.89
115.00	53.92	-14.91	-38.22	23438.93	17.11	-10.79
120.00	53.25	-14.93	15.43	4853.28	16.49	-10.52
125.00	52.39	-14.81	26.82	-316.70	15.73	-9.50
130.00	51.42	-14.70	14.24	-4699.74	14.90	-8.14
135.00	50.39	-14.70	-18.02	-7984.05	14.06	-6.78
140.00	49.34	-14.89	-56.38	-7360.24	13.23	-5.62
145.00	48.29	-15.26	-91.73	-6785.44	12.41	-4.68
150.00	47.22	-15.80	-124.34	-6265.83	11.59	-3.94

TIME (MS)	R BAG ACC (G'S)	RBV WR GND (FPS)	RBV WR CST (FPS)	RBV WR DSH (FPS)	RBD WR GND (INCHES)	RBD WR DSH (INCHES)
0.	0.	52.80	0.	0.	-4.00	-4.00
5.00	-0.00	52.80	0.00	0.00	-0.83	-4.00
10.00	-12.86	51.77	-1.04	0.00	2.31	-4.00
15.00	-15.78	49.14	-3.64	0.00	5.34	-4.00
20.00	-1561.66	-50.03	-102.74	-96.93	6.58	-5.64
25.00	-2257.90	-36.46	-89.09	-81.71	3.94	-11.04
30.00	-2492.38	-22.89	-75.63	-67.09	-1.65	-19.31
35.00	-1.00	43.74	-9.19	0.00	-3.50	-23.79
40.00	-19.12	42.12	-10.90	-0.00	-0.91	-23.80
45.00	148.56	37.83	-15.32	0.00	1.50	-23.80
50.00	3668.41	52.40	-0.06	19.20	3.96	-23.46
55.00	-5.71	51.69	0.	21.14	7.17	-21.41
60.00	-7.51	50.20	0.	23.68	10.23	-20.05
65.00	-12.16	48.05	0.	28.58	13.18	-18.42
70.00	-17.53	45.04	0.	28.64	15.97	-16.61
75.00	-23.89	41.11	0.	26.08	18.56	-14.90
80.00	-30.07	36.28	0.	24.63	20.88	-13.34
85.00	-36.44	30.54	0.	22.92	22.89	-11.84
90.00	-41.85	24.00	0.	17.79	24.53	-10.59
95.00	-44.21	16.82	0.	13.26	25.75	-9.64
100.00	-43.10	9.64	0.	7.69	26.54	-9.00
105.00	-41.04	2.75	0.	1.60	26.90	-8.71
110.00	-36.15	-3.50	0.	-3.85	26.87	-8.78
115.00	-30.40	-8.87	0.	-8.41	26.49	-9.16
120.00	-20.23	-12.92	0.	-11.66	25.83	-9.77
125.00	-11.25	-15.43	0.	-13.36	24.97	-10.53
130.00	-3.88	-16.61	0.	-13.81	24.00	-11.35
135.00	0.83	-16.77	0.	-13.42	22.99	-12.18
140.00	0.77	-16.65	0.	-12.89	21.99	-12.98
145.00	0.71	-16.53	0.	-12.53	21.00	-13.75
150.00	0.66	-16.42	0.	-12.34	20.01	-14.51

TIME (MS)	U BAG ACC (G'S)	UBV WR GND (FPS)	UBV WR CST (FPS)	UBV WR DSH (FPS)	UBD WR GND (INCHES)	UBD WR DSH (INCHES)
0.	0.	52.80	0.	0.	-4.00	-4.00
5.00	-0.00	52.80	0.00	0.00	-0.83	-4.00
10.00	-12.86	51.77	-1.04	0.00	2.31	-4.00
15.00	-15.78	49.14	-3.64	0.00	5.34	-4.00
20.00	-910.38	-34.75	-87.46	-81.65	6.65	-5.57
25.00	-1347.54	-3.46	-56.09	-48.71	5.43	-9.55
30.00	-1255.25	10.16	-42.57	-34.03	3.27	-14.39
35.00	-1164.42	-1.29	-54.22	-45.03	2.42	-17.88
40.00	-744.85	-16.58	-69.60	-58.70	2.30	-20.59
45.00	-41.05	37.73	-15.42	-0.09	2.75	-22.55
50.00	-524.41	33.12	-19.35	-0.09	3.85	-23.57
55.00	-5.00	30.55	-21.14	-0.00	5.72	-23.60
60.00	-45.00	26.53	-23.68	-0.00	7.46	-23.60
65.00	-32.11	19.47	-28.58	-0.00	8.82	-23.61
70.00	-6.00	16.40	-28.64	0.00	9.87	-23.61
75.00	-11.00	15.03	-26.08	0.00	10.82	-23.61
80.00	-31.00	11.65	-24.63	0.00	11.63	-23.61
85.00	-11.00	7.62	-22.92	-0.00	12.19	-23.62
90.00	-13.00	6.21	-17.79	0.00	12.61	-23.62
95.00	-15.00	3.57	-13.26	0.00	12.90	-23.62
100.00	-5.00	1.96	-7.69	-0.00	13.06	-23.62
105.00	-5.00	1.15	-1.60	0.00	13.15	-23.62
110.00	-5.00	0.35	3.85	-0.00	13.20	-23.62
115.00	-5.00	-0.46	8.41	-0.00	13.19	-23.62
120.00	-5.00	-1.26	11.66	-0.00	13.14	-23.62
125.00	-5.00	-2.07	13.36	-0.00	13.04	-23.62
130.00	-4.00	-2.79	13.81	-0.00	12.89	-23.62
135.00	-3.00	-3.36	13.42	0.00	12.71	-23.62
140.00	-2.00	-3.76	12.89	0.00	12.49	-23.62
145.00	-1.00	-4.00	12.53	-0.00	12.26	-23.62
150.00	-0.00	-4.08	12.34	0.00	12.02	-23.62

TIME (MS)	CST F BSP (LBS)	STN F BSP (LBS)	STV WR CST (FPS)	RLD WR STN (INCHES)	STD WR CST (INCHES)	DTORSO (INCHES)
0.	0.00	0.	0.	0.	-0.00	27.18
5.00	-3.29	0.	0.08	0.	0.00	27.15
10.00	-3.68	0.	0.08	0.	0.01	27.13
15.00	-3.97	0.	0.07	0.	0.01	26.99
20.00	-4.33	0.	0.07	0.	0.02	26.75
25.00	-3.59	0.	0.05	0.	0.02	26.31
30.00	0.35	0.	-0.01	0.	0.00	25.79
35.00	0.91	0.	0.03	0.	-0.02	25.23
40.00	-0.18	0.	0.06	0.	-0.02	24.61
45.00	0.41	37.73	0.06	-0.02	-0.02	23.76
50.00	-3.24	1221.26	-0.06	-0.76	0.05	22.68
55.00	0.	0.	0.	0.	0.	21.41
60.00	0.	0.	0.	0.	0.	20.05
65.00	0.	0.	0.	0.	0.	18.42
70.00	0.	0.	0.	0.	0.	16.61
75.00	0.	0.	0.	0.	0.	14.90
80.00	0.	0.	0.	0.	0.	13.34
85.00	0.	0.	0.	0.	0.	11.84
90.00	0.	0.	0.	0.	0.	10.59
95.00	0.	0.	0.	0.	0.	9.64
100.00	0.	0.	0.	0.	0.	9.00
105.00	0.	0.	0.	0.	0.	8.71
110.00	0.	0.	0.	0.	0.	8.78
115.00	0.	0.	0.	0.	0.	9.16
120.00	0.	0.	0.	0.	0.	9.77
125.00	0.	0.	0.	0.	0.	10.53
130.00	0.	0.	0.	0.	0.	11.35
135.00	0.	0.	0.	0.	0.	12.18
140.00	0.	0.	0.	0.	0.	12.98
145.00	0.	0.	0.	0.	0.	13.75
150.00	0.	0.	0.	0.	0.	14.51

TIME (MS)	HEAD BP. (INCHES)	BAG VOL. (CU.IN.)	BAG PRESS. (PSIG)	HW/A FORCE (LBS)	HP FORCE (LBS)	INT. VOL (CU.IN.)
=======	=======	=======	=======	=======	=======	=======
0.	0.	348.44	0.	0.	0.	0.
5.00	0.	348.44	0.	0.	0.	0.
10.00	0.	348.53	0.	0.	0.	0.
15.00	0.	348.77	-0.01	0.	0.	0.
20.00	0.	618.12	12.12	0.	0.	0.
25.00	0.	1640.70	8.05	0.	0.	0.
30.00	0.	3614.71	3.55	0.	0.	0.
35.00	0.	5570.35	2.04	0.	0.	0.
40.00	0.	7415.87	0.90	0.	0.	0.
45.00	0.	8939.55	0.04	0.	0.	0.
50.00	0.71	9569.89	0.42	0.68	10.41	224.99
55.00	1.64	9372.38	1.82	11.19	73.59	448.51
60.00	2.68	9108.74	2.81	36.30	146.09	714.27
65.00	4.20	8763.31	3.67	80.92	208.03	1063.33
70.00	6.01	8369.32	4.50	142.33	255.43	1458.88
75.00	7.71	7991.59	5.21	210.84	295.17	1837.32
80.00	9.27	7643.73	5.76	280.49	326.61	2186.95
85.00	10.78	7310.48	6.28	355.87	356.09	2522.26
90.00	12.08	7033.67	6.59	418.14	373.46	2799.80
95.00	13.09	6829.03	6.59	453.54	373.72	3005.81
100.00	13.80	6695.51	6.29	456.29	356.58	3140.15
105.00	14.14	6647.02	5.64	418.94	319.59	3189.06
110.00	14.10	6678.48	4.70	348.69	266.75	3158.01
115.00	13.72	6775.27	3.62	260.96	205.15	3061.64
120.00	13.06	6919.75	2.50	171.88	141.93	2917.57
125.00	12.23	7093.53	1.46	94.15	83.03	2744.21
130.00	11.33	7280.27	0.58	34.35	32.71	2557.85
135.00	10.42	7467.58	0.	0.	0.	2370.82
140.00	9.56	7648.89	0.	0.	0.	2189.72
145.00	8.72	7825.00	0.	0.	0.	2013.73
150.00	7.91	7997.80	0.	0.	0.	1840.98

TIME (MS)	CHEST AP (G'S)	CHEST SI (G'S)	HEAD AP (G'S)	HEAD SI (G'S)	NECK F. (LBS)	NECK M. (IN-LBS)
0.	-0.00	-0.00	-0.00	0.00	0.	0.
5.00	0.06	0.02	0.08	-0.00	0.	0.
10.00	0.07	-0.02	0.08	-0.05	0.	0.
15.00	0.05	-0.26	0.11	-0.33	0.	0.
20.00	0.01	-0.76	0.14	-0.90	0.	0.
25.00	-0.08	-1.43	0.18	-1.65	0.	0.
30.00	-0.22	-1.71	0.22	-1.92	0.	0.
35.00	-0.24	-1.66	0.27	-1.85	0.	0.
40.00	-0.22	-1.59	0.31	-1.76	0.	0.
45.00	-0.23	-1.49	0.35	-1.63	0.	0.
50.00	-1.40	-1.55	-0.48	-1.36	1.73	4.05
55.00	-7.30	-3.73	-3.77	-2.23	12.27	28.62
60.00	-12.25	-8.38	-10.19	-6.30	24.35	56.81
65.00	-17.13	-9.52	-17.08	-6.53	34.67	80.90
70.00	-22.64	-10.24	-23.19	-6.45	42.57	99.33
75.00	-27.76	-9.09	-29.32	-4.86	49.19	114.79
80.00	-32.39	-7.58	-35.01	-3.66	54.43	127.01
85.00	-37.09	-6.18	-40.97	-3.36	59.35	138.48
90.00	-41.17	-4.99	-43.74	-4.12	62.24	145.24
95.00	-42.59	-4.10	-45.14	-5.67	62.29	145.34
100.00	-41.52	-3.29	-44.09	-6.95	59.43	138.67
105.00	-37.69	-1.92	-39.68	-7.35	53.27	124.29
110.00	-31.57	-1.09	-32.71	-7.29	44.46	103.74
115.00	-24.17	-0.32	-24.45	-6.28	34.19	79.78
120.00	-15.31	0.17	-19.58	-3.65	23.66	55.20
125.00	-8.51	0.52	-11.85	-1.22	13.84	32.29
130.00	-2.93	0.75	-5.48	0.48	5.45	12.72
135.00	0.56	0.76	-1.58	1.17	0.	0.
140.00	0.51	0.71	-1.44	1.11	0.	0.
145.00	0.47	0.67	-1.31	1.06	0.	0.
150.00	0.43	0.63	-1.19	1.03	0.	0.

TIME (MS)	STN ACC (G'S)	ROLL RAD (INCHES)	XC B CTR (INCHES)	YC B CTR (INCHES)	WRB (LBS)	WURB (LBS)
=======	=======	=======	=======	=======	=======	=======
0.	0.00	20.03	15.50	24.50	0.69	0.37
5.00	-1.32	20.03	15.50	24.50	0.69	0.37
10.00	-1.47	20.03	15.50	24.50	0.69	0.37
15.00	-1.59	20.03	15.50	24.50	0.69	0.37
20.00	-1.73	20.02	16.29	24.50	0.65	0.35
25.00	-1.43	20.01	18.28	24.50	0.51	0.30
30.00	0.14	19.97	20.70	24.50	0.31	0.24
35.00	0.37	19.91	22.44	24.50	0.21	0.20
40.00	-0.07	19.84	23.79	24.50	0.22	0.17
45.00	-14.93	19.71	24.78	24.50	0.23	0.14
50.00	-489.80	19.95	25.29	24.50	0.27	0.13
55.00	-6.20	19.54	25.30	24.50	0.30	0.13
60.00	-8.10	19.43	25.30	24.50	0.33	0.13
65.00	-13.02	19.28	25.30	24.50	0.37	0.13
70.00	-18.59	19.09	25.31	24.50	0.42	0.13
75.00	-25.07	18.88	25.31	24.50	0.46	0.13
80.00	-31.20	18.67	25.31	24.50	0.50	0.13
85.00	-37.42	18.49	25.31	24.50	0.54	0.13
90.00	-42.62	18.33	25.31	24.50	0.57	0.13
95.00	-44.76	18.22	25.31	24.50	0.59	0.13
100.00	-43.44	18.14	25.31	24.50	0.61	0.13
105.00	-41.24	18.09	25.31	24.50	0.61	0.13
110.00	-36.25	18.06	25.31	24.50	0.61	0.13
115.00	-30.48	18.05	25.31	24.50	0.60	0.13
120.00	-20.29	18.05	25.31	24.50	0.59	0.13
125.00	-11.30	18.08	25.31	24.50	0.57	0.13
130.00	-3.91	18.12	25.31	24.50	0.55	0.13
135.00	0.84	18.17	25.31	24.50	0.53	0.13
140.00	0.78	18.24	25.31	24.50	0.51	0.13
145.00	0.72	18.31	25.31	24.50	0.49	0.13
150.00	0.67	18.39	25.31	24.50	0.47	0.13

```
ENTER 1 TO CALCULATE HIC?1

THE HIC IS    [illegible].9767538E+02
T1=    7.0000000E-02
T2=    1.2000000E-01
```

APPENDIX D: MODIFICATION TO DRACR/PAC FEMUR LOAD ROUTINE

MODIFICATION TO DRACR FEMUR LOAD ROUTINE

This appendix describes the changes made to DRACR for alleviating the computational problems associated with the severe "squatting" position of the dummy in sled test #1663. Figure D-1 illustrates the femur/tibia "linkage" arrangement. Figure D-la shows the arrangement modeled in DRACR. Note that for this arrangement, as the femur angle (THEF) increases toward 90^0 the hip reaction force F_x drops to zero. However, in real life the dummy's joints will begin to "lock" before the 90^0 condition is reached. This "locking" is caused by "flesh - on - flesh" compression. The locked configuration is illustrated in Figure D-lb. This configuration permits the transmission of the hip retarding force F_x. Figure D-lc shows the modification made to DRACR so that the force F_x will not reduce to zero in the "sqaut" configuration of the dummy. The following statements were changed in DRACR:

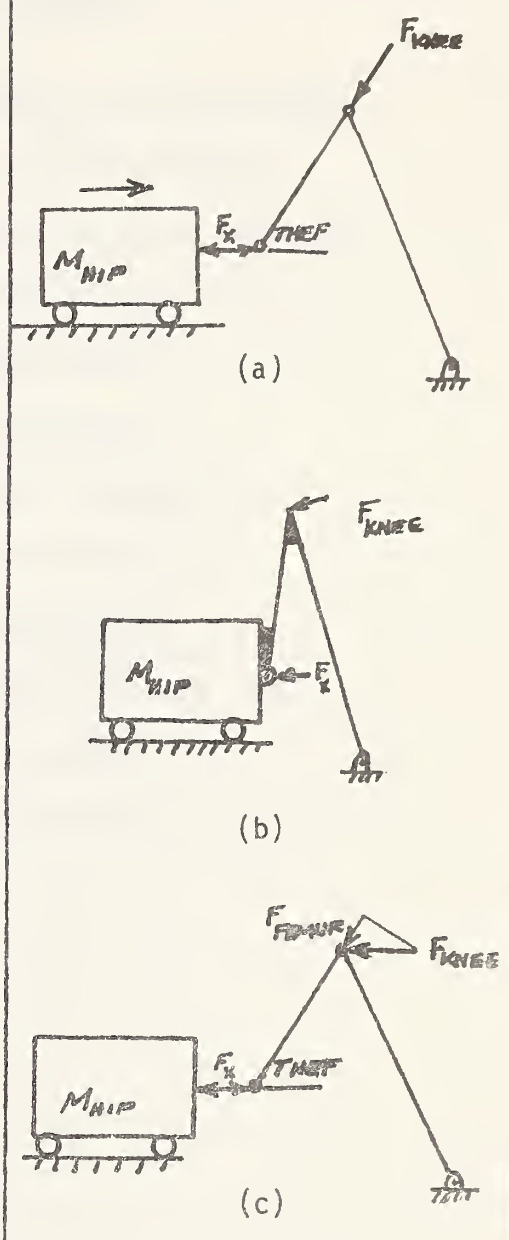

Figure D-1

- Statement 18505
  - Changed From: FX=-(SF + FKNEE*COS(THEF) + ...) + FHEAD ....
  - Changed To: FX=-(SF + FKNEE + ...) + FHEAD .....

o Statement 23640

. Changed From: X1(4,N) = FKNEE/2.

. Changed To: X1(4,N) = FKNEE * COS(THEF)/2.

MODIFICATION TO PAC FEMUR LOAD ROUTINE

Modifications are the same as those for DRACR. The following statements were changed in PAC:

o Statement 9400

. Changed from: FX=-(SF + FKNEE*COS(THEF) + ...) + FHEAD ....

. Changed to: FX=-(SF + FKNEE + ...) + FHEAD .....

o Statement 12260

. Changed from: X1(4,N) = FKNEE/2.

. Changed to: X1(4,N) = FKNEE * COS(THEF)/2.

o Statement 12680

. Changed from: X1(4,N) = FKNEE/2.

. Changed to: X1(4,N) = FKNEE * COS(THEF)/2.

APPENDIX E: MODIFICATION TO DRACR HEAD FORCE ROUTINE

MODIFICATION TO DRACR HEAD FORCE ROUTINE

This appendix describes a minor change that was made in this study to the DRACR head force routine. This modification was used in all of the DRACR simulations discussed in this report.

The modification that was made basically adds the bag wrap-around forces to the top and bottom of the head mass (the original DRACR routine calculates the wrap-around forces only for the sides of the head mass). The modification involved the following statement change in DRACR:

Statement 14340

- Changed from:

  ```
  FHEAD = 2.*RHEAD*(WH*PG1+FFT/ABST)
  ```

- Changed to:

  ```
  FHEAD = 2.*RHEAD*WH*PG1+2.*RHEAD*FFT/ABST+2.*WH*FFT/ABST
  ```

APPENDIX F: PRELIMINARY DUMMY DATA

U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY SAFETY BUREAU
WASHINGTON, D.C. 20591

August 31, 1970
IN REPLY REFER TO:
43-10

Mr. William Rup
ESV Program Manager
AMF Incorporated
Advanced Systems Laboratory
924 Anacapa Street
Santa Barbara, California 93102

Dear Mr. Rup:

One of the ESV contractors has requested a copy of the NHSB Anthropometric Summary Standards referenced in the contracts. These standards are not available, but we are forwarding a listing of preliminary dimensions for the 5th percentile female and the 95th percentile male. For convenience, a listing of the dimensions of the 50th percentile male, including the SAE letter designations of dimensions where appropriate, as given in SAE Recommended Practice J963, is also included.

We cannot give assurance that these preliminary dimensions will not be modified, but we do believe the listed dimensions are adequate as design guidance for the Experimental Safety Vehicle.

We hope that this information will be of assistance to you.

Sincerely,

A. J. Slechter, Jr.
Acting Assistant Director
Office of Experimental Safety
Vehicle Programs

Preliminary Dimensions for 5th percentile Female and 95th percentile Male compared with 50th percentile Male (SAE J963)

SAE Letter Desig.	Title	VALUE: 5th Per. Female	VALUE: 50th Per. Male, SAE J963	VALUE: 95th Per. Male
	Height	59.0		73.3
	Weight	102.0±3.0	164±3	215.0±4.0
I	Shoulder-elbow lght.	12.5±0.3	14.1±0.3	15.5±0.5
	Mid-shoulder hgth.	20.5±0.5		26.6±0.5
L	Popliteal height	14.0±0.3	17.3±0.2	19.3±0.5
M	Knee height (sitting)	17.9±0.3	21.4±0.3	23.4±0.5
N	Buttock-popliteal lgth.	17.0±0.3	19.5±0.3	21.6±0.5
O	Chest depth	7.5±0.3	9.0±0.4	10.5±0.5
P	Buttock-knee length	20.4±0.3	23.3±0.3	25.2±0.5
Q	Thigh clearance hgth.	4.1±0.3	5.7±0.3	6.9±0.3
R	Elbow-finger tip lgth.	16.3±0.5	18.7±0.5	20.3±0.5
S	Foot Length	8.7±0.2	10.5±0.2	11.3±0.3
T	Head Length	6.8±0.2	7.7±0.2	$8.2^{+0.0}_{-0.5}$
U	Sitting Hgth.(erect)	$30.9^{+0.0}_{-0.5}$	35.7±0.5	$38.0^{+0.5}_{-0.0}$
V	Shoulder breadth (bi-deltoid)	15.7±0.4	17.9±0.4	19.5±0.4
W	Foot breadth	3.2±0.2	3.8±0.3	4.1±0.3
X	Head Circumference	20.7±0.5	22.5±0.5	23.2±0.5
Y	Chest Circumference		37.7±1.0	44.5±1.0
Z	Waist Circum. (sitting)	23.6±1.0	33.0±1.0	42.5 ±1.0

SAE Letter Designation	Title	VALUE 5th Per. Female	50th Per. Male, SAE J963	95th Per. Male
AA	Head breadth	5.4±0.2	6.1±0.2	6.4±0.3
	Hip breadth (sitting)	12.3 $^{+1.0}_{-0.0}$		15.9 $^{+1.0}_{-0.0}$
	Hip circumference (sit)	35.9 $^{+1.0}_{-0.0}$		46.7 $^{+1.0}_{-0.0}$
	Chest width	9.2±0.3		