...partment
...nsportation
...onal Highway
...c Safety
...nistration

DOT HS 807 024
Final Report

May 1986

Computer Study to Determine the Combined Performance of Air Bags and Belt Restraint Systems

This document is available to the public from the National Technical Information Service, Springfield, Virginia 22161

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 807 024		

4. Title and Subtitle
Computer Study to Determine the Combined Performance of Air Bags and Belt Restraint Systems

5. Report Date
May 1986

6. Performing Organization Code

7. Author's)
Michael Fitzpatrick, M. (Michael).

8. Performing Organization Report No.

9. Performing Organization Name and Address
Fitzpatrick Engineering
Route 5 - Box 495A
Warsaw, IN 46580

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
P.O. DTNH-86-P-07157

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
National Highway Traffic Safety Administration
400 7th Street, S.W.
Washington, DC 20590

13. Type of Report and Period Covered
Final Report
12/85 - 5/86

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The primary goal of this study was to determine the performance of the "air bag alone" restraint type versus those of the "air bag plus three-point belt" restraint type as they affect driver injury. The National Highway Traffic Safety Administration (NHTSA) contracted with Fitzpatrick Engineering to identify the competing and complementary benefits of each restraint type. Through the use of BDRACR - a driver restraint system computer model, parameters were identified which most strongly influence the degree of injury received by the driver when restrained by each of the two restraint types. Recommendations which can be used to assist automotive restraint designers in their selection of restraint systems components were formulated. The conclusion drawn from this study pertain to the frontal crash mode only. For all crash modes, i.e., rollover, side impact, etc., NHTSA has determined that the combination of air bags and seat belt systems provide the most effective system for both injury and fatality reduction.

17. Key Words	18. Distribution Statement
Air Bags, Seat Belts, Crash Sensors/ Tethering, Belt Pre-Tensioning	Document is available to the public through the National Technical Information Service, Springfield, VA 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	57	$9,950

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

TABLE OF CONTENTS

1.0 BAG VERSUS BAG PLUS THREE-POINT BELTS: GOALS

The primary goal of this study was to determine the performance of the "airbag alone" restraint type versus those of the "airbag plus three-point belt" restraint type as they affect driver injury. The National Highway and Traffic Safety Administration (NHTSA) contracted with Fitzpatrick Engineering to identify the competing and complementary benefits of each restraint type. Through the use of BDRACR - a company developed driver restraint system computer model - Fitzpatrick Engineering was to identify parameters which most strongly influence the degree of injury received by the driver when restrained by each of the two restraint types. These conclusions would then be formulated into recommendations which could be used to assist automotive restraint designers in their selection of restraint system components. The conclusions drawn from this study would pertain to the frontal crash mode only. For all crash modes, i.e. rollover, side impacts, etc., NHTSA has concluded that the combination of air bags and seat belt systems provide the most effective system for both injury and fatality reduction. A total of approximately 90 computer runs were made in conducting this study.

1.1 GENERAL APPROACH

Within this study five major parameters which were felt to most strongly influence the performance of the airbag/belt system combination were investigated:

1. Driver seat position - three seat positions

2. Airbag shape - three airbag shapes (shape modification accomplished through airbag tethering)

3. Sensing time - three sensing times

4. Pretensioning of three-point belts - three different degrees of belt pretensioning

5. Belt webbing elongation characteristics - four different belt webbing stretch characteristics

For numbers 1, 2, and 3 above, simulations were made for both airbag only restraint types and airbag plus belt restraint types. Numbers 4 and 5 required runs to be made with airbag plus belt restraint types.

The crash mode for this study was held constant and was a 35 mph frontal barrier crash. Three driver sizes were subjected to the 35 mph frontal barrier crashes. These driver sizes were: 50th percentile male; 95th percentile male; and 5th percentile female. The car was simulated was a "real" compact sized car and was based on data in our files. Due to fact that the actual data used is proprietary, we are unable to provide additional details.

Many of the comparisons are made relative to the per cent of injury based on criteria limits. These criteria limits are:

1. HIC (Head Injury Criterion), limit = 1000
2. PCG (Peak Chest G's -3 msec), limit = 60 g's
3. PFL (Peak Femur Load)
    a. 50th percentile male, limit = 2250 lbs
    b. 95th percentile male, limit = 2750 lbs
    c. 5th percentile female, limit = 1750 lbs

The <u>nominal</u> sensing time was 25 milliseconds, and was set to be a conservative estimate of a sensing time for a sensor mounted aft of the radiator but forward of the firewall in the car. As previously mentioned, the sensing time was varied from this value in a portion of the study to investigate the sensitivity of this parameter.

The nominal airbag had dimensions of 11.246 inches for the major axis radius and 7.497 inches for the minor axis radius. This results in an elliptical bag volume of 2.298 cubic feet. Again, the airbag shape was varied from this nominal shape in the tethering portion of the study. An 87 gram propellant, production inflator was used throughout.

The nominal three-point belts had a webbing elongation of 8.0%.

2.0 BAG VERSUS BAG PLUS THREE-POINT BELTS: SEAT POSITION

The purpose of this first portion of the investigation was to determine the effect on driver injury of two basic restraint environments - airbags acting alone and airbags plus belts. This was done as a function of the seated position of the driver in the fore-aft direction.

2.1 Approach

All three dummy sizes were modeled. The seat position was varied from among three positions:

Seat Position #1 - full forward position
Seat Position #2 - middle position
Seat Position #3 - full rearward position

Only the 50th percentile male was simulated in all three positions. It was unreasonable to consider the 95th percentile male in the full forward position or the 5th percentile female in the full rearward position. Also, the lap belt anchors were assumed to have been attached to the seat and thus moved with the seat as its position changed. The upper torso anchor, of course, was fixed to a non-moving surface.

Simulations were made for each driver size in the respective positions as described. Two cases were run for each: airbag only and airbag plus three-point belts. Other specific parameters included: vent area = 2.0 square inches; sensing time = 25 ms; bag volume = 2.298 cubic feet; belt webbing elongation = 8.0%.

2.2 Results and Discussion

All three driver sizes respond to the changing of the seat position to some degree. Generally, the effect is small for the airbag only simulations. Referring to Figures 1 through 9, we see that the greatest influence due to seat position arises when both airbag and seat belts are used together. Also, these figures show that the addition of belts causes a greater increase in HIC and peak chest PCG for the 50th and 95th percentile males than does increasing their rearward position. In contrast, the response of the 5th percentile female depends on a combination of both her seated position and the restraint type - airbag only vs airbag plus belts.

In the following discussion, the results in this portion of the study will be presented as follows:

1. The influence of restraint type on injury,

2. The influence of driver size on injury,

3. The influence of seated position on injury.

RESTRAINT TYPE VS PER CENT OF INJURY CRITERIA LIMIT

(AVERAGED OVER ALL SEAT POSITIONS AND DRIVER SIZES)

RESTRAINT	AVG HIC	AVG CRIT. %	AVG PCG	AVG CRIT. %	AVG PFL	AVG CRIT. %	AVG % EX-PFL (WITH PFL)
BAG ONLY	304	30.4	37.38	62.3	1428	64.0	46.4 (52.2)
BAG + BELTS	470	47.0	41.40	69.0	729	32.4	58.0 (49.5)

This small table of the overall values is illustrative of the trade-off associated with airbag versus airbag plus belts. The airbag alone results in a 16.6% reduction in HIC and in a 6.7% reduction in PCG as compared to the airbag plus belts configuration. The airbag plus belts, however, allows the largest change of all - a reduction in the PFL of 31.6%. The net result overall with femur injury included is marginally better performance with airbag plus belts as compared to the airbag only case. However a consideration that must be made is that both head and chest injury may be life threatening while femur load is not. Thus, the primary comparisons throughout this report will be made on the basis of the "ex-PFL" values shown in the table. Ex-PFL average simply means the average of the values with the PFL excluded, i.e. just the average of the HIC and the PCG. This will enable us to focus primarily on the most serious injury measures. However, the table averages with the PFL included are retained in parentheses and are presented for comparison. Thus, the overall increase in the average per cent of the criteria limit, ex-PFL, when belts are employed in conjunction with the airbag is 11.6% -from 46.4% to 58.0%.

Therefore, **for frontal impacts**, the broad conclusion that can be drawn from this table is that the addition of three-point belts to the airbag only system significantly increases the average injury measure ex-PFL throughout the range of seated position and driver size.

Table 1 expands on the previous table and shows that each of the three driver sizes experiences the increase in HIC and PCG and the decrease in PFL as the restraint changes from bag only to bag plus belt.

TABLE 1

SEAT POSITION STUDY

RESTRAINT TYPE VS PER CENT OF INJURY CRITERIA LIMIT

(FOR EACH DRIVER SIZE AVERAGED OVER ALL SEAT POSITIONS)

RESTRAINT	AVG HIC	AVG CRIT. %	AVG PCG	AVG CRIT. %	AVG PFL	AVG CRIT. %	AVG % EX-PFL (WITH PFL)
BAG ONLY							
50TH MALE	299	29.9	34.20	57.0	1421	63.2	43.4 (50.0)
95TH MALE	260	26.0	35.13	58.6	1428	59.8	42.3 (48.1)
5TH FEMALE	358	35.8	44.43	74.1	1222	69.9	55.0 (59.9)
AVERAGE		30.4		62.3		64.0	46.4
BAG + BELTS							
50TH MALE	471	47.1	40.06	66.8	670	29.8	57.0 (47.9)
95TH MALE	465	46.5	38.25	63.8	1199	43.6	55.2 (51.3)
5TH FEMALE	474	47.4	46.59	77.7	438	25.0	62.6 (50.0)
AVERAGE		47.0		69.0		32.4	58.0

2.3 Conclusions: Seat Position vs Restraint Type and Driver Size

1. Figures 1 through 9 show that in every case but one, the sensitivity of primary injury measure (HIC or PCG) as a function of seat position was greater for the airbag plus three-point belts than for the airbag alone.

2. The degree of driver injury for the airbag only restraint type was generally found to have only a minor sensitivity to seat position (the exception was the peak femur load for the 50th % male and the 5th % female as the peak femur load increased significantly as the driver moved further away from the knee bolster so that he had higher relative velocity at contact).

3. On the other hand the airbag plus three-point belts restraint type, showed a significant increase in HIC and PCG injury measures as the driver moved rearward and away from immediate contact with the bag.

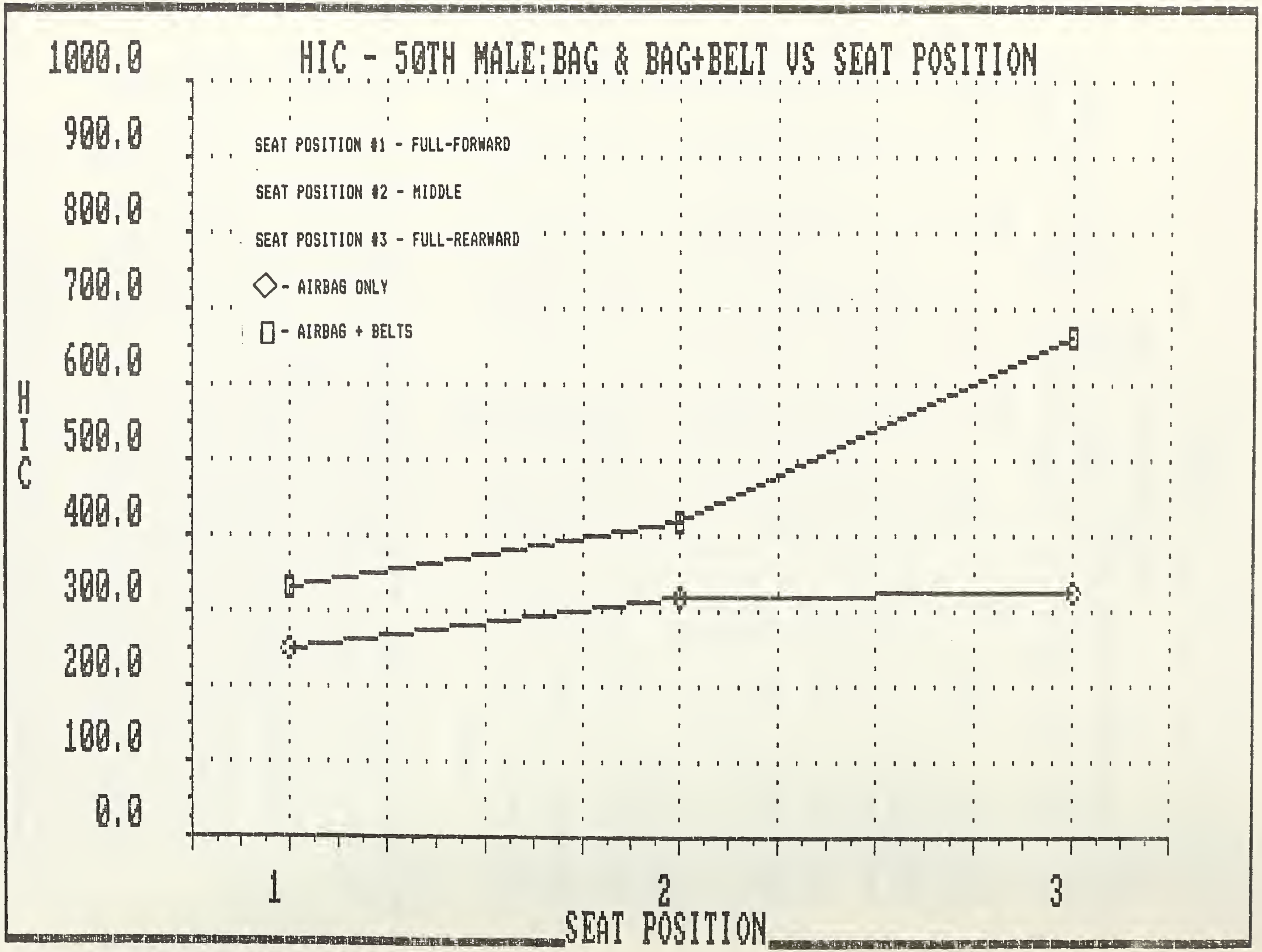

HIC - 50TH MALE:BAG & BAG+BELT VS SEAT POSITION
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
HIC
SEAT POSITION #1 - FULL-FORWARD
SEAT POSITION #2 - MIDDLE
SEAT POSITION #3 - FULL-REARWARD
◇ - AIRBAG ONLY
□ - AIRBAG + BELTS
1
2
3
SEAT POSITION

FIGURE 1

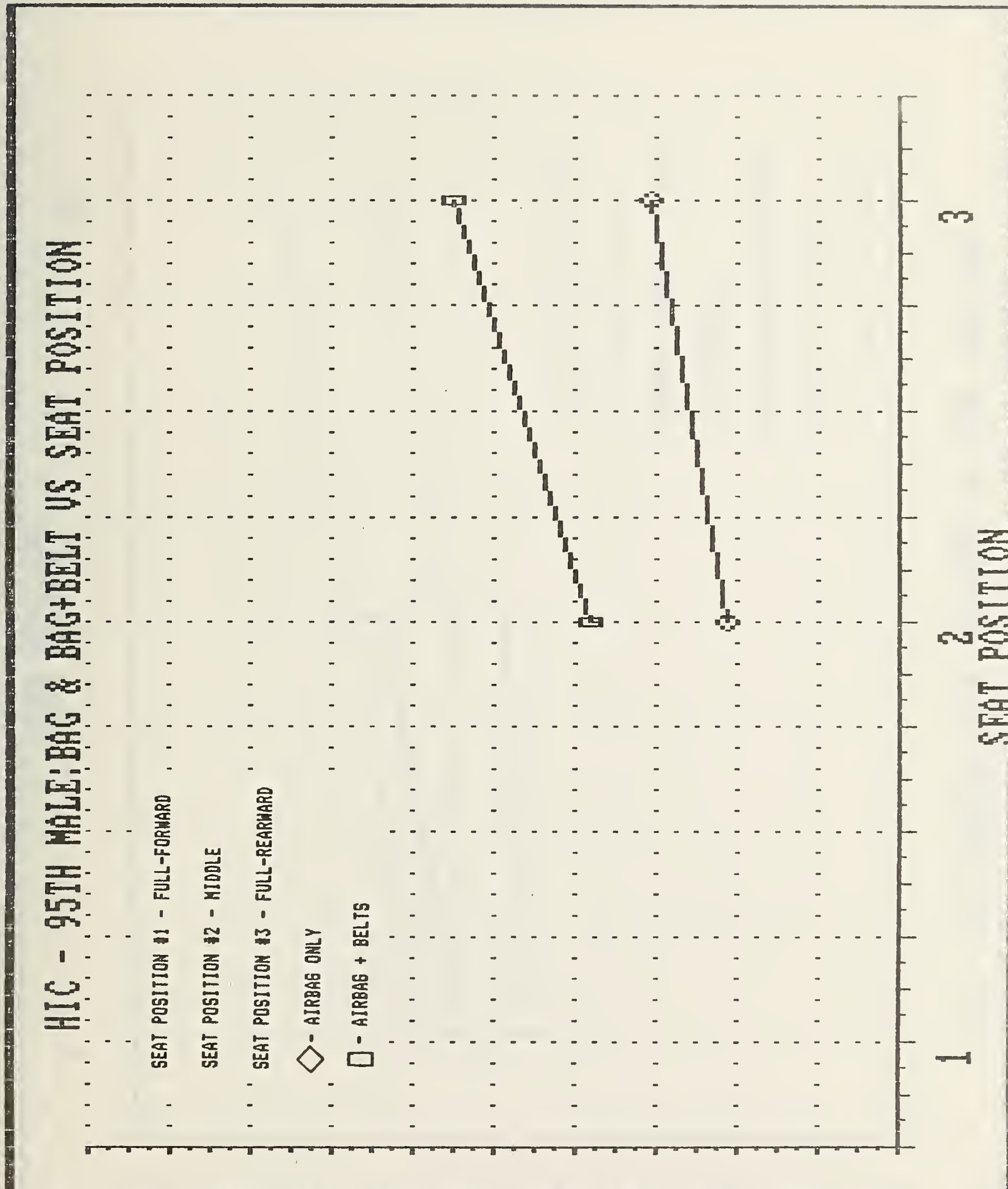

HIC - 95TH MALE; BAG & BAG+BELT VS SEAT POSITION
SEAT POSITION #1 - FULL-FORWARD
SEAT POSITION #2 - MIDDLE
SEAT POSITION #3 - FULL-REARWARD
◇- AIRBAG ONLY
□- AIRBAG + BELTS
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
HIC
1
2
3
SEAT POSITION

FIGURE 2

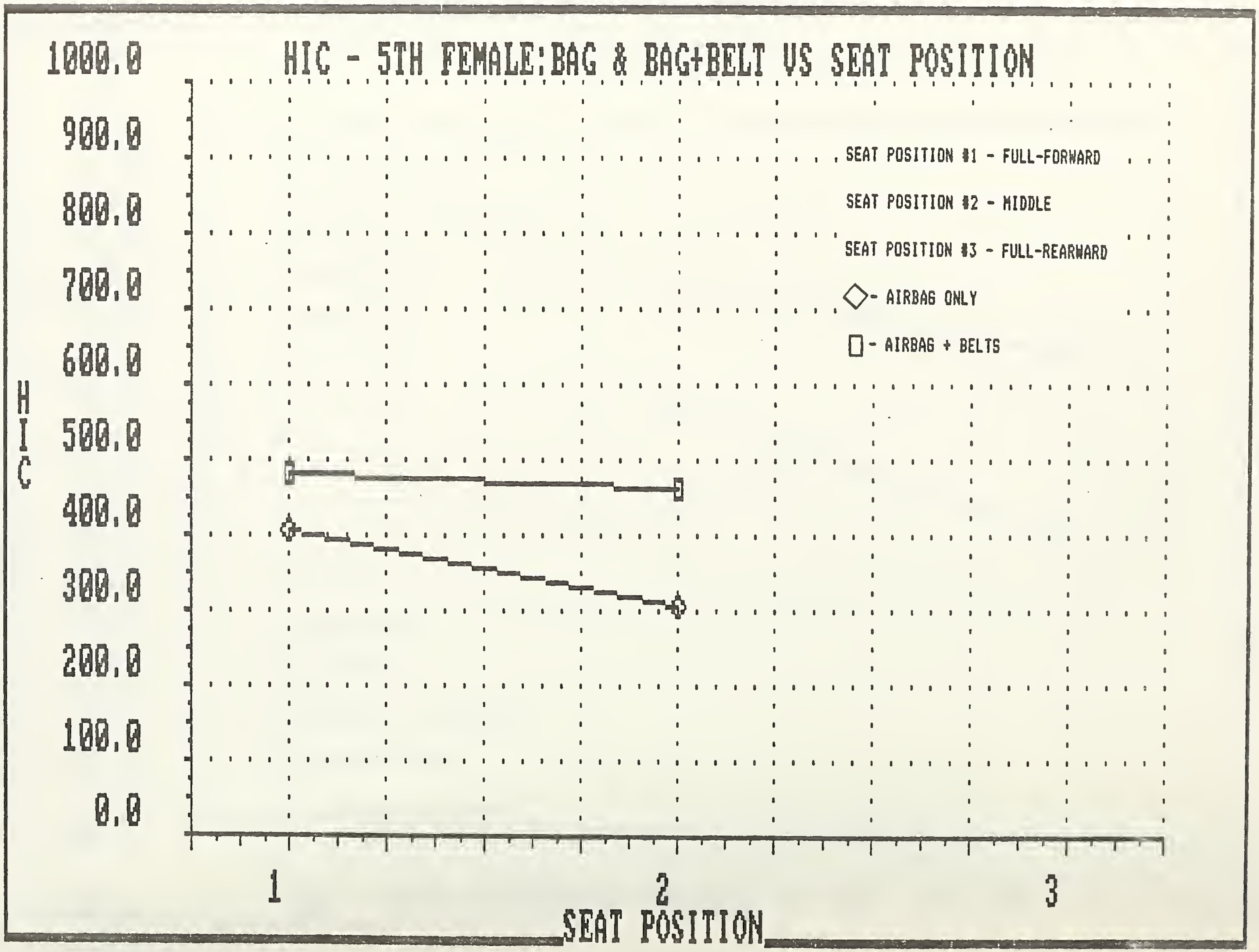

HIC - 5TH FEMALE:BAG & BAG+BELT VS SEAT POSITION
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
HIC
SEAT POSITION #1 - FULL-FORWARD
SEAT POSITION #2 - MIDDLE
SEAT POSITION #3 - FULL-REARWARD
◇- AIRBAG ONLY
□- AIRBAG + BELTS
1
2
3
SEAT POSITION

FIGURE 3

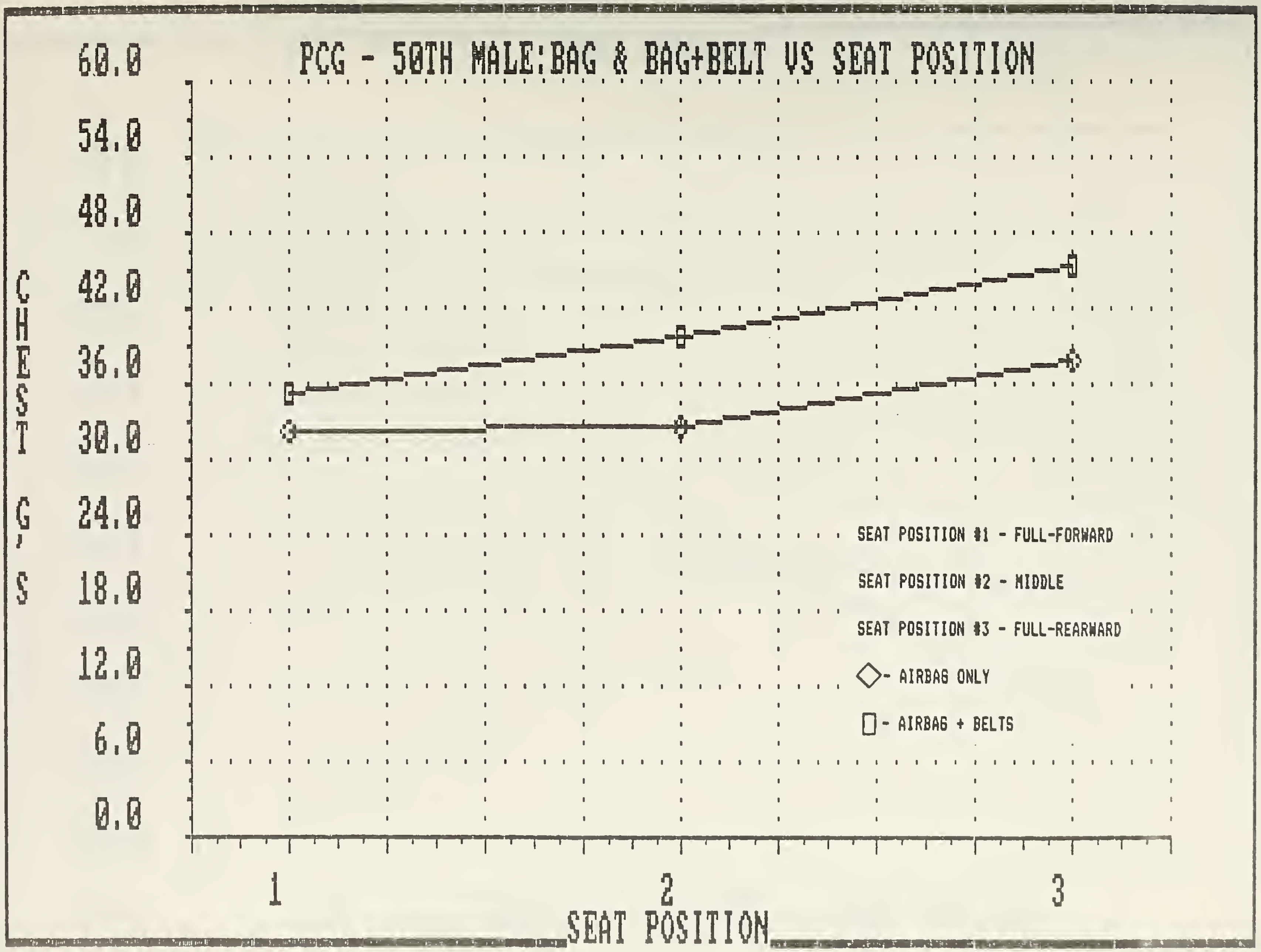

PCG - 50TH MALE:BAG & BAG+BELT VS SEAT POSITION
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.0
0.0
CHEST G'S
1
2
3
SEAT POSITION
SEAT POSITION #1 - FULL-FORWARD
SEAT POSITION #2 - MIDDLE
SEAT POSITION #3 - FULL-REARWARD
◇- AIRBAG ONLY
▯- AIRBAG + BELTS

FIGURE 4

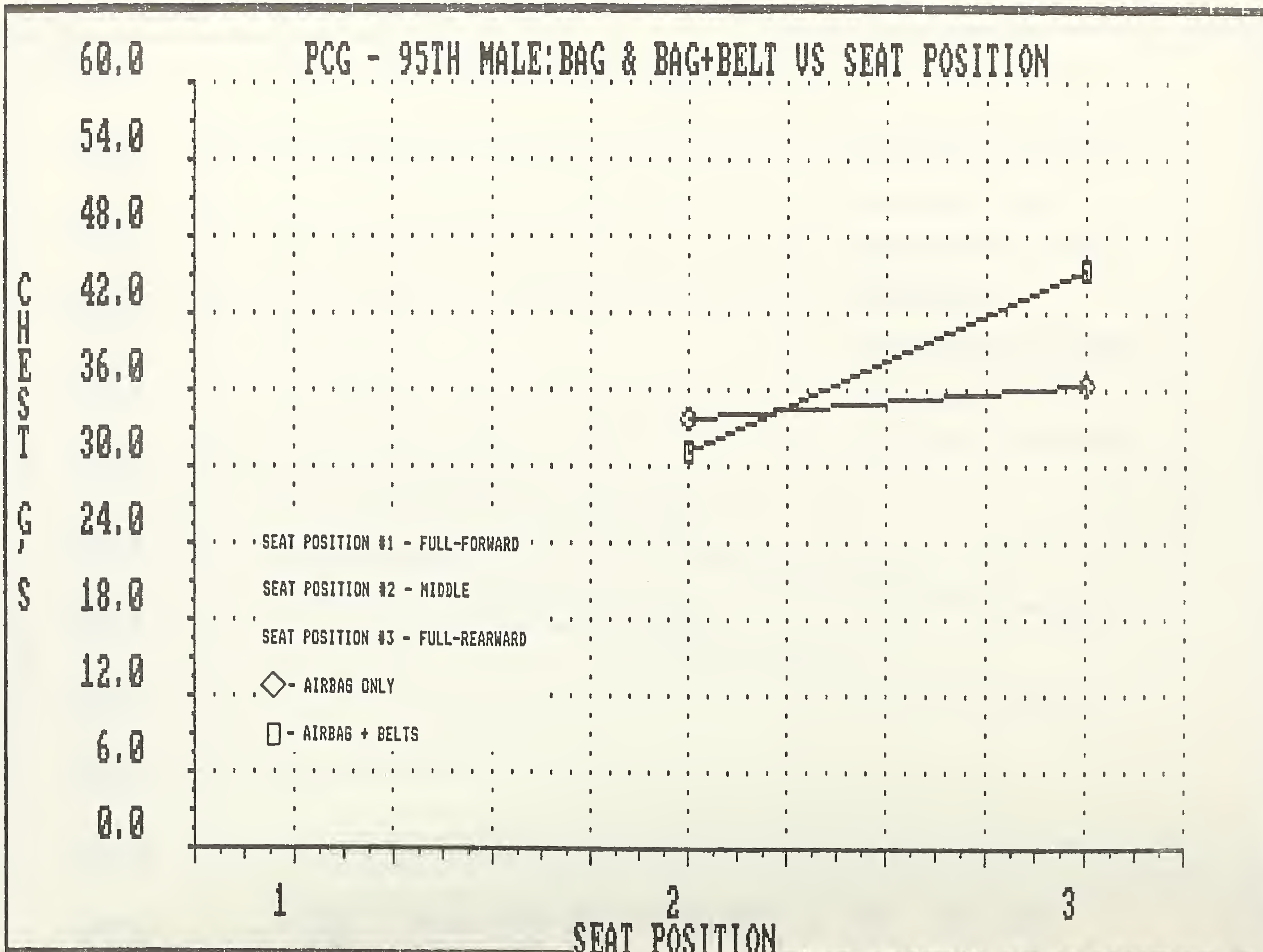

PCG - 95TH MALE:BAG & BAG+BELT VS SEAT POSITION
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.0
0.0
CHEST G'S
SEAT POSITION #1 - FULL-FORWARD
SEAT POSITION #2 - MIDDLE
SEAT POSITION #3 - FULL-REARWARD
- AIRBAG ONLY
- AIRBAG + BELTS
1
2
3
SEAT POSITION

FIGURE 5

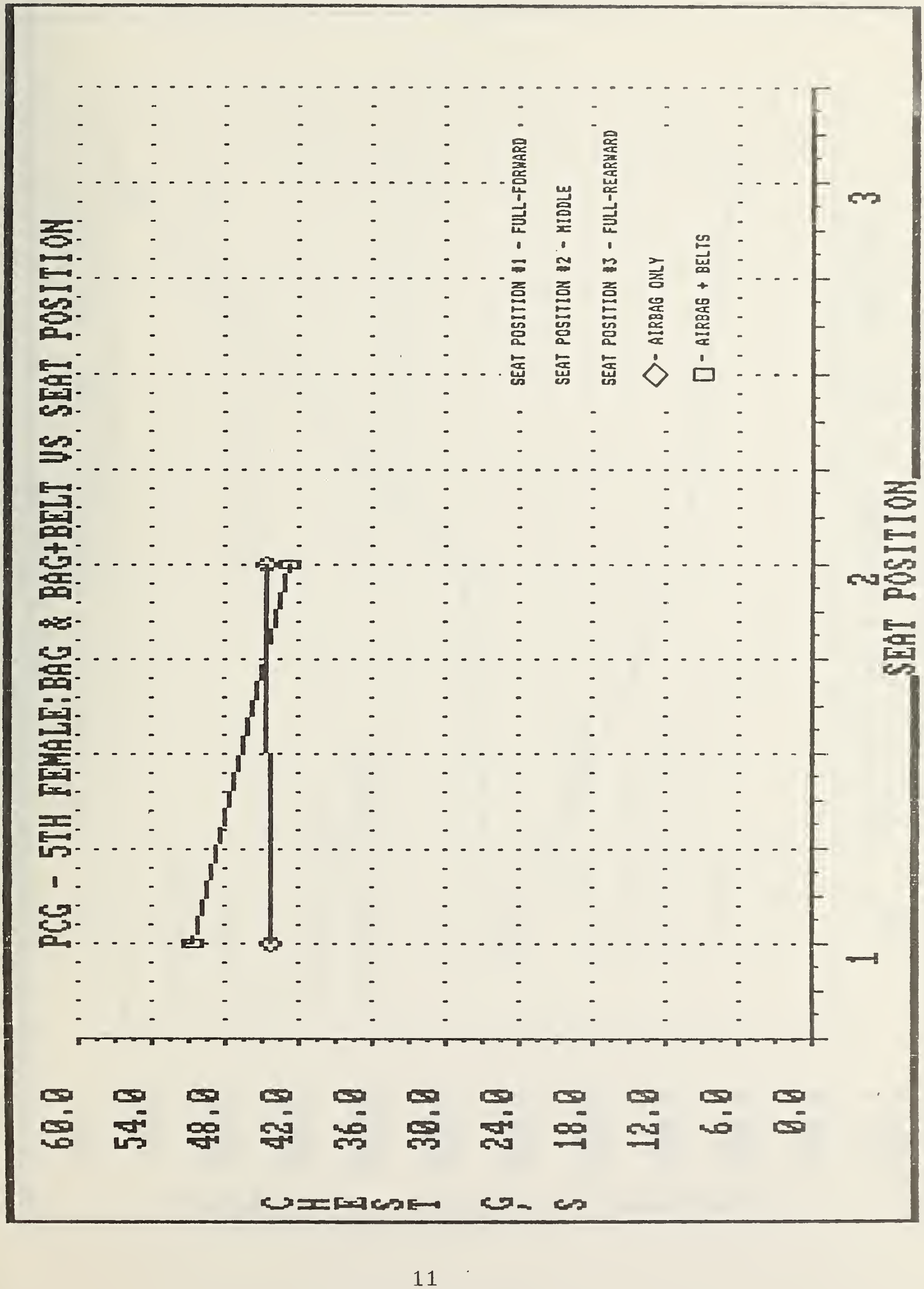

PCG - 5TH FEMALE:BAG & BAG+BELT VS SEAT POSITION
CHEST G' S
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.0
0.0
1
2
3
SEAT POSITION
SEAT POSITION #1 - FULL-FORWARD
SEAT POSITION #2 - MIDDLE
SEAT POSITION #3 - FULL-REARWARD
◇- AIRBAG ONLY
□- AIRBAG + BELTS

FIGURE 6

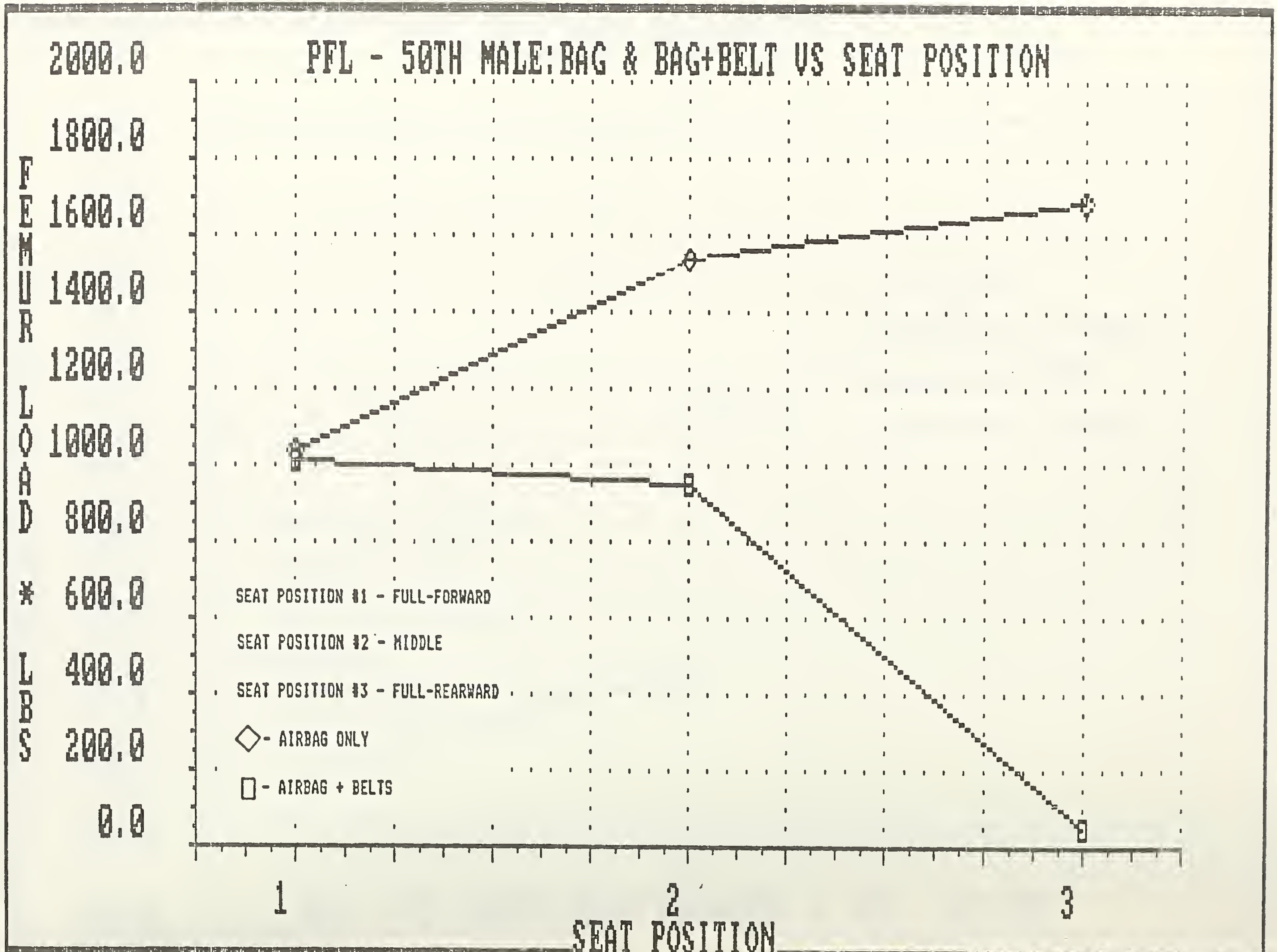

PFL - 50TH MALE:BAG & BAG+BELT VS SEAT POSITION
FEMUR LOAD * LBS
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
SEAT POSITION #1 - FULL-FORWARD
SEAT POSITION #2 - MIDDLE
SEAT POSITION #3 - FULL-REARWARD
◇- AIRBAG ONLY
□- AIRBAG + BELTS
1
2
3
SEAT POSITION

FIGURE 7

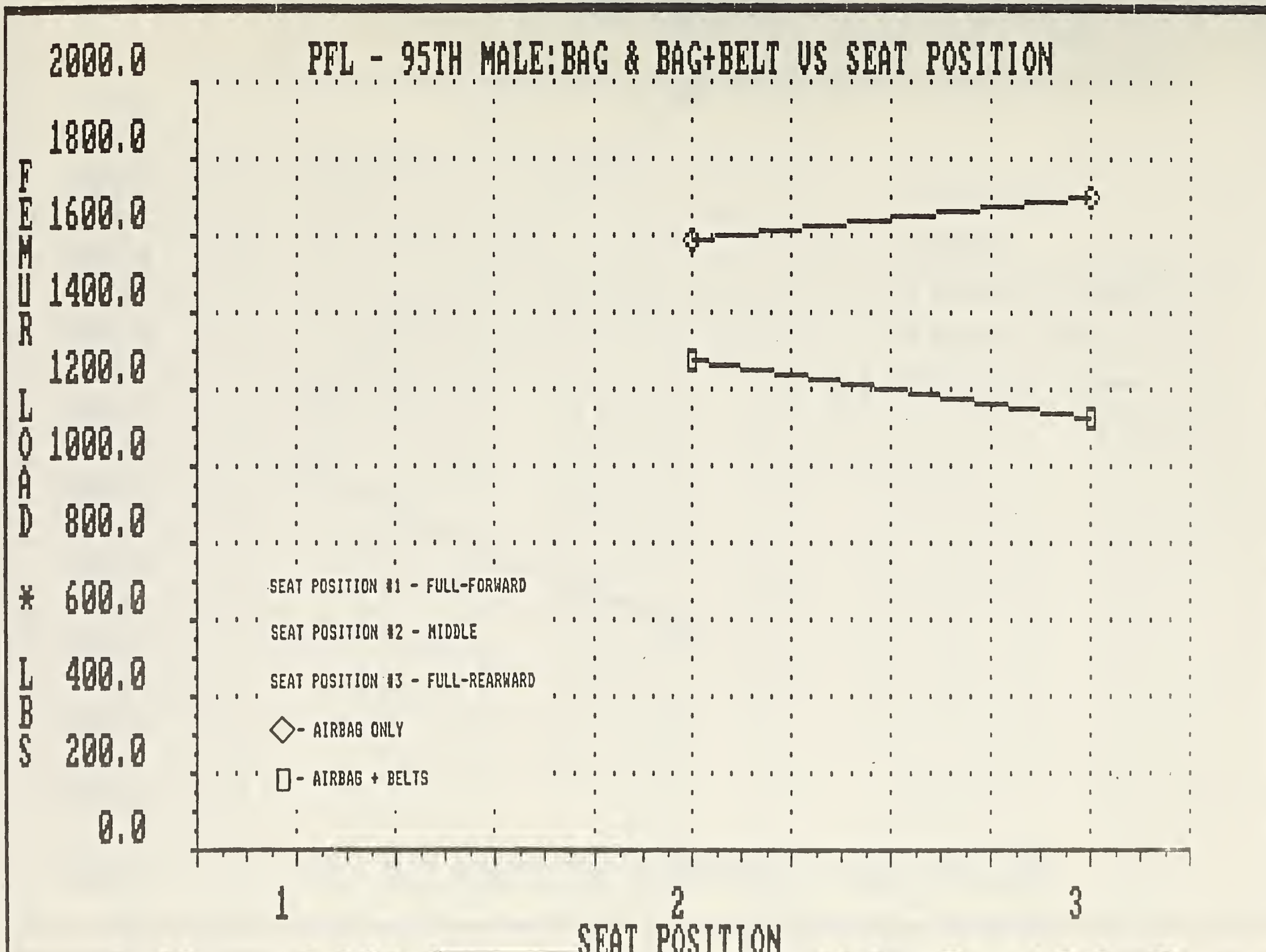

PFL - 95TH MALE:BAG & BAG+BELT VS SEAT POSITION
FEMUR LOAD * LBS
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
SEAT POSITION #1 - FULL-FORWARD
SEAT POSITION #2 - MIDDLE
SEAT POSITION #3 - FULL-REARWARD
◇- AIRBAG ONLY
□- AIRBAG + BELTS
1
2
3
SEAT POSITION

FIGURE 8

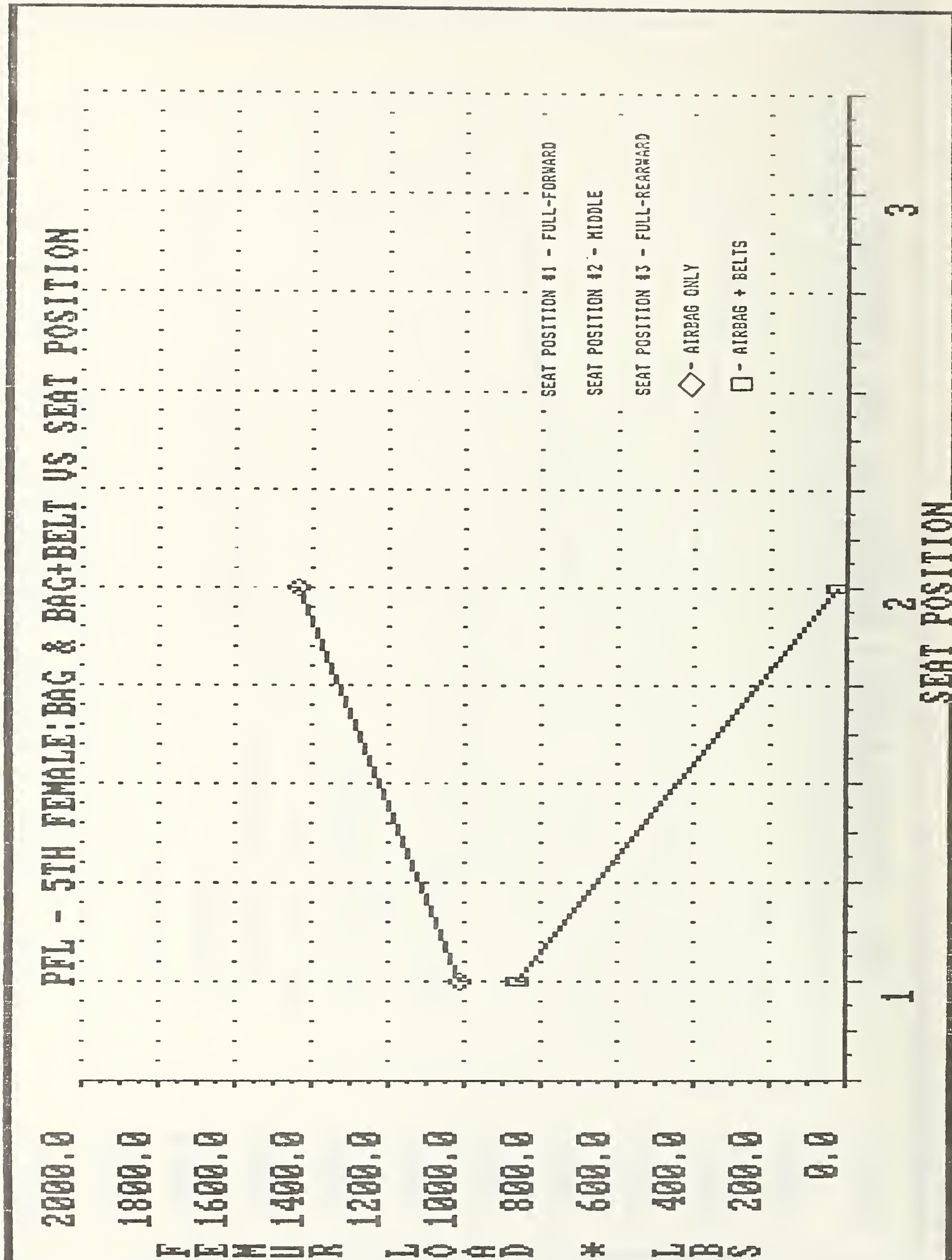

PFL - 5TH FEMALE: BAG & BAG+BELT VS SEAT POSITION
FEMUR LOAD * LBS
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
SEAT POSITION #1 - FULL-FORWARD
SEAT POSITION #2 - MIDDLE
SEAT POSITION #3 - FULL-REARWARD
◇ - AIRBAG ONLY
□ - AIRBAG + BELTS
1
2
3
SEAT POSITION

FIGURE 9

a. This is manifested in an increase in HIC for the airbag plus belt restraint type because the belt restraint causes an increased head rotational velocity. Thus, as the driver moves rearward, away from the airbag, more rotational kinetic energy is acquired before the head receives support from the airbag.

b. The PCG that occurs from chest/airbag interaction is due to a combination of airbag and belt force contributions. Here again, the longer the driver must wait to receive airbag support results in a loss of "ride-down" energy absorbed with a concomitant increase in belt force required to bring the driver to rest. When contact with the airbag is finally made, the chest g contribution due to the belt is additive.

4. For the <u>airbag only</u> restraint type, femur injury increases as driver seated position is moved rearward. Again, this is due to the higher relative velocity acquired prior to knee bolster contact.

5. For the <u>airbag plus three-point belt restraint type</u>, femur injury decreased greatly as the driver seated position was moved rearward. Of course this is due to the fact that the lap belt retards knee bolster penetration - at times to the point of almost eliminating contact altogether. Therefore, even the highest femur loads when belts are utilized are exceptionally low.

6. In terms of seat position, the HIC and PCG are highest when three-point belts are used in conjunction with an airbag and then generally <u>increase</u> as the driver moves further rearward away from the airbag. Conversely, for the airbag plus belts restraint type, the PFL is reduced as the driver sits further rearward away from the knee bolster. This is due to increasing the time during which the belts are active prior to knee bolster contact.

7. In general, the 5th percentile female would fare better if her distance from the airbag could be increased somewhat. Her head injury is the only injury measure that increases as the seated position is moved forward. This is because, in the forward position, she has the highest initial bag "wraparound" and initial airbag penetration resulting in comparatively high initial airbag pressure and, ultimately, comparatively high head and chest g's.

3.0 BAG VERSUS BAG PLUS THREE-POINT BELTS: AIRBAG SHAPE

The second phase of the airbag versus airbag plus three-point belts study considered the effect of tethering the airbag. The tethering alters the airbag shape thus offering different restraint characteristics. Tethering refers to the technique of internally connecting two opposite sides of the airbag together via small bands or tethers to accomplish this shape alteration.

3.1 Approach

Three different airbag shapes were simulated. All were elliptical in cross section. The overall airbag volume remained 2.298 cubic feet, and the vent area remained 2.0 square inches. The bag shapes simulated were:

1. Bag Shape #1 - this is the same airbag as described in Section 2.1. It is an untethered airbag, and is therefore the most round one studied.

   major axis radius = 11.246 inches
   minor axis radius = 7.497 inches

2. Bag Shape #2 - This a tethered airbag. It has an intermediate shape between bag shapes #1 and #3.

   major axis radius = 12.080 inches
   minor axis radius = 6.497 inches

3. Bag Shape #3 - This, also, is a tethered airbag with the highest degree of tethering considered in this study. It is therefore the tallest and narrowest airbag simulated.

   major axis radius = 13.133 inches
   minor axis radius = 5.497 inches

As with the seat position study, cases were run for both airbag only and airbag plus three-point belts. The different driver sizes were modeled in their nominal seat positions: 50th percentile male - mid-seat position; 95th percentile male - full rearward position; 5th percentile female - full forward position. These positions were not varied for this bag shape study. The sensing time was 25 milliseconds and the belt webbing elongation was 8.0% throughout.

3.2 Results and Discussion

The general trends observed from the seat position section are also found in this section dealing with the effect of different airbag shapes as a result of tethering. These trends are shown by Figures 10 through 18. These figures show:

1. The change in primary injury measure (HIC or PCG) as a function of airbag tethering was greater for the airbag plus three-point belts than for the airbag alone.

2. The airbag only restraint type produced very little change in the primary injury measures as the degree of tethering was varied.

These findings are similar to the seated position findings discussed in the previous section. This is because one of the key variables is still distance from the airbag, i.e. as the airbag narrows due to increased tethering, the initial position of the driver becomes further away from the inflated airbag -just as it did when the seated position was moved rearward.

The following tables summarize the results presented in these figures and presents the overall effect of the airbag only restraint type versus the airbag plus belts restraint type. As before the HIC and the PCG increase and the PFL decreases when belts are added to the airbag restraint (the average, ex-PFL, shows an increase of 16.5% of injury criteria limit from 47.4% to 63.9%).

3.2.1 Overall Averages - Bag Shape, Driver Size, Restraint Type

RESTRAINT TYPE VS PER CENT OF INJURY CRITERIA LIMIT
(AVERAGED OVER ALL BAG SHAPES AND DRIVER SIZES)

RESTRAINT	AVG HIC	AVG CRIT. %	AVG PCG	AVG CRIT. %	AVG PFL	AVG CRIT. %	AVG % EX-PFL (WITH PFL)
BAG ONLY	327	32.7	37.33	62.2	1400	62.2	47.4 (52.4)
BAG + BELTS	517	51.7	45.64	76.1	1101	44.5	63.9 (57.4)

3.2.2 Average for Each Driver Size over All Tethered Shapes

Table 2 contains the overall averages presented as a function of driver size. The following trends are seen:

1. HIC - When the restraint type is changed from airbag only to airbag plus belts, the 50th and 95th percentile males show a large percentage increase in average head injury. For the 50th percentile male the HIC as a percentage of the criteria limit increases by 20.2%. For the 95th percentile male the HIC as a percentage of the criteria limit more than doubles as the value rises from 29.2% to 61.4%.

2. PCG - When the restraint type changes from airbag only to airbag plus belts, the 95th percentile male experiences the greatest increase in chest injury. Here

the percentage of the criteria limit increases from 62.6% to 84.7%. The resulting average chest injury for the 5th percentile female is also quite high - 47.48 g's or 79.1% of the criteria limit.

3. PFL - When the restraint type changes from airbag only to airbag plus belts, the 50th percentile male and the 95th percentile male demonstrate essentially equal amounts of decrease in the femur injury - 67.3% to 41.4% and 61.8% to 41.1%, respectively.

TABLE 2

BAG SHAPE STUDY

RESTRAINT TYPE VS PER CENT OF INJURY CRITERIA LIMIT

(FOR EACH DRIVER SIZE AVERAGED OVER ALL BAG SHAPES)

RESTRAINT	AVG HIC	CRIT. %	AVG PCG	CRIT. %	AVG PFL	CRIT. %	EX-PFL (WITH PFL)
BAG ONLY							
50TH MALE	302	30.2	33.17	55.3	1514	67.3	42.8 (50.9)
95TH MALE	292	29.2	37.53	62.6	1698	61.8	45.9 (51.2)
5TH FEMALE	387	38.7	41.27	68.8	1008	57.6	53.8 (55.0)
AVERAGE		32.7		62.2		62.2	47.5
BAG + BELTS							
50TH MALE	504	50.4	38.62	64.4	931	41.4	57.4 (52.1)
95TH MALE	614	61.4	50.83	84.7	1131	41.1	73.0 (62.4)
5TH FEMALE	432	43.2	47.48	79.1	890	50.8	61.2 (57.7)
AVERAGE		51.7		76.1		44.4	63.9

3.2.3 Effect of Tethering

Trends as a function of airbag shape are best seen in Figures 10 through 18. Here the results are plotted versus bag shapes #1, #2, and #3 as described above. Notice first the trend for HIC as seen in Figures 10 through 12. Generally, the airbag

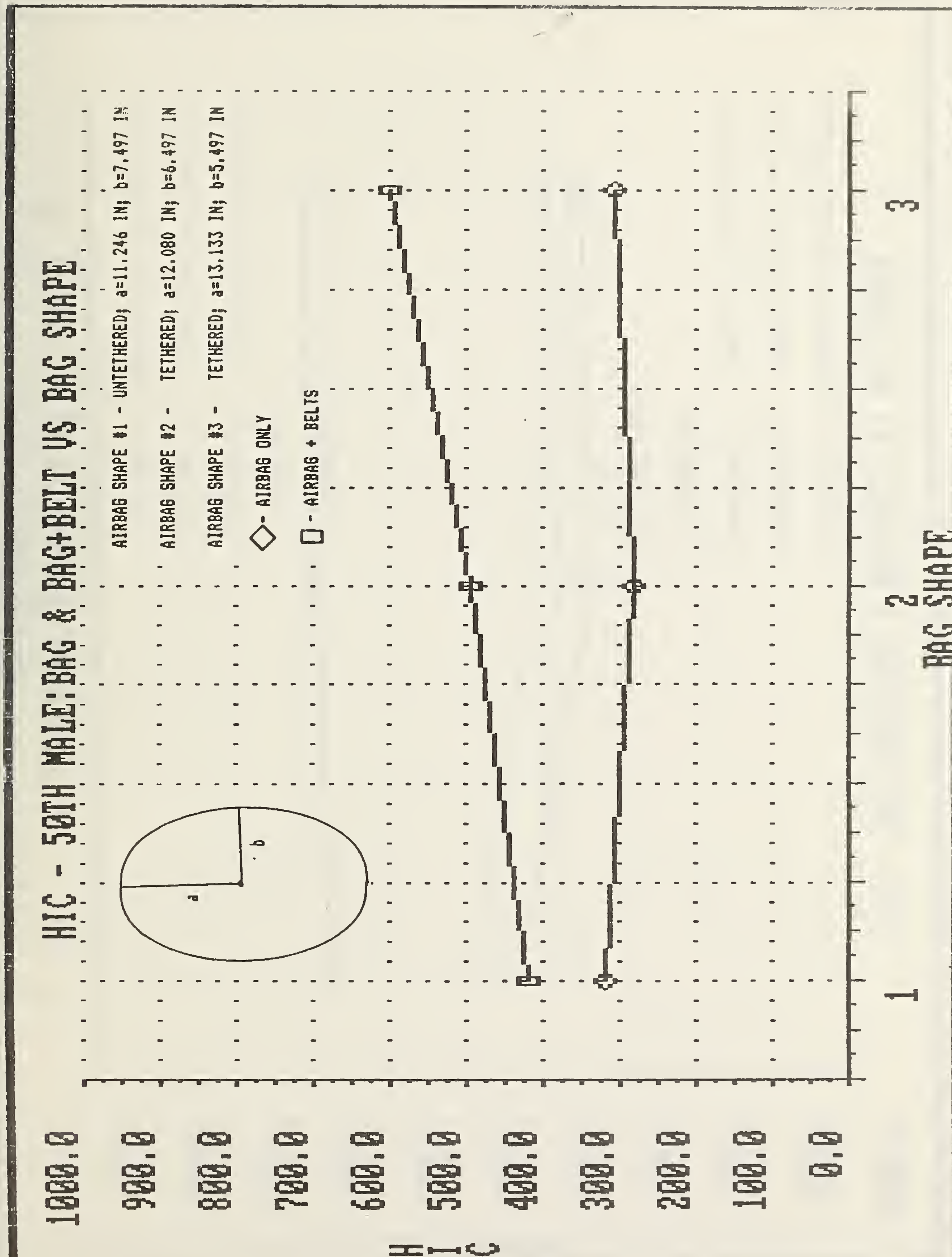

HIC - 50TH MALE:BAG & BAG+BELT VS BAG SHAPE
AIRBAG SHAPE #1 - UNTETHERED; a=11.246 IN; b=7.497 IN
AIRBAG SHAPE #2 - TETHERED; a=12.080 IN; b=6.497 IN
AIRBAG SHAPE #3 - TETHERED; a=13.133 IN; b=5.497 IN
◇- AIRBAG ONLY
□- AIRBAG + BELTS
a
b
HIC
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
1
2
3
BAG SHAPE

FIGURE 10

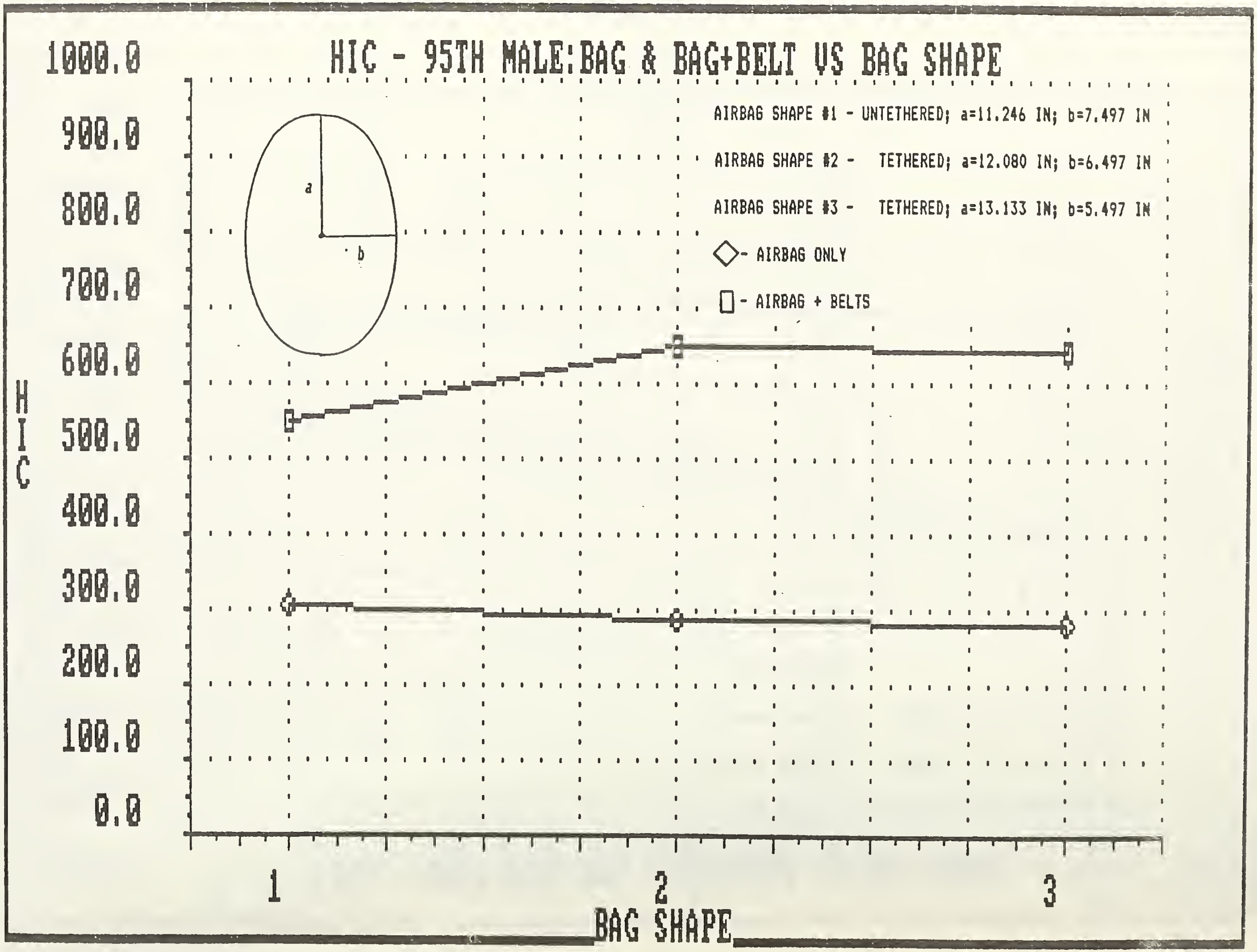

HIC - 95TH MALE:BAG & BAG+BELT VS BAG SHAPE
AIRBAG SHAPE #1 - UNTETHERED; a=11.246 IN; b=7.497 IN
AIRBAG SHAPE #2 - TETHERED; a=12.080 IN; b=6.497 IN
AIRBAG SHAPE #3 - TETHERED; a=13.133 IN; b=5.497 IN
◇- AIRBAG ONLY
□- AIRBAG + BELTS
a
b
HIC
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
1
2
3
BAG SHAPE

FIGURE 11

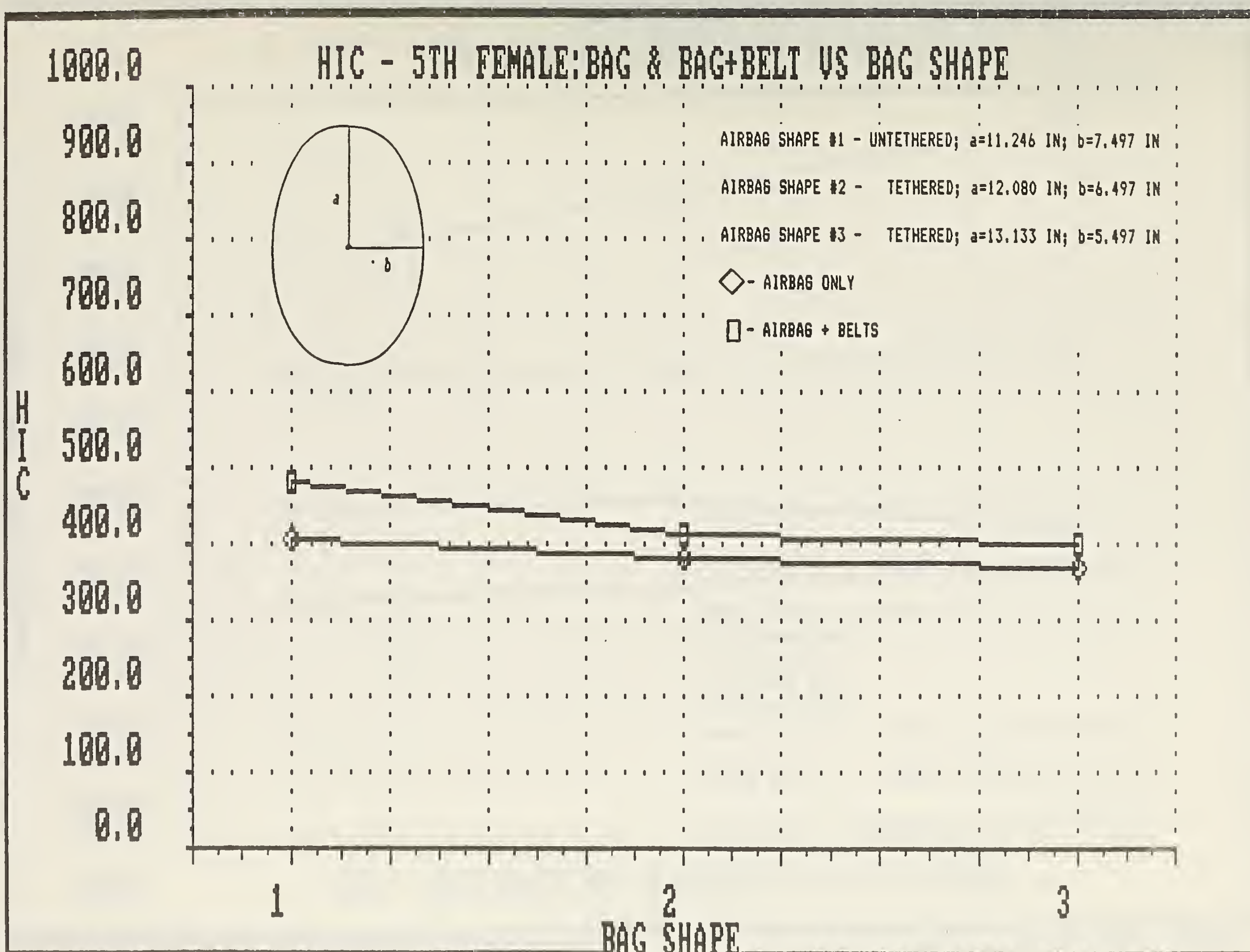
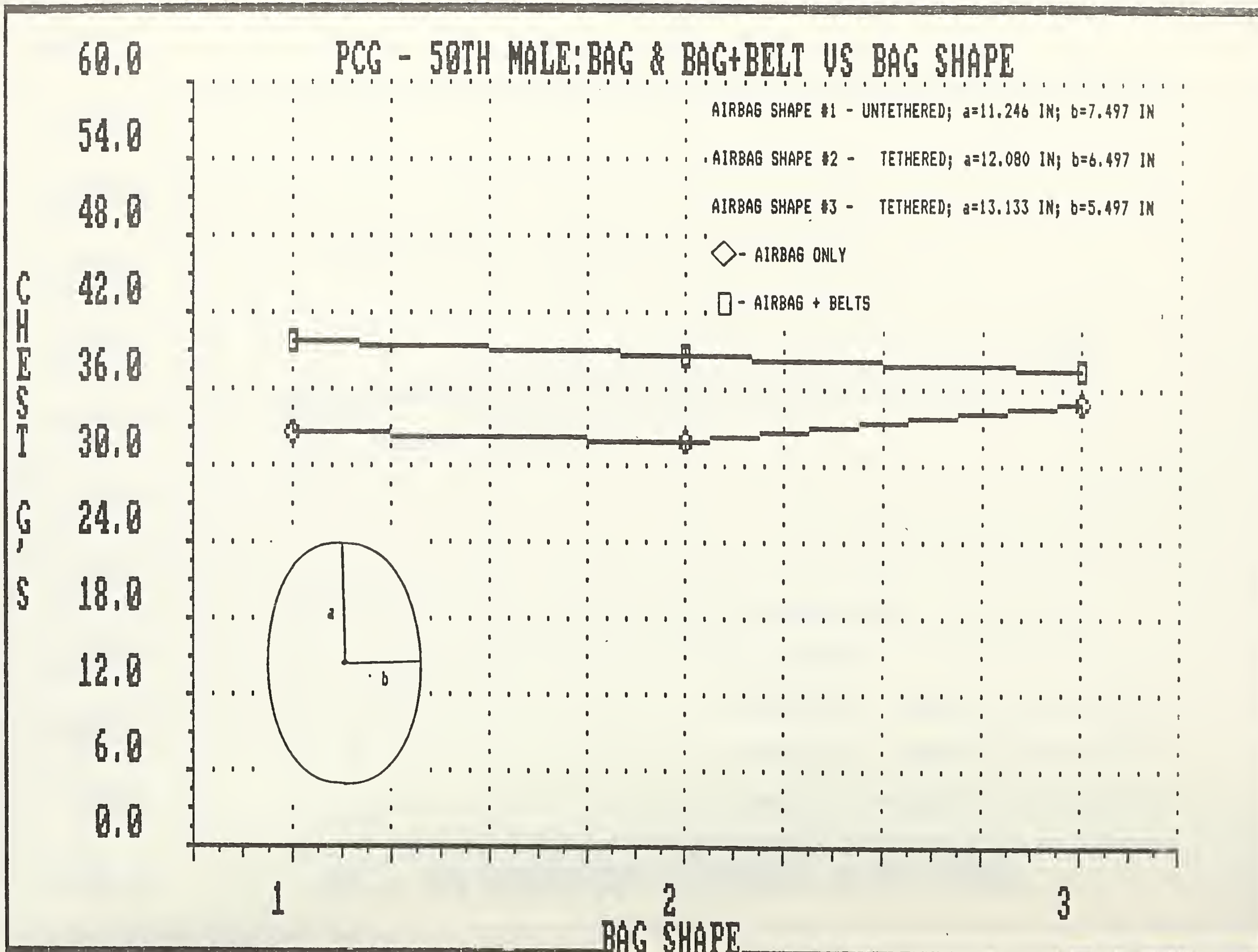

HIC - 5TH FEMALE:BAG & BAG+BELT VS BAG SHAPE
AIRBAG SHAPE #1 - UNTETHERED; a=11.246 IN; b=7.497 IN
AIRBAG SHAPE #2 - TETHERED; a=12.080 IN; b=6.497 IN
AIRBAG SHAPE #3 - TETHERED; a=13.133 IN; b=5.497 IN
◇ - AIRBAG ONLY
□ - AIRBAG + BELTS
a
b
HIC
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
1
2
3
BAG SHAPE

FIGURE 12



PCG - 50TH MALE:BAG & BAG+BELT VS BAG SHAPE
AIRBAG SHAPE #1 - UNTETHERED; a=11.246 IN; b=7.497 IN
AIRBAG SHAPE #2 - TETHERED; a=12.080 IN; b=6.497 IN
AIRBAG SHAPE #3 - TETHERED; a=13.133 IN; b=5.497 IN
- AIRBAG ONLY
- AIRBAG + BELTS
CHEST G'S
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.0
0.0
1
2
3
BAG SHAPE
a
b

FIGURE 13

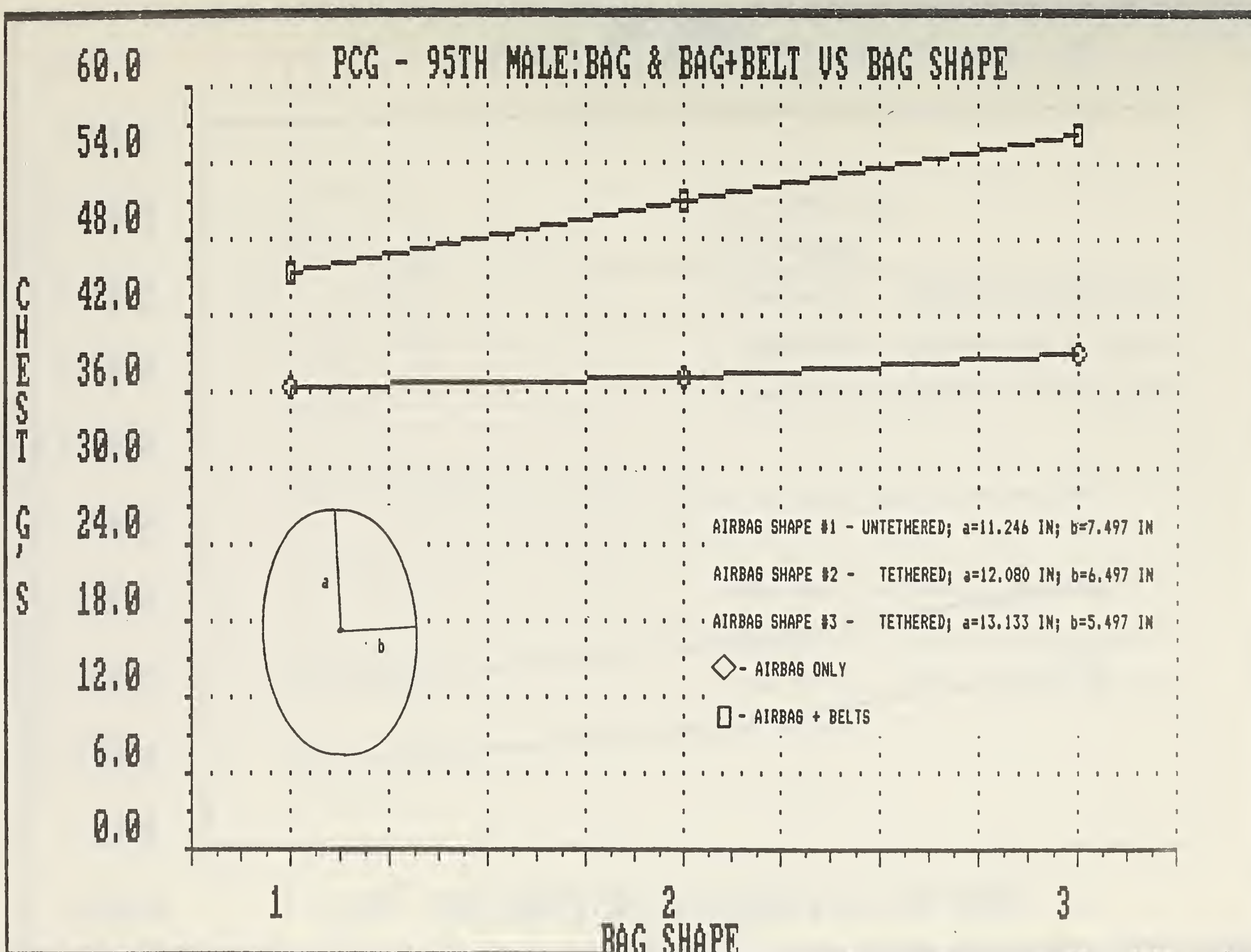

PCG - 95TH MALE:BAG & BAG+BELT VS BAG SHAPE
CHEST G'S
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.0
0.0
1
2
3
BAG SHAPE
a
b
AIRBAG SHAPE #1 - UNTETHERED; a=11.246 IN; b=7.497 IN
AIRBAG SHAPE #2 - TETHERED; a=12.080 IN; b=6.497 IN
AIRBAG SHAPE #3 - TETHERED; a=13.133 IN; b=5.497 IN
- AIRBAG ONLY
- AIRBAG + BELTS

FIGURE 14

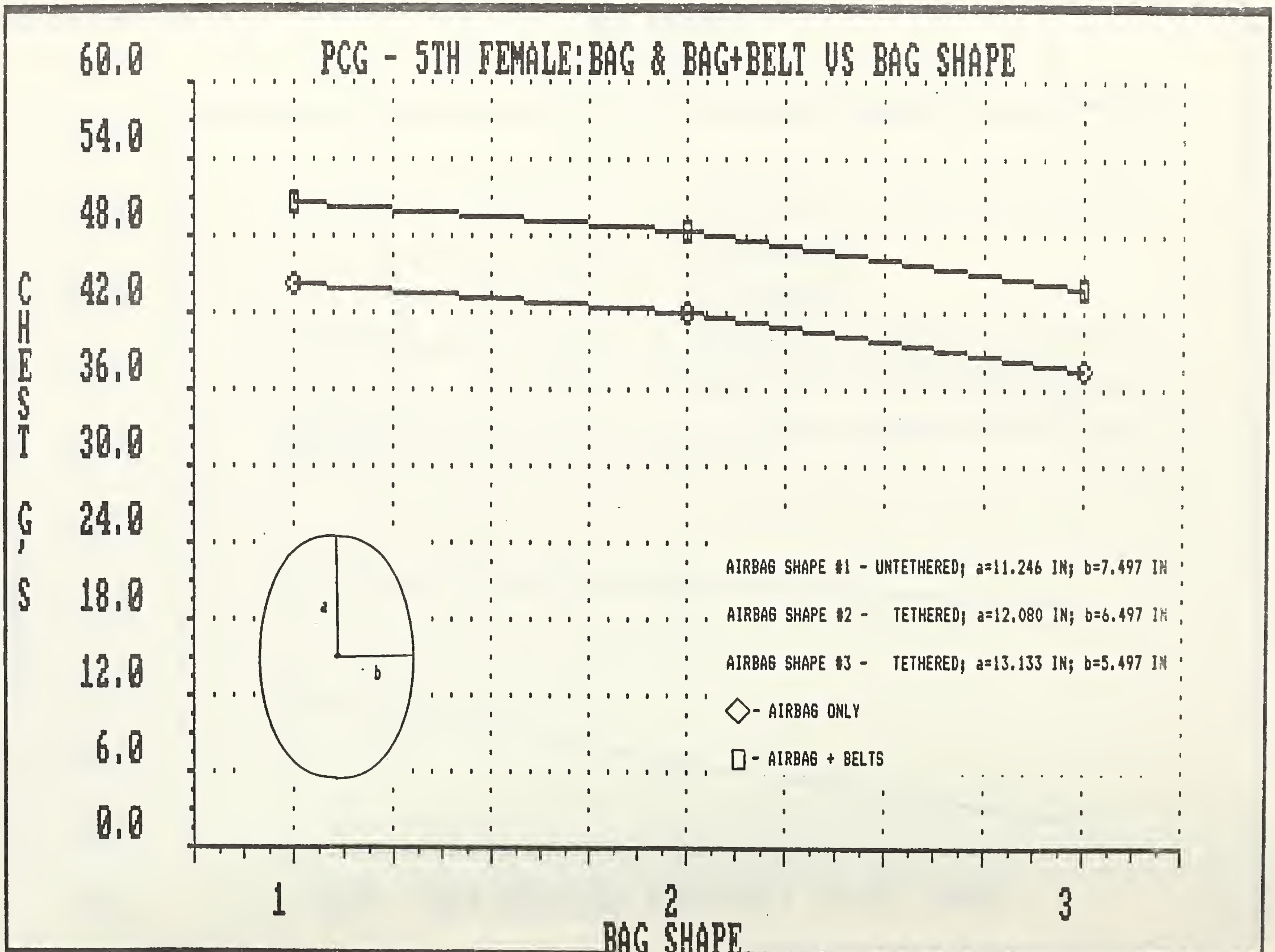

PCG - 5TH FEMALE:BAG & BAG+BELT VS BAG SHAPE
CHEST G'S
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.0
0.0
1
2
3
BAG SHAPE
a
b
AIRBAG SHAPE #1 - UNTETHERED; a=11.246 IN; b=7.497 IN
AIRBAG SHAPE #2 - TETHERED; a=12.080 IN; b=6.497 IN
AIRBAG SHAPE #3 - TETHERED; a=13.133 IN; b=5.497 IN
◇- AIRBAG ONLY
□- AIRBAG + BELTS

FIGURE 15

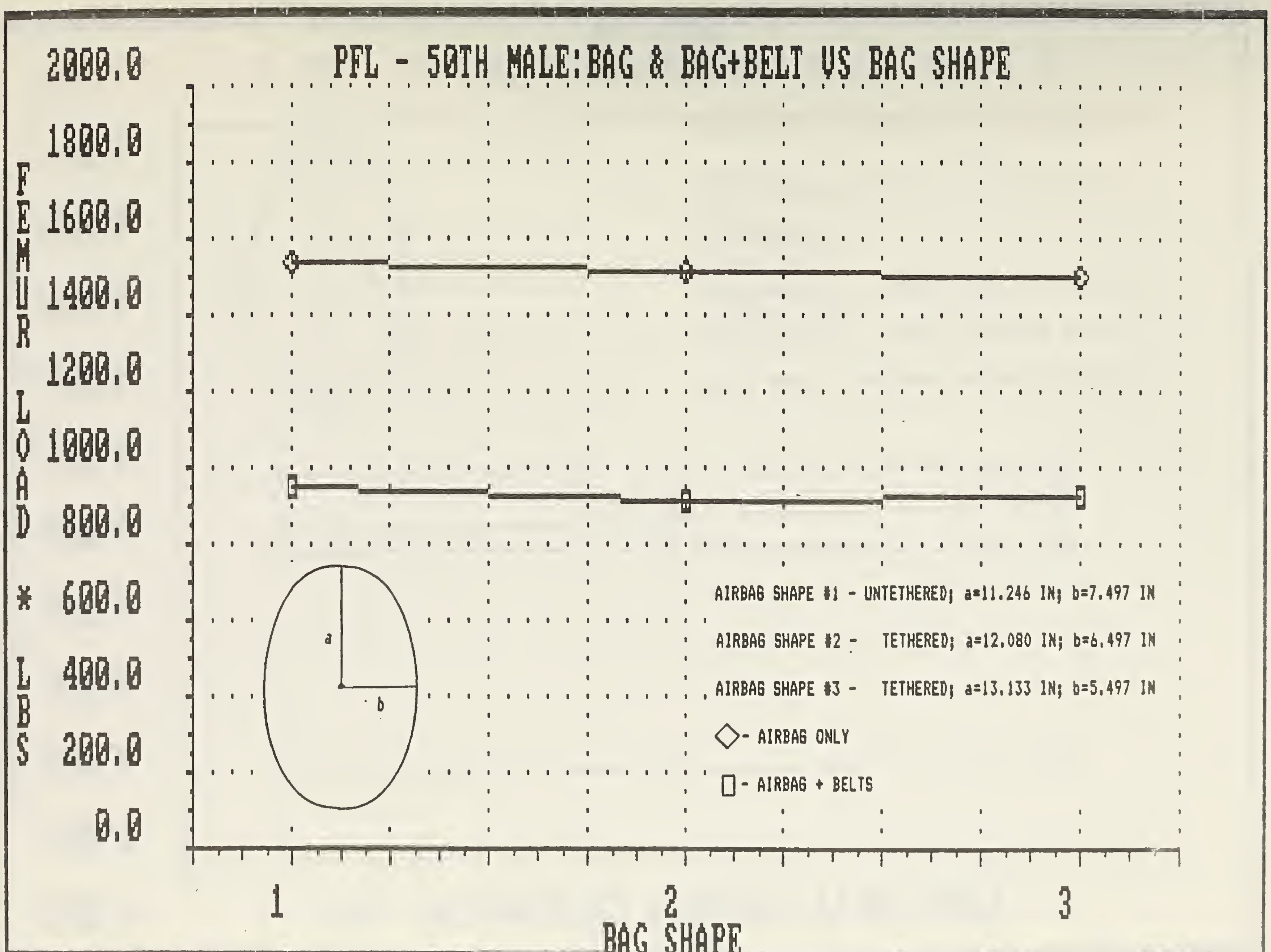

PFL - 50TH MALE:BAG & BAG+BELT VS BAG SHAPE
FEMUR LOAD * LBS
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
1
2
3
BAG SHAPE
a
b
AIRBAG SHAPE #1 - UNTETHERED; a=11.246 IN; b=7.497 IN
AIRBAG SHAPE #2 - TETHERED; a=12.080 IN; b=6.497 IN
AIRBAG SHAPE #3 - TETHERED; a=13.133 IN; b=5.497 IN
◇- AIRBAG ONLY
□- AIRBAG + BELTS

FIGURE 16

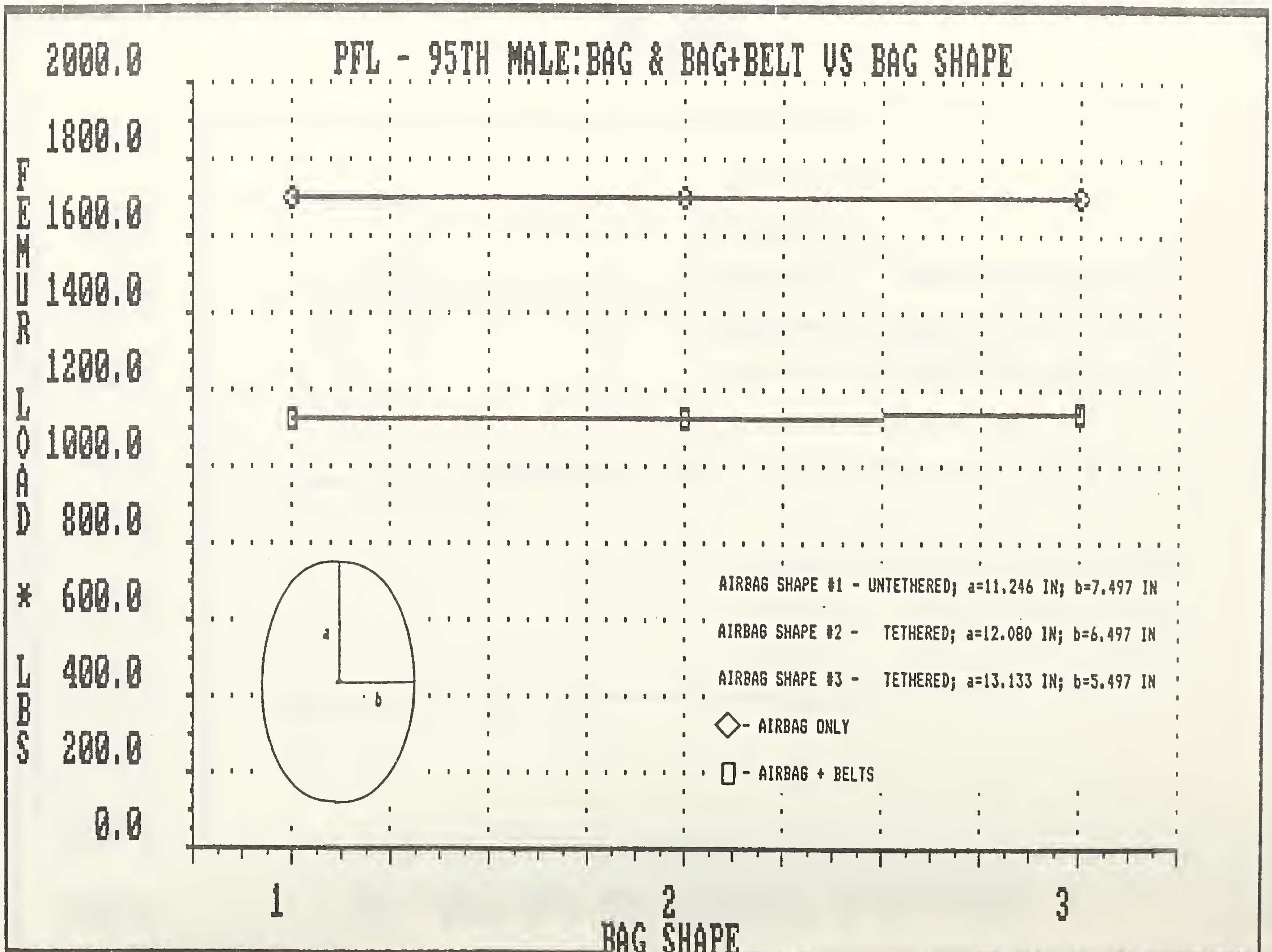

PFL - 95TH MALE:BAG & BAG+BELT VS BAG SHAPE
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
FEMUR LOAD * LBS
1
2
3
BAG SHAPE
a
b
AIRBAG SHAPE #1 - UNTETHERED; a=11.246 IN; b=7.497 IN
AIRBAG SHAPE #2 - TETHERED; a=12.080 IN; b=6.497 IN
AIRBAG SHAPE #3 - TETHERED; a=13.133 IN; b=5.497 IN
- AIRBAG ONLY
- AIRBAG + BELTS

FIGURE 17

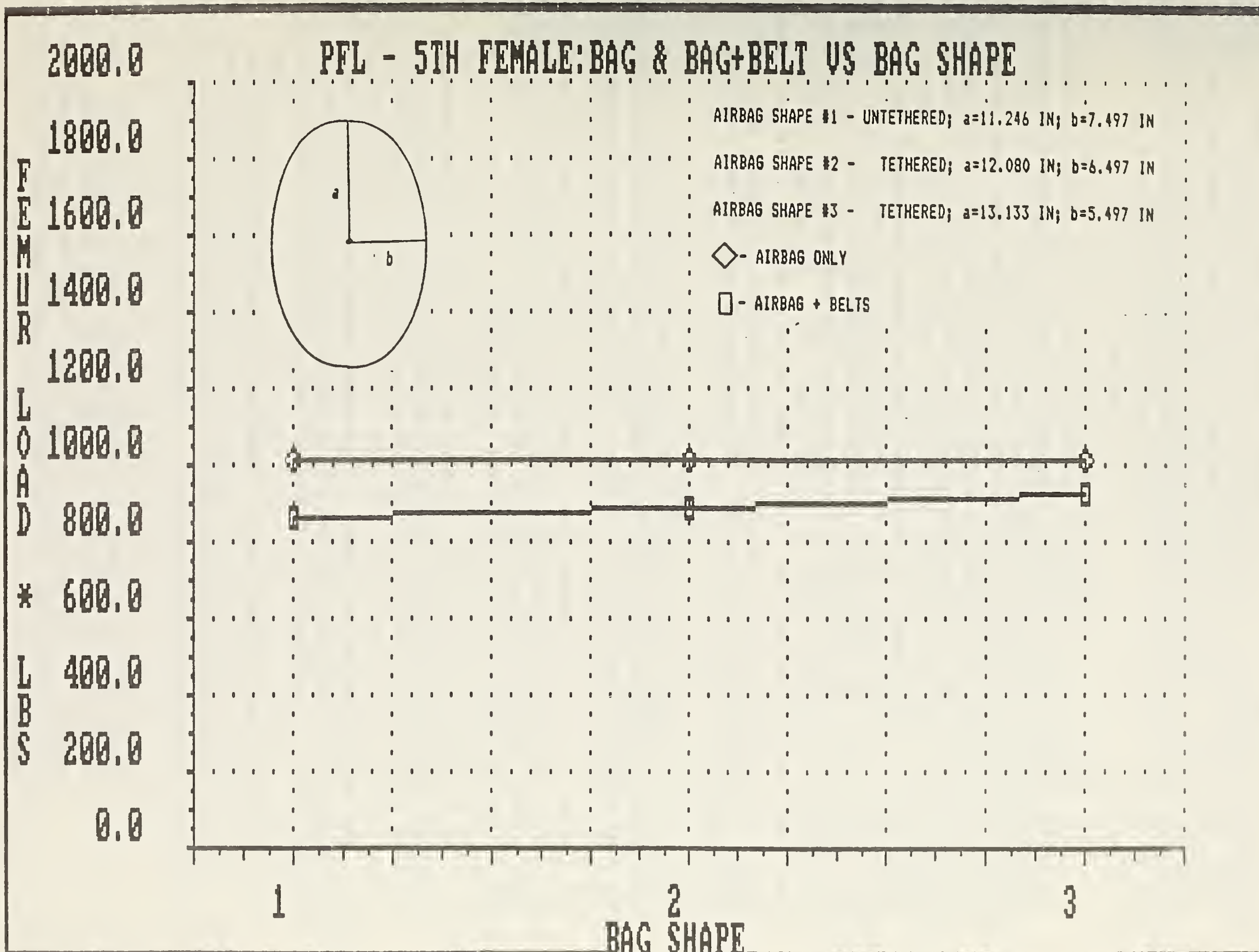

PFL - 5TH FEMALE:BAG & BAG+BELT VS BAG SHAPE
AIRBAG SHAPE #1 - UNTETHERED; a=11.246 IN; b=7.497 IN
AIRBAG SHAPE #2 - TETHERED; a=12.080 IN; b=6.497 IN
AIRBAG SHAPE #3 - TETHERED; a=13.133 IN; b=5.497 IN
- AIRBAG ONLY
- AIRBAG + BELTS
a
b
FEMUR LOAD * LBS
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
1
2
3
BAG SHAPE

FIGURE 18

only data shows very little sensitivity to the bag shape. Also, generally speaking, for the belt plus airbag restraint system and the 50th and 95th percentile males, the greater the degree of tethering, the less ride-down energy which is absorbed. This results in injury measures which are slightly higher for the case of greatest tethering. However, even here the effect of tethering is fairly minor as it relates to injury.

In spite of the general conclusions listed above, a minor anomaly arises for the 95th percentile male (Figure 11). Contrary to expectations based on the increase in head injury as a function of airbag shape observed for the 50th percentile male, the HIC levels off between airbag shapes #2 and #3. Investigation showed that this occurred because of a trade-off in the magnitude of the head g's and the duration over which these g's were sustained. Although for the belts plus bag case there is a more severe initial airbag impact with bag shape #3 than for bag shape #2 (the relative velocity of impact increases with an increase in the degree of tethering), the **duration** of the highest g forces on the head is shorter than for bag shape #2. Conversely, the maximum head g values for bag shape #2 are actually lower than for bag shape #3, but they are sustained for a longer period of time. The net result are HIC values which are essentially equivalent.

In contrast to the 50th and 95th percentile male, the 5th percentile female has slightly **lower** injury measures as tethering is increased (Figures 12 and 15). Here again, the controlling variable is the distance of her chest from the deploying airbag. As tethering is increased her chest is further from the airbag. The loss in ride-down associated with this is more than offset by the lower initial wraparound of the airbag. Therefore her injury declines slightly with increased tethering.

The effect of varying airbag shape on PFL can be seen in Figures 16 to 18. Since the seat position did not change as airbag shape was changed, the knees maintained a constant relationship with the knee bolster so that very little change in PFL was anticipated or seen. The major observation remains that the use of three-point belts in conjunction with the airbag significantly reduces the femur injuries of all of the drivers.

3.3 Conclusions: Tethering vs Restraint Type and Driver Size

Two major observations arise from the study of tethering vs restraint type and driver size.

1. The degree of tethering has a minor effect on all injury measures compared to the dominating influence of the addition of three-point belts to the airbag restraint system. The airbag alone case resulted in almost no injury changes as the airbag shape was varied through tethering.

2. When sensitivity to tethering is evidenced by higher injury measures, it occurs when three-point belts are used in conjunction with the airbag. This is most noticeable for the 50th and 95th percentile male drivers - especially the 50th percentile male HIC and the 95th percentile HIC and PCG.

These trends complement those observed from the seat position study. The controlling variable for each type of restraint system in both studies so far, especially for the three-point belts plus airbag system, has really been distance from the deploying airbag. We say this because many of the injury measures produced as the degree of tethering was varied fell perfectly between the appropriate values from the seat position study, e.g. the 50th percentile male HIC values for airbag plus belts formed a perfect progression as the distance from the airbag increased as follows: seat position #1, seat position #2 (both with airbag shape #1), seat position #2 with airbag shape #2, seat position #2 with airbag shape #3, seat position #3 with airbag shape #1.

On the other hand, most of the injury measures for the 5th percentile female, which also varied with distance, decreased as she was removed further away from the airbag. the reason for this, as stated earlier, was because as tethering is increased her chest is further from the airbag. The loss in ride-down associated with this is more than offset by the lower initial wraparound of the airbag. Therefore her injury declines slightly with increased tethering.

In summary, the restraint designer must be aware that the addition of three-point belts is far more influential to the injury measures for all driver sizes than the variations modeled due to tethering. Therefore, any optimization effort should be concentrated on the three-point belts until fine-tuning is required. At that point the degree of tethering may make a difference.

Finally, the 5th percentile female is the only driver size to exhibit a reduction in injury as the degree of tethering was increased. This means that there could be design situations where the marginal improvement for the 5th percentile female gained by narrowing the airbag through tethering may be worthwhile, particularly in light of the fact that the other two driver sizes are relatively insensitive to tethering - especially for the airbag only cases.

4.0 BAG VERSUS BAG PLUS THREE-POINT BELTS: SENSING TIME

For this portion of the study only the sensing times were varied. The sensing time as used here refers to the time that elapses after initial vehicle impact to when the inflator first begins to produce gas.

4.1 Approach

Up to this point in the study a sensing time of 25 milliseconds has been used. For this portion of the investigation the sensing time included the values of 15 milliseconds, 25 milliseconds, and 35 milliseconds which would roughly compare to sensors mounted in the radiator support, the frame rails and the firewall/steering wheel areas respectively. As before, simulations were made comparing the competing influences of airbag only versus airbag plus three-point belts.

Other variables that remain the same are: bag shape #1 (major axis radius = 11.246 inches; minor axis radius = 7.497 inches); airbag volume = 2.298 cubic feet; vent area = 2.0 square inches; and belt webbing elongation = 8.0%.

The different driver sizes were modeled in their nominal seat positions: 50th percentile male -mid-seat position; 95th percentile male - full rearward position; 5th percentile female - full forward position. These positions were not varied for this sensing time study.

4.2 Results and Discussion

4.2.1 Averages - Sensing Time, Driver Size, Restraint Type

The brief table below depicts the **averaged** effect of the addition of three-point belts to the airbag restraint when the sensing time is varied while Figures 19 through 27 show the individual effect. Generally speaking, both the 50th and 95th percentile male degree of injury varies more by the addition of belts to the restraint system than by changing the sensing time. The 5th percentile female injury, on the other hand, varies more with the changing of the sensing time.

This will be demonstrated when Figures 19 through 27 are reviewed in detail later. At this point it is sufficient to note that in the general sense the driver receives lowest injury for the airbag only case for all sensing times. This can be seen by the increase in the average per cent of injury criteria limit from 49.2% to 62.9% (ex-PFL).

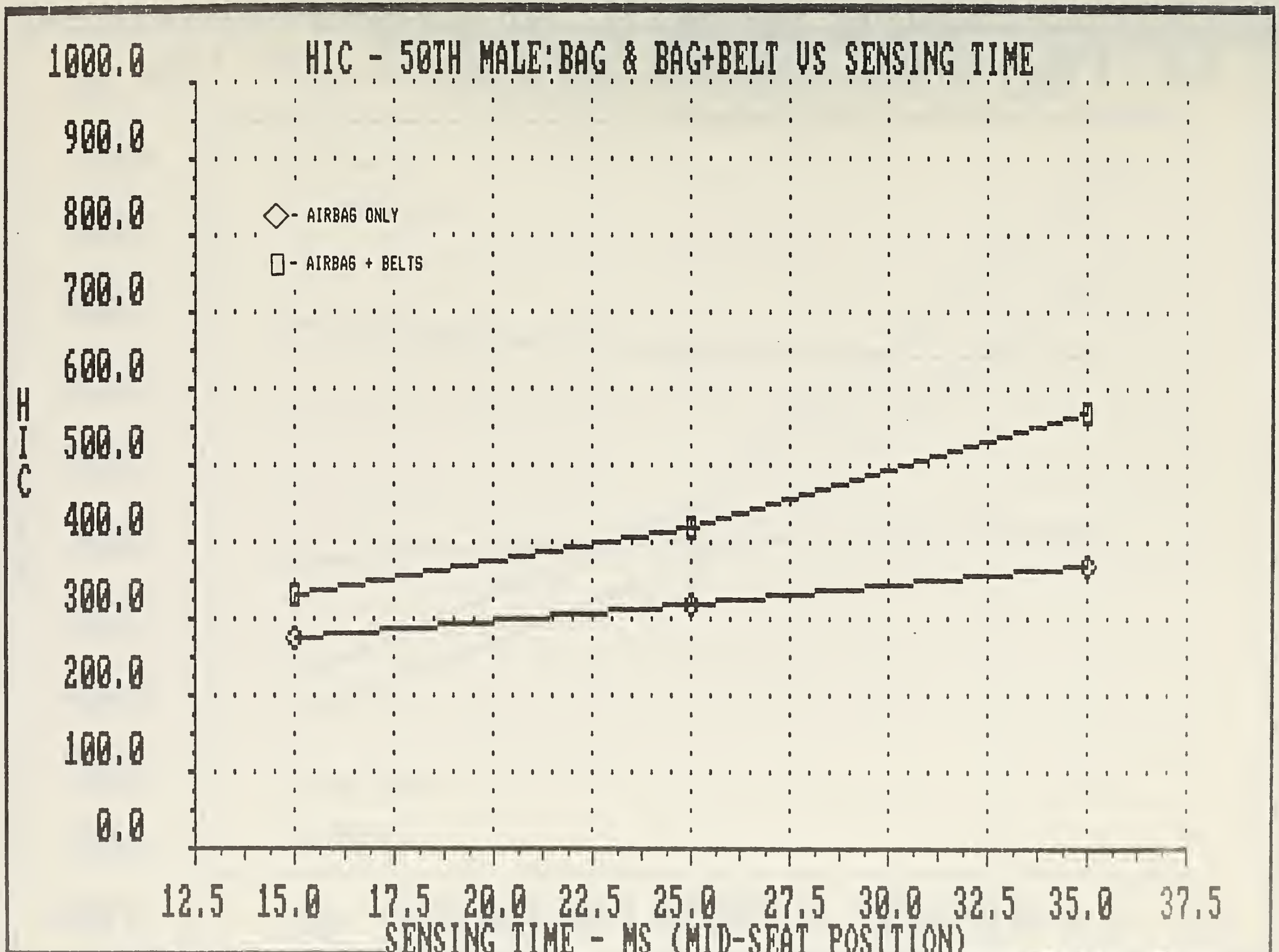

HIC - 50TH MALE:BAG & BAG+BELT VS SENSING TIME
- AIRBAG ONLY
- AIRBAG + BELTS
HIC
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
32.5
35.0
37.5
SENSING TIME - MS (MID-SEAT POSITION)

FIGURE 19

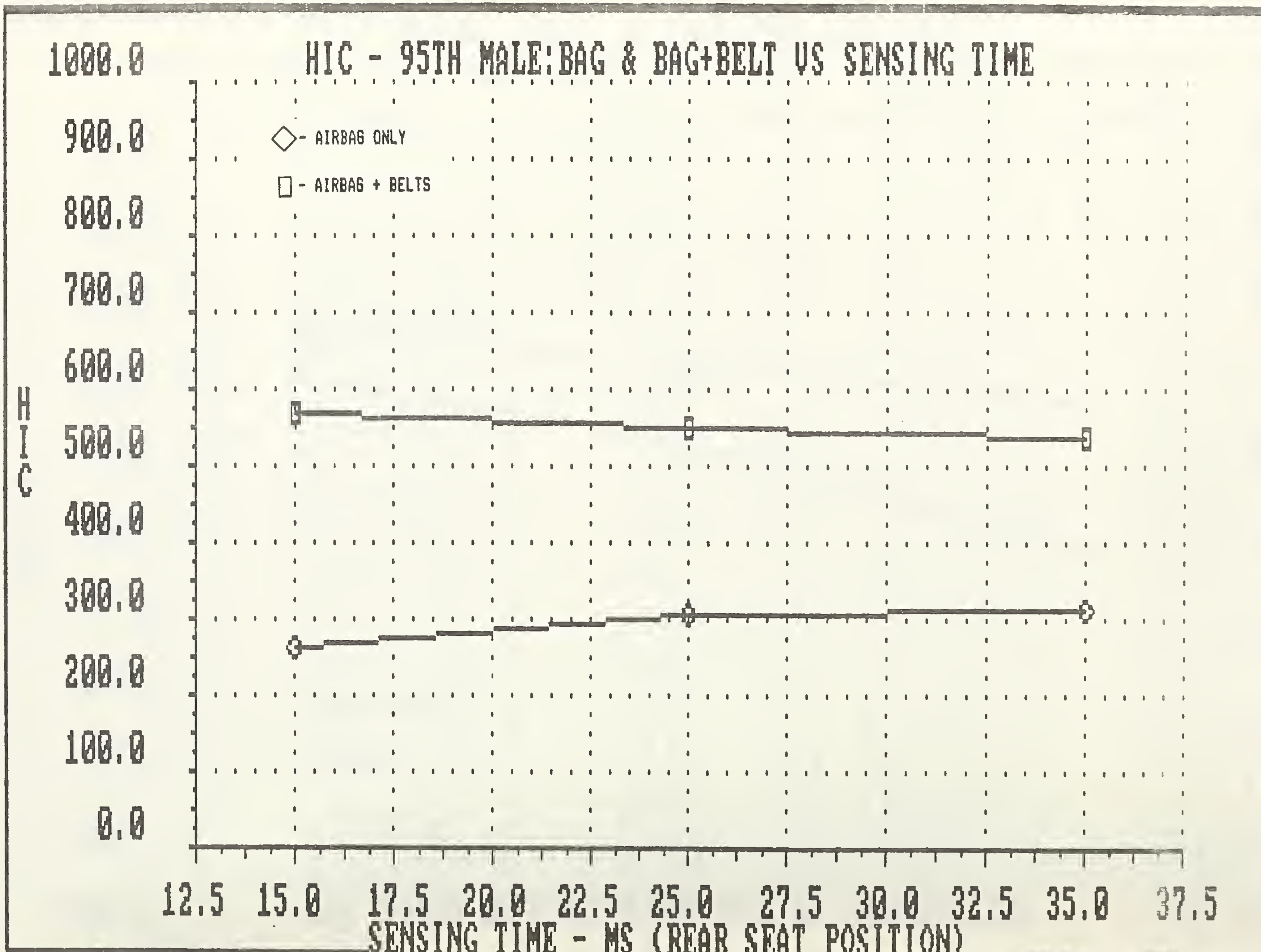

HIC - 95TH MALE:BAG & BAG+BELT VS SENSING TIME
◇- AIRBAG ONLY
□ - AIRBAG + BELTS
HIC
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
32.5
35.0
37.5
SENSING TIME - MS (REAR SEAT POSITION)

FIGURE 20

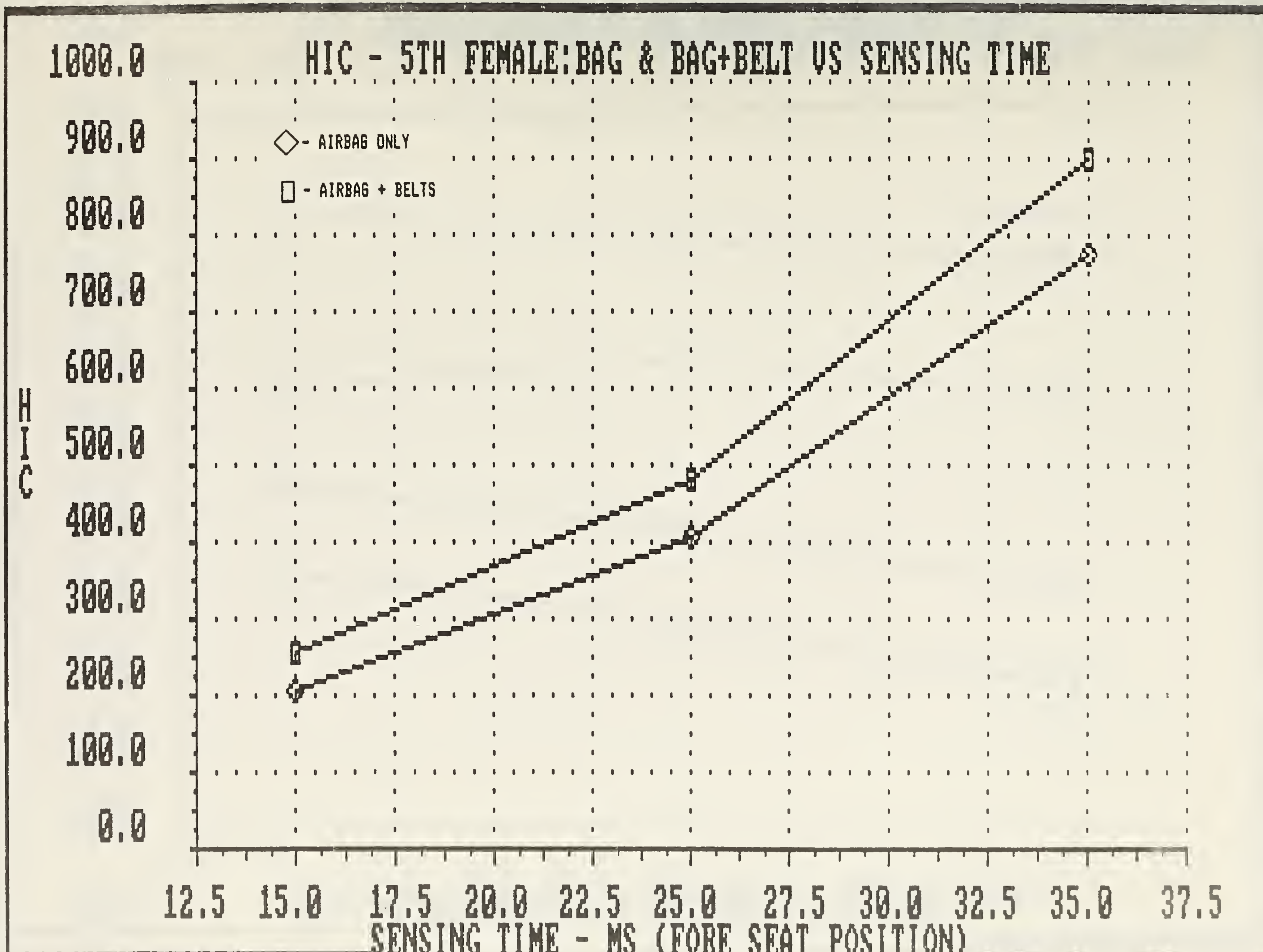

HIC - 5TH FEMALE:BAG & BAG+BELT VS SENSING TIME
- AIRBAG ONLY
- AIRBAG + BELTS
HIC
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
32.5
35.0
37.5
SENSING TIME - MS (FORE SEAT POSITION)

FIGURE 21

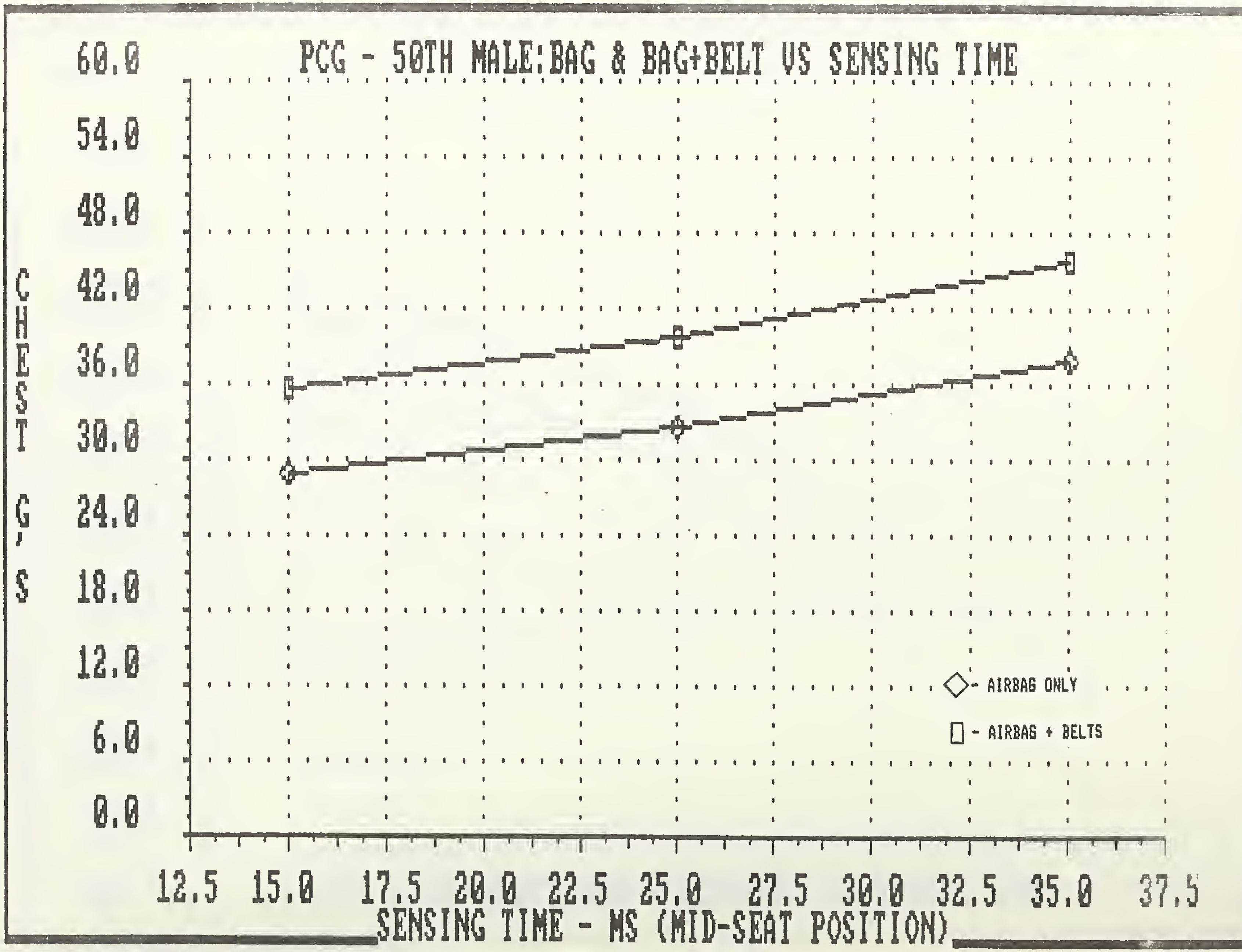

PCG - 50TH MALE:BAG & BAG+BELT VS SENSING TIME
CHEST G'S
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.0
0.0
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
32.5
35.0
37.5
SENSING TIME - MS (MID-SEAT POSITION)
- AIRBAG ONLY
- AIRBAG + BELTS

FIGURE 22

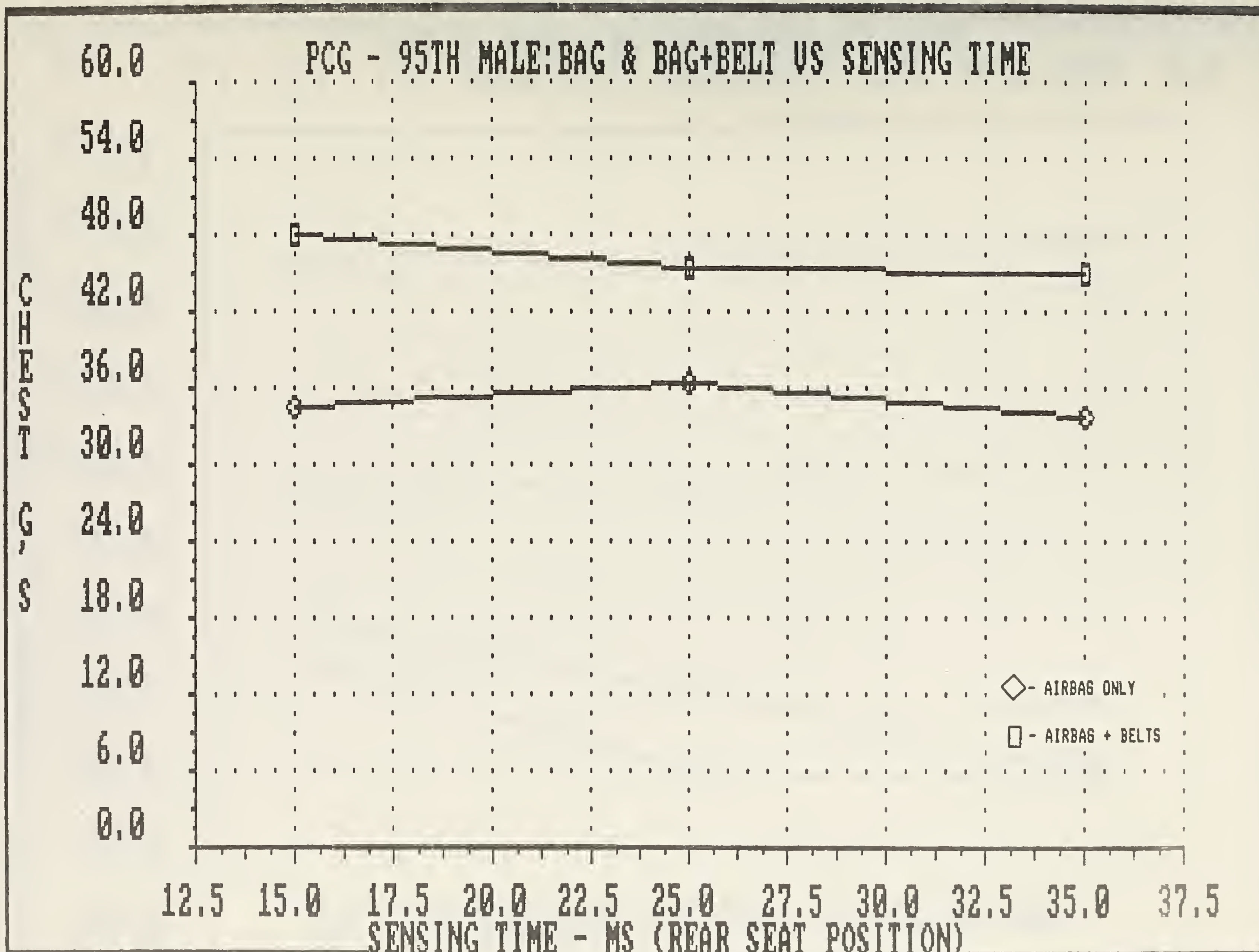

PCG - 95TH MALE:BAG & BAG+BELT VS SENSING TIME
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.0
0.0
CHEST G'S
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
32.5
35.0
37.5
SENSING TIME - MS (REAR SEAT POSITION)
◇- AIRBAG ONLY
□- AIRBAG + BELTS

FIGURE 23

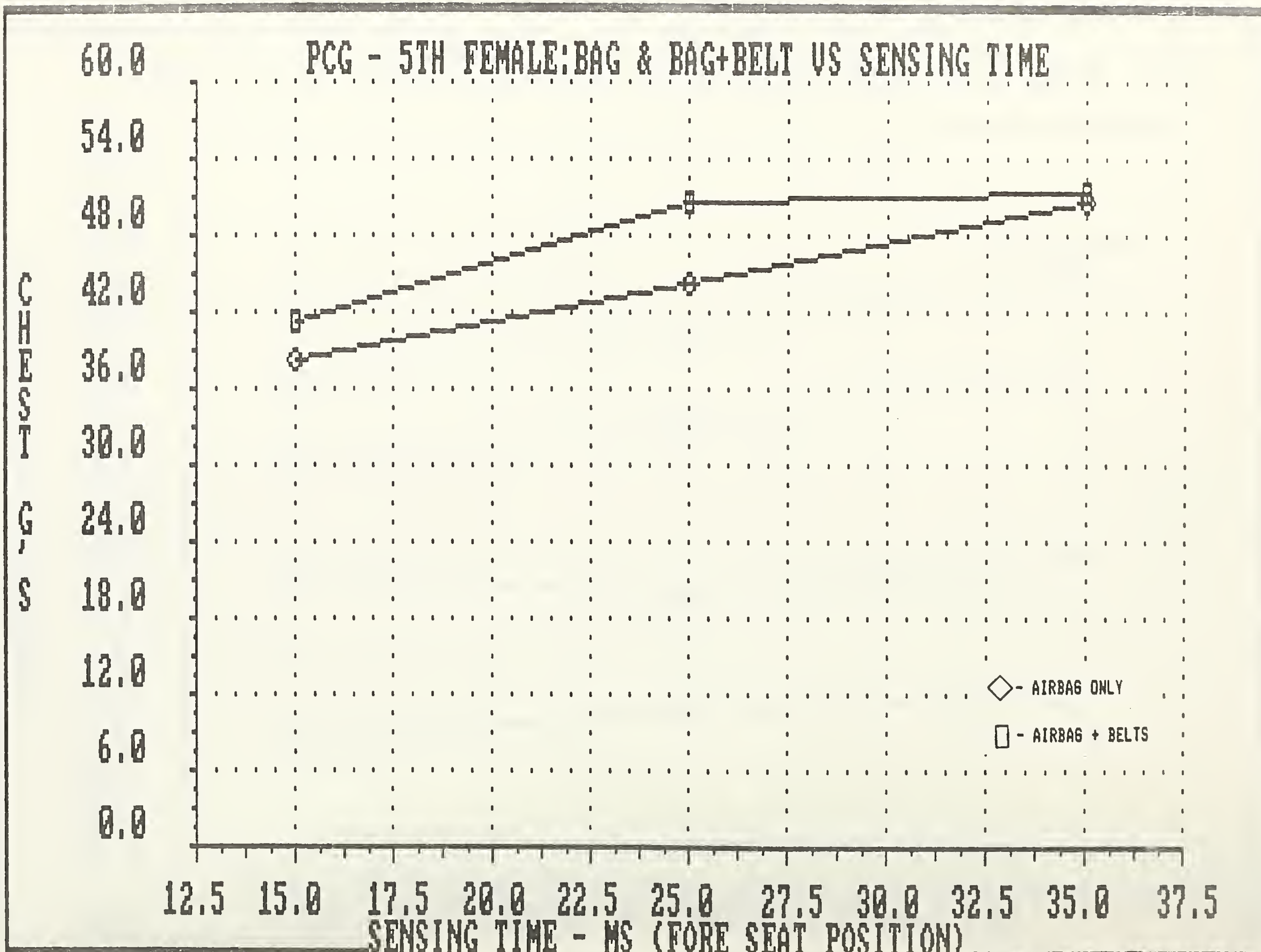

PCG - 5TH FEMALE:BAG & BAG+BELT VS SENSING TIME
CHEST G'S
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.0
0.0
12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
SENSING TIME - MS (FORE SEAT POSITION)
◇- AIRBAG ONLY
□ - AIRBAG + BELTS

FIGURE 24

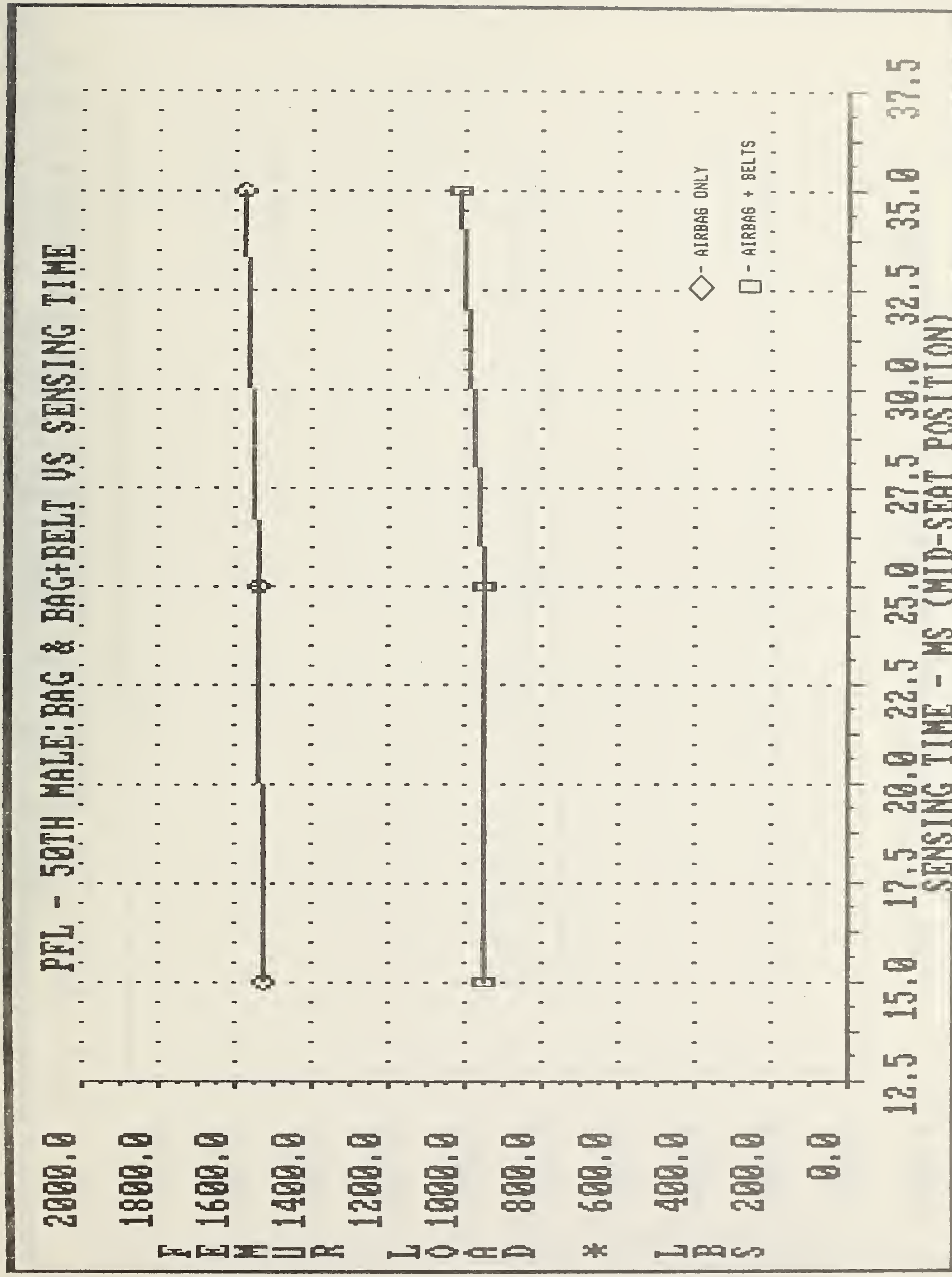

PFL - 50TH MALE; BAG & BAG+BELT VS SENSING TIME
FEMUR LOAD * LBS
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
SENSING TIME - MS (MID-SEAT POSITION)
- AIRBAG ONLY
- AIRBAG + BELTS

FIGURE 25

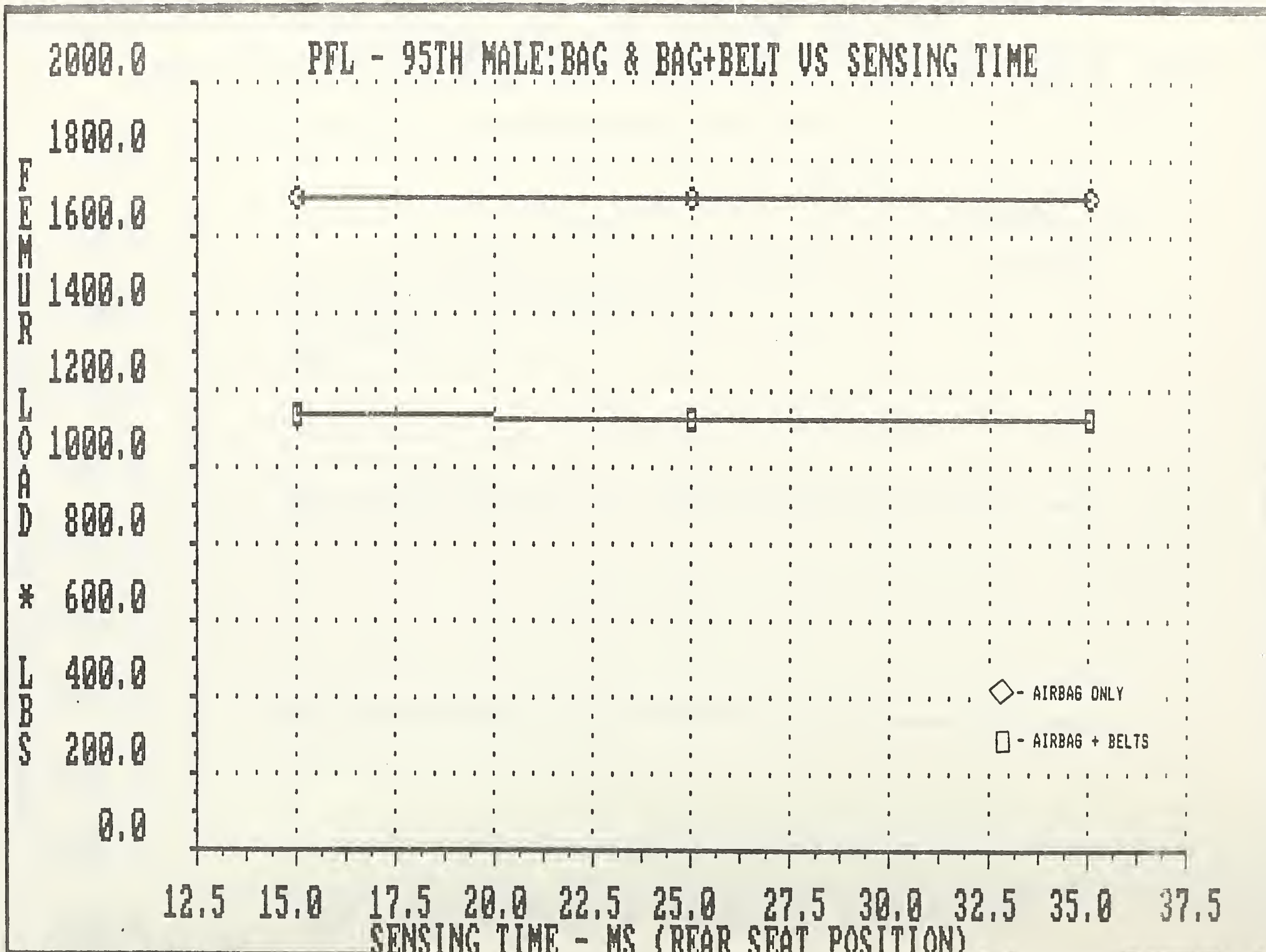

PFL - 95TH MALE:BAG & BAG+BELT VS SENSING TIME
FEMUR LOAD * LBS
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
SENSING TIME - MS (REAR SEAT POSITION)
◇ - AIRBAG ONLY
□ - AIRBAG + BELTS

FIGURE 26

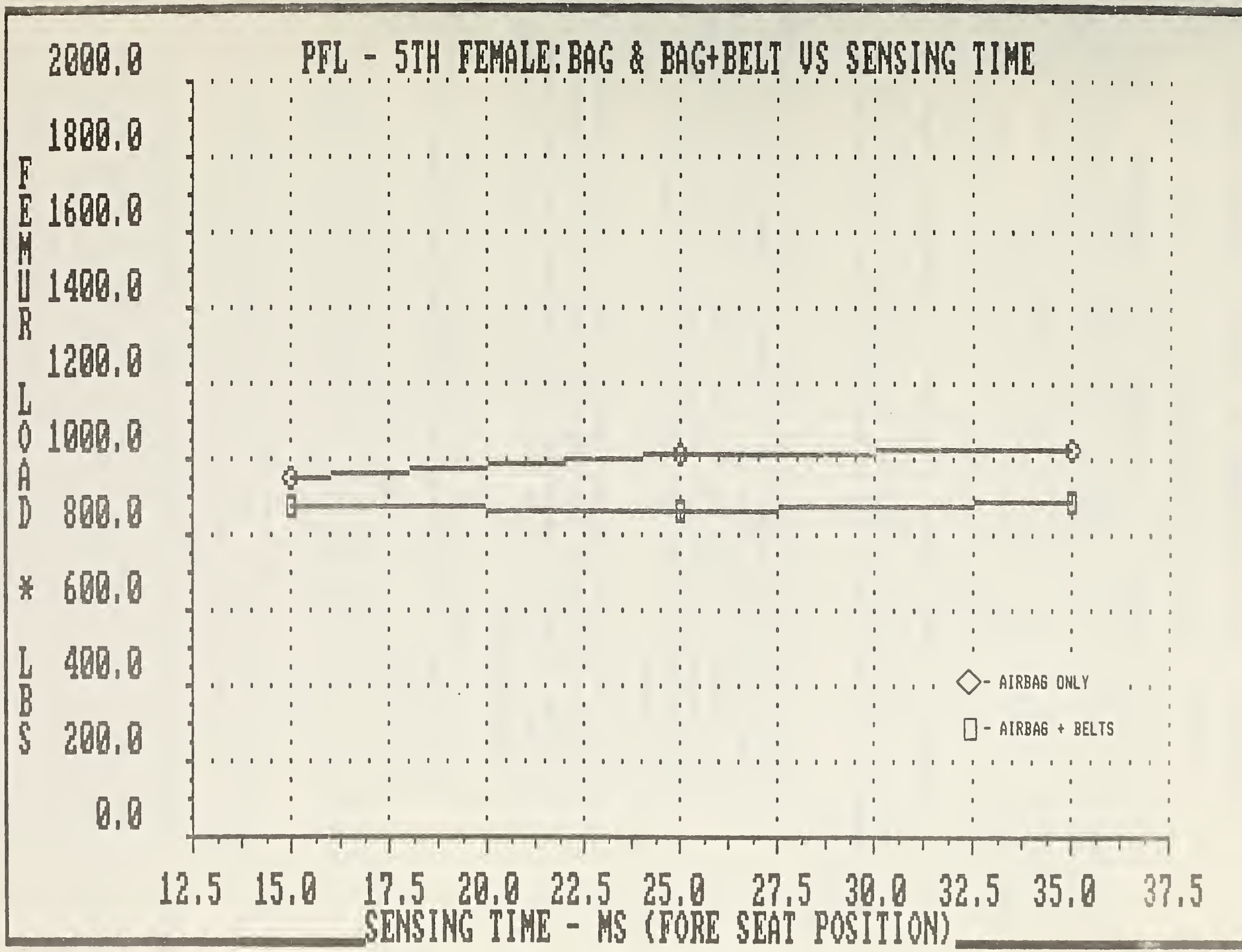

PFL - 5TH FEMALE:BAG & BAG+BELT VS SENSING TIME
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
FEMUR LOAD * LBS
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
32.5
35.0
37.5
SENSING TIME - MS (FORE SEAT POSITION)
- AIRBAG ONLY
- AIRBAG + BELTS

FIGURE 27

RESTRAINT TYPE VS PER CENT OF INJURY CRITERIA LIMIT

(AVERAGED OVER ALL SENSING TIMES AND DRIVER SIZES)

RESTRAINT	AVG HIC	AVG CRIT. %	AVG PCG	AVG CRIT. %	AVG PFL	AVG CRIT. %	AVG % EX-PFL (WITH PFL)
BAG ONLY	360	36.0	37.48	62.5	1404	62.4	49.2 (53.6)
BAG + BELTS	512	51.2	44.72	74.5	1006	44.7	62.9 (56.8)

4.2.2 Average for Each Driver Size over All Sensing Times

Table 3 presents the results of the sensing time study on the basis of driver size. These results can be summarized as follows:

1. HIC - for the airbag plus belts restraint type, the 95th percentile male exhibits a large increase in HIC - growing by 25.6% from 29.5% to 55.1% of criteria limits- as compared to the airbag only case. This is true over the range of sensing times studied. Both the 50th and 5th percentile drivers demonstrate much smaller increases.

2. PCG - all of the driver sizes incur a higher chest injury when belts are added to the airbag restraint system; however the effect is greatest for the larger drivers. This is true over the entire range of sensing times studied.

3. PFL - as before, when belts are used in conjunction with the airbag, the PFL for all three driver sizes decreases.

TABLE 3

SENSING TIME STUDY

RESTRAINT TYPE VS PER CENT OF INJURY CRITERIA LIMIT

(FOR EACH DRIVER SIZE AVERAGED OVER ALL SENSING TIMES)

RESTRAINT	AVG HIC	AVG CRIT. %	AVG PCG	AVG CRIT. %	AVG PFL	AVG CRIT. %	AVG % EX-PFL (WITH PFL)
BAG ONLY							
50TH MALE	321	32.1	33.10	55.2	1546	68.7	43.6 (52.0)
95TH MALE	295	29.5	34.93	58.2	1699	61.8	43.8 (49.8)
5TH FEMALE	464	46.4	44.40	74.0	993	56.8	60.2 (59.1)
AVERAGE		36.0		62.5		62.4	49.2
BAG + BELTS							
50TH MALE	439	43.9	40.36	67.3	970	43.1	55.6 (51.4)
95TH MALE	551	55.1	46.10	76.8	1130	41.1	66.0 (57.7)
5TH FEMALE	547	54.7	47.72	79.5	873	50.0	67.1 (61.4)
AVERAGE		51.2		74.5		44.7	62.9

4.2.3 Effect of Sensing Time

As discussed above, the addition of belts to the airbag restraint differs among the driver sizes as the sensing time is changed. The most accurate understanding of this phenomena is obtained through Figures 19 through 27.

Figures 19 through 24 show the response of the HIC and PCG for each of the three driver sizes. The effect of sensing time on HIC in Figure 21 for the 5th percentile female is dramatic.

For the airbag alone restraint type the HIC increases from a value of 207 at a sensing time of 15 ms to a HIC of 777 at 35 ms. sensing time. A similar increase is seen for the airbag plus belts case - from a HIC of 258 to 901 over the same sensing time range. This demonstrates that the 5th percentile female is more affected by changes in sensing time than the addition of belts to the restraint system. The reason for this is that the 5th percentile female is already seated fairly close to the airbag when it deploys. As the sensing time is increased, she moves even closer to the airbag at the time of deployment. This causes a very high degree of initial bag wraparound with high bag pressures with concomitantly higher injury. This injury is more pronounced for HIC (Figure 21) than PCG (Figure 24) because HIC is a function of head g's to the 2.5 power.

The converse is true for the 95th percentile male. Due to his more rearward seated position and higher mass, he is affected more by the restraint type than by sensing time. This is shown by Figures 20 and 23.

The 50th percentile male falls in between - not only in size but also in the effect sensing time and restraint type have on injury. Note from Figures 19 and 22 that both the HIC and PCG increase **both** with increasing sensing time and the addition of belts to the restraint system.

4.3 Conclusions: Sensing Time vs Restraint Type and Driver Size

Generally, all of the studies so far discussed have shown that the addition of belts to the airbag restraint system has a greater effect on injury than variations in either seat position or airbag shape. The only exception has been that the 5th percentile female injury measures may respond more to changes in her position relative to the airbag than to the addition of belts.

This sensing time portion of the study generally follows this pattern although sensing time has shown to have a significant effect as well; i.e.:

1. 5th percentile female - HIC and PCG - a major increase in injury occurs as sensing time is increased. This is true for both restraint types.

2. 50th percentile male - PCG - a similar degree of sensitivity to sensing time exists for both restraint types. Here the effect on chest injury is greatest.

3. 95th percentile male - HIC and PCG - there is basically no change in the injury measures for this driver size as a function of sensing time (see Figures 20 and 23). The addition of belts to the airbag has far more effect on injury than sensing time.

Therefore, this data indicates that the shorter sensing time produces lower injury measures. Longer sensing times allow both the 50th and 5th percentile drivers to become too close to the airbag as it deploys, and they incur higher injuries as they absorb the energy and encounter the reduced volumes and higher pressures associated with the deploying airbag.

5.0 BAG VERSUS BAG PLUS THREE-POINT BELTS: PRETENSIONING

Pretensioning refers to the sensor-triggered tightening of the belts against the body of the driver prior to significant forward movement. The degree of tightening, or tension against the body, can be varied as a design factor. We have found that the greatest benefit of pretensioning occurs for belt only cases. Here the belts must react all the driver loads so that pretensioning of the belts has a greater overall effect on driver injury.

Pretensioning reduces injuries because it causes closer coupling of the driver and the vehicle by reducing the movement of the occupant relative to the automobile interior which, in turn, reduces his relative velocity so that a greater proportion of the total driver kinetic energy is absorbed in ride-down.

5.1 Approach

Fixed variables include: 25 millisecond sensing time; untethered airbag (airbag shape #1); 2.0 square inch vent area; 8.0% belt webbing elongation characteristics; and each driver size in their respective nominal seat position (see section 4.1).

To complement the simulations made prior to this pretensioning study (i.e., airbag only and airbag plus belts without pretensioning), three different degrees of pretensioning were studied. In Figures 28 through 30, both the prior work just mentioned and the special pretensioning runs are presented together for comparison.

5.2 Results and Discussion

The performances of five restraint options for this pretensioning study are presented in Figures 28 through 30. The identification of each restraint is as follows:

1. Restraint Option #1 - airbag only

2. Restraint Option #2 - airbag plus three-point belts with no pretensioning

3. Restraint Option #3 - airbag plus three-point belts with low pretensioning

4. Restraint Option #4 - airbag plus three-point belts with medium pretensioning

5. Restraint Option #5 - airbag plus three-point belts with high pretensioning.

Table 4 below shows two things:

1. the amount of interference in the lap and shoulder after

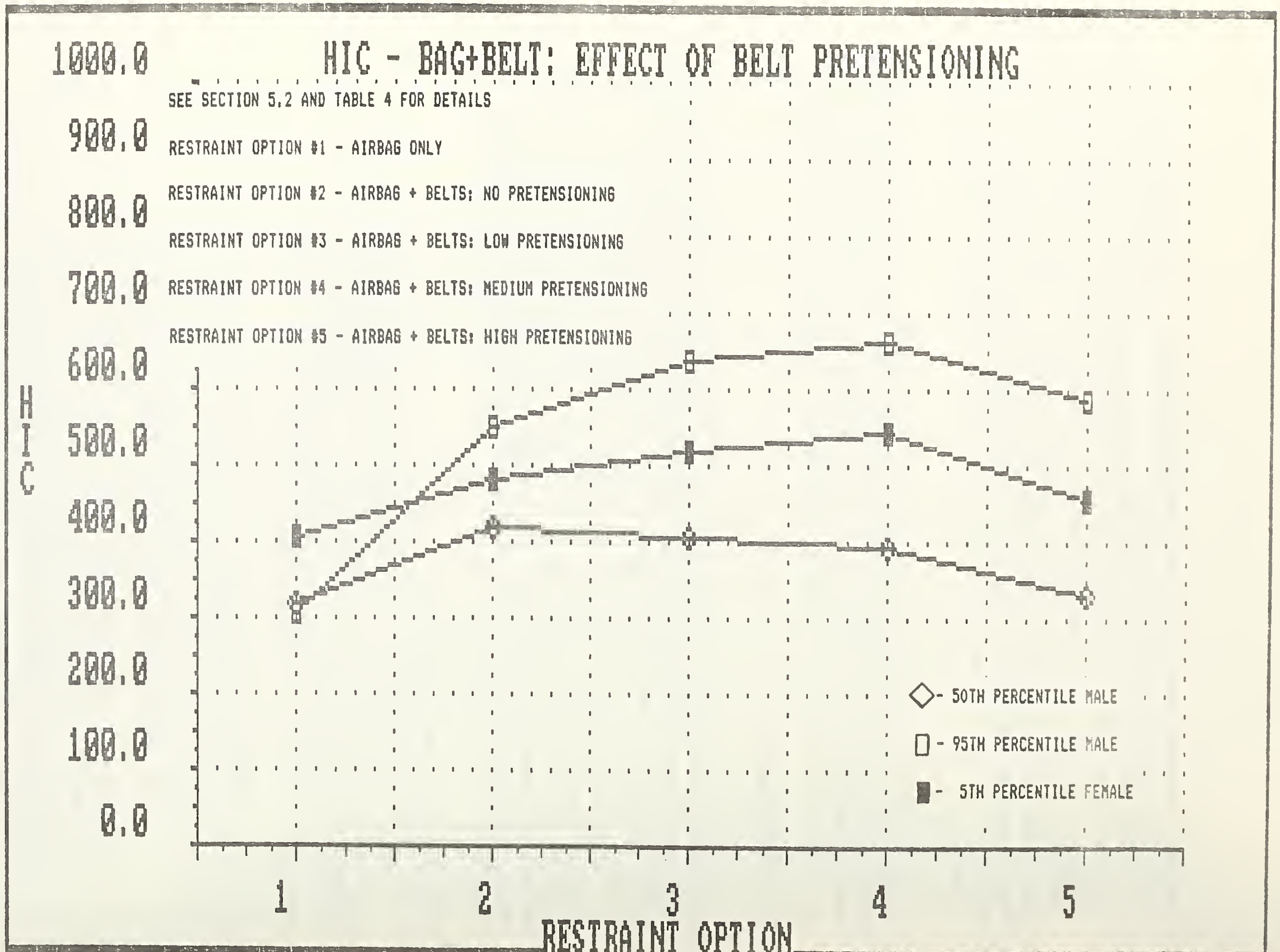

HIC - BAG+BELT: EFFECT OF BELT PRETENSIONING
SEE SECTION 5.2 AND TABLE 4 FOR DETAILS
RESTRAINT OPTION #1 - AIRBAG ONLY
RESTRAINT OPTION #2 - AIRBAG + BELTS: NO PRETENSIONING
RESTRAINT OPTION #3 - AIRBAG + BELTS: LOW PRETENSIONING
RESTRAINT OPTION #4 - AIRBAG + BELTS: MEDIUM PRETENSIONING
RESTRAINT OPTION #5 - AIRBAG + BELTS: HIGH PRETENSIONING
HIC
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
1
2
3
4
5
RESTRAINT OPTION
- 50TH PERCENTILE MALE
- 95TH PERCENTILE MALE
- 5TH PERCENTILE FEMALE

FIGURE 28

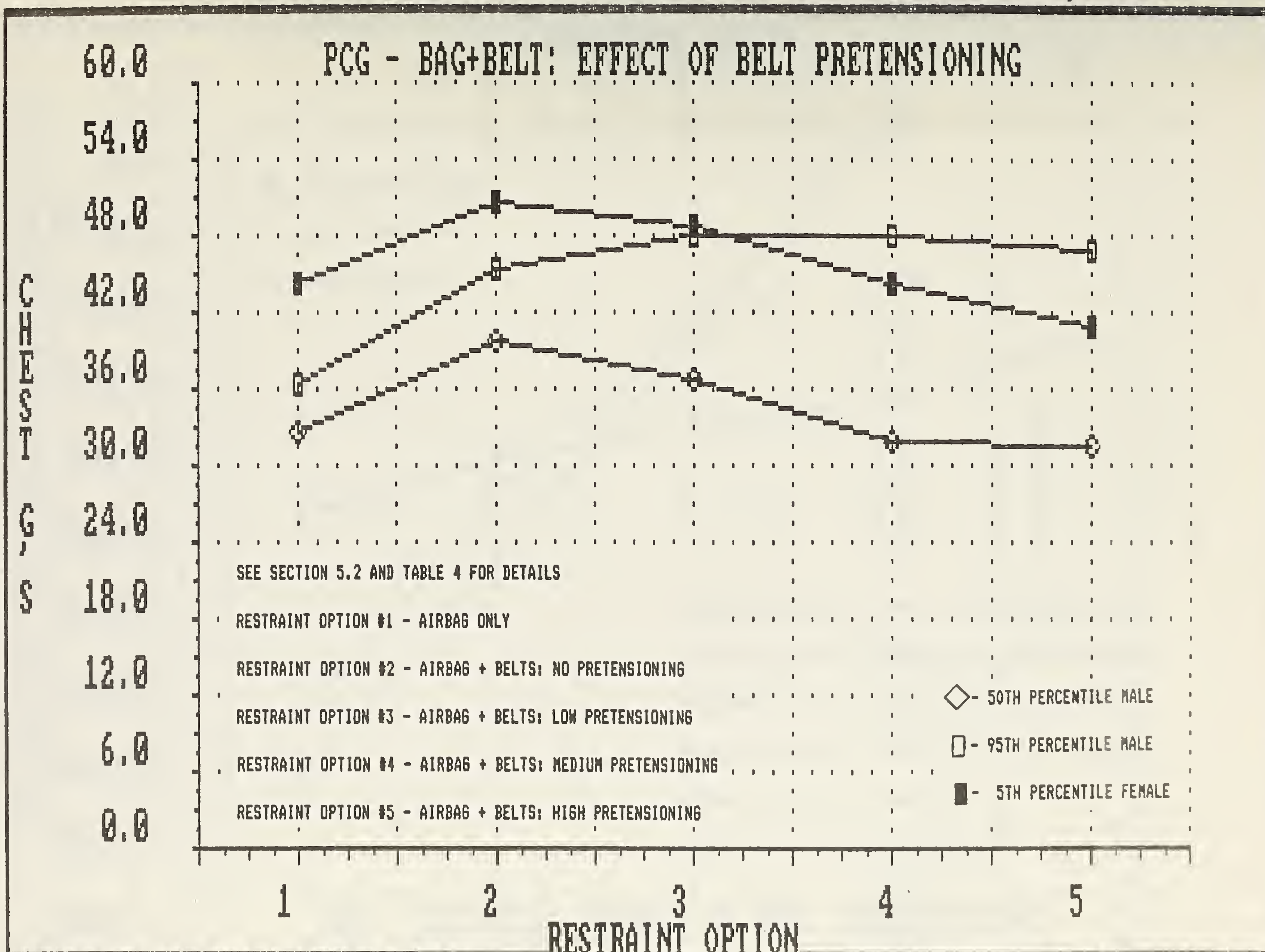

PCG - BAG+BELT: EFFECT OF BELT PRETENSIONING
CHEST G'S
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.0
0.0
SEE SECTION 5.2 AND TABLE 4 FOR DETAILS
RESTRAINT OPTION #1 - AIRBAG ONLY
RESTRAINT OPTION #2 - AIRBAG + BELTS: NO PRETENSIONING
RESTRAINT OPTION #3 - AIRBAG + BELTS: LOW PRETENSIONING
RESTRAINT OPTION #4 - AIRBAG + BELTS: MEDIUM PRETENSIONING
RESTRAINT OPTION #5 - AIRBAG + BELTS: HIGH PRETENSIONING
- 50TH PERCENTILE MALE
- 95TH PERCENTILE MALE
- 5TH PERCENTILE FEMALE
1
2
3
4
5
RESTRAINT OPTION

FIGURE 29

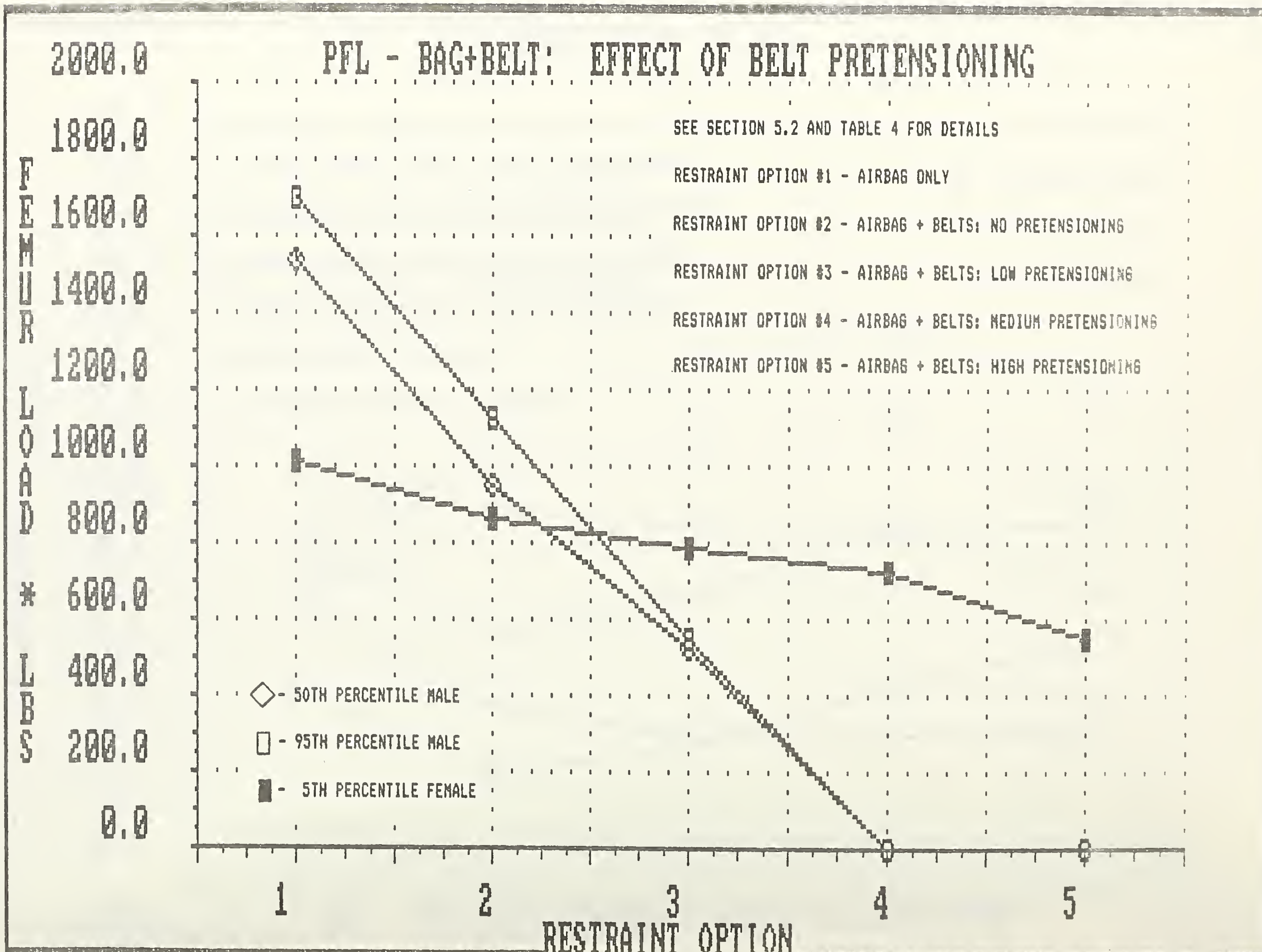

PFL - BAG+BELT: EFFECT OF BELT PRETENSIONING
SEE SECTION 5.2 AND TABLE 4 FOR DETAILS
RESTRAINT OPTION #1 - AIRBAG ONLY
RESTRAINT OPTION #2 - AIRBAG + BELTS: NO PRETENSIONING
RESTRAINT OPTION #3 - AIRBAG + BELTS: LOW PRETENSIONING
RESTRAINT OPTION #4 - AIRBAG + BELTS: MEDIUM PRETENSIONING
RESTRAINT OPTION #5 - AIRBAG + BELTS: HIGH PRETENSIONING
FEMUR LOAD * LBS
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
- 50TH PERCENTILE MALE
- 95TH PERCENTILE MALE
- 5TH PERCENTILE FEMALE
1
2
3
4
5
RESTRAINT OPTION

FIGURE 30

pretensioning is applied and,

2. the resulting tensile force in the lap and torso belts for each pretensioning case (restraint options #3, #4, and #5).

PRETENSIONING STUDY

PRETENSIONING INTERFERENCE AND APPLIED FORCE

DRIVER SIZE	LAP BELT INTERFER- ENCE, IN.	LAP BELT PRETENSION POUNDS	TORSO BELT INTERFER- ENCE, IN.	TORSO BELT PRETENSION POUNDS
50TH MALE				
OPTION #3	0.5	96.0	1.0	511.0
OPTION #4	1.0	291.0	2.0	938.0
OPTION #5	1.5	423.0	3.0	1461.0
95TH MALE				
OPTION #3	0.5	136.0	1.0	465.0
OPTION #4	1.0	301.0	2.0	1025.0
OPTION #5	1.5	454.0	3.0	1560.0
5TH FEMALE				
OPTION #3	0.5	91.0	1.0	497.0
OPTION #4	1.0	265.0	2.0	918.0
OPTION #5	1.5	404.0	3.0	1408.0

Interference refers to the sum of the distance that the driver's lap or torso is compressed and the belt stretch in the same direction immediately after the pretensioner is activated. There is a direct relationship between this distance of compression and the force required to accomplish it for each driver size.

As shown by Figures 28 through 30 and Table 4, airbag only case generally resulted in lower injury than when belts of any kind - pretensioned or not - were added. This was true for both HIC (Figure 28) and PCG (Figure 29). The only exception was for PCG with restraint option #5. Here when the highest degree of pretensioning was used with the 50th and 5th percentile drivers the PCG's were lower than in any other case. However, the improvement is marginal and the pretensioning forces very high.

As expected the femur injury (Figure 30) continued to diminish as the influence of the belts was allowed to increase, i.e. as pretensioning increased. For PFL the 5th percentile female demonstrated much less decrease with successively greater pretensioning due to her relatively close proximity to the knee bolster. Even though these figures suggest that continued increase of pretensioning result in ever lower femur loads, this would be unreasonable because the interference and applied belt forces would become excessive.

5.3 Conclusions: Pretensioning vs Restraint Type and Driver Size

The effect of pretensioning may be summarized as follows:

1. The greatest benefit of pretensioning occurs for belt only cases which were not the subject of this study. Here the belts must react all the driver loads so that pretensioning of the belts has a greater overall effect on driver injury. However, when three-point belts are added to airbags, we see no appreciable reduction in injury - in fact, the reverse is usually true.

2. HIC - (Figure 28) only the 50th percentile male had any benefit at all from pretensioning (compare the HIC for option #2 and #3). However, the amount of pretensioning required to significantly affect injury was so large that we consider it impractible.

   For both the 95th and 5th percentile drivers pretensioning caused their HIC to increase prior to any subsequent decrease. The reason for this is that HIC increases with pretensioning at first because the reduced effect of the airbag on head support overwhelms the increase in ride-down obtained. The increased belt restraint forces allow the head to gain more rotational energy since the torso is stabilized sooner by pretensioning. As pretensioning is increased still further, the increased ride-down benefit begins to overwhelm the lack of head restraint.

3. PCG - (Figure 29) Here the results are similar to the HIC conclusions drawn above and for mostly the same reasons. Airbag interaction is significantly reduced for high belt pretensioning because of a high degree of early restraint. This quick restraining action applied to the chest which is achieved by pretensioning results in a large percentage of the driver energy being absorbed in ride-down and a low coupling with the airbag with injury measures strongly a function of belt forces.

   For lower degrees of pretensioning, both the belts and airbag are still active on the chest so that the forces are relatively high.

4. PFL - (Figure 30) all three driver sizes show reduction in femur injury as pretensioning increases. The reduction is dramatic for both the 50th and 95th percentile drivers. It is still significant, however, for the 5th percentile female. The degree of reduction for her is less because of her initial proximity to the knee bolster. Conversely, the greater initial distance for the two male drivers permits the maximum pretensioning to prevent any contact with the knee bolster at all.

5. As can be seen from a review of the preceding discussion, the initial seat position is a significant factor in the response to pretensioning. The HIC and PCG for the 95th percentile male are not aided by the degrees of pretensioning studied because of his large distance from the airbag and his greater mass. Only a minor improvement results for the 5th percentile female since she is so close to the airbag and this adds but another force to contend with. The 50th percentile male benefits some because his distance allows a positive synergy to exist between the restraint of the pretensioning and that of the airbag. However, for reasonable pretensioning values, the effect on injury reduction is so small that it not an important design factor.

   For both the 95th and 5th percentile drivers the initial pretensioning must be so great to overcome the complicating factors associated with their respective seat positions with respect to the airbag, that pretensioning can be eliminated as a design factor that shows much promise in injury reduction when the airbag is a part of the total restraint system.

6. The more critical injuries (head and chest) are not reduced through the use of belt pretensioning when it is used in conjunction with an airbag. A more positive response would be seen in belt only designs. The marginal improvement in the cases noted above does not justify the added expense of the pretensioning system when the car is equipped with airbags.

6.0 BAG VERSUS BAG PLUS THREE-POINT BELTS: WEBBING ELONGATION

Webbing elongation refers to the design characteristic that controls the amount that the belts will stretch under a given load - usually 2500 pounds. For example: an 80.0 inch torso belt with a webbing elongation characteristic of 8.0% will stretch 6.4 inches under a load of 2500 pounds. This segment of the study investigated the sensitivity of driver injuries to varying webbing types.

6.1 Approach

All of the simulations prior to this utilized a stretch characteristic of 8.0% for a load of 2500 pounds. Three additional webbing elongation factors were considered in this portion of the study: 4.0%, 12.0% and 16.0% - all under a 2500 pound load. Simulations were made for each driver size in his respective position. Other parameters that did not vary were: airbag shape #1; vent area = 2.0 square inches; sensing time = 25 ms; and no pretensioning.

6.2 Results and Discussion

Figures 31 through 33 depict the influence that various webbing stretch characteristics have on driver injuries. Generally, the effect is small. The most pronounced differences occur for 95th percentile male HIC and 50th and 95th percentile male PFL. More detailed analysis of these figures shows the following:

1. HIC - (Figure 31) the 95th percentile's greater distance from the airbag allows him to respond most to the changes in belt elongation. His HIC decreases from 608 at 4.0% stretch to 488 at 16.0% stretch - a 20% decrease. This decrease occurs because the more flexible belt (16.0%) has a lower tension for a given forward movement so that when head contact with the airbag is made, the head rotational velocity is relatively low. The other two driver sizes are close enough to the airbag to experience no significant changes as the influence of the airbag predominates.

2. PCG - (Figure 32) the 95th percentile male responds with a small increase in chest injury as the belt restraining force is loosened - just as he did when the belts were effectively tightened in the pretensioning study. This apparent contradiction serves to illustrate the tenuous relationship between the airbag and belts. The chest g increase from pretensioning occurs because the belts exerted a higher force on the chest prior to airbag impact. (The pretensioning was not high enough to maximize initial restraint and ride-down.) Now, when the stretch characteristic is increased, the PCG rises because the softer restraint from the belts results in a

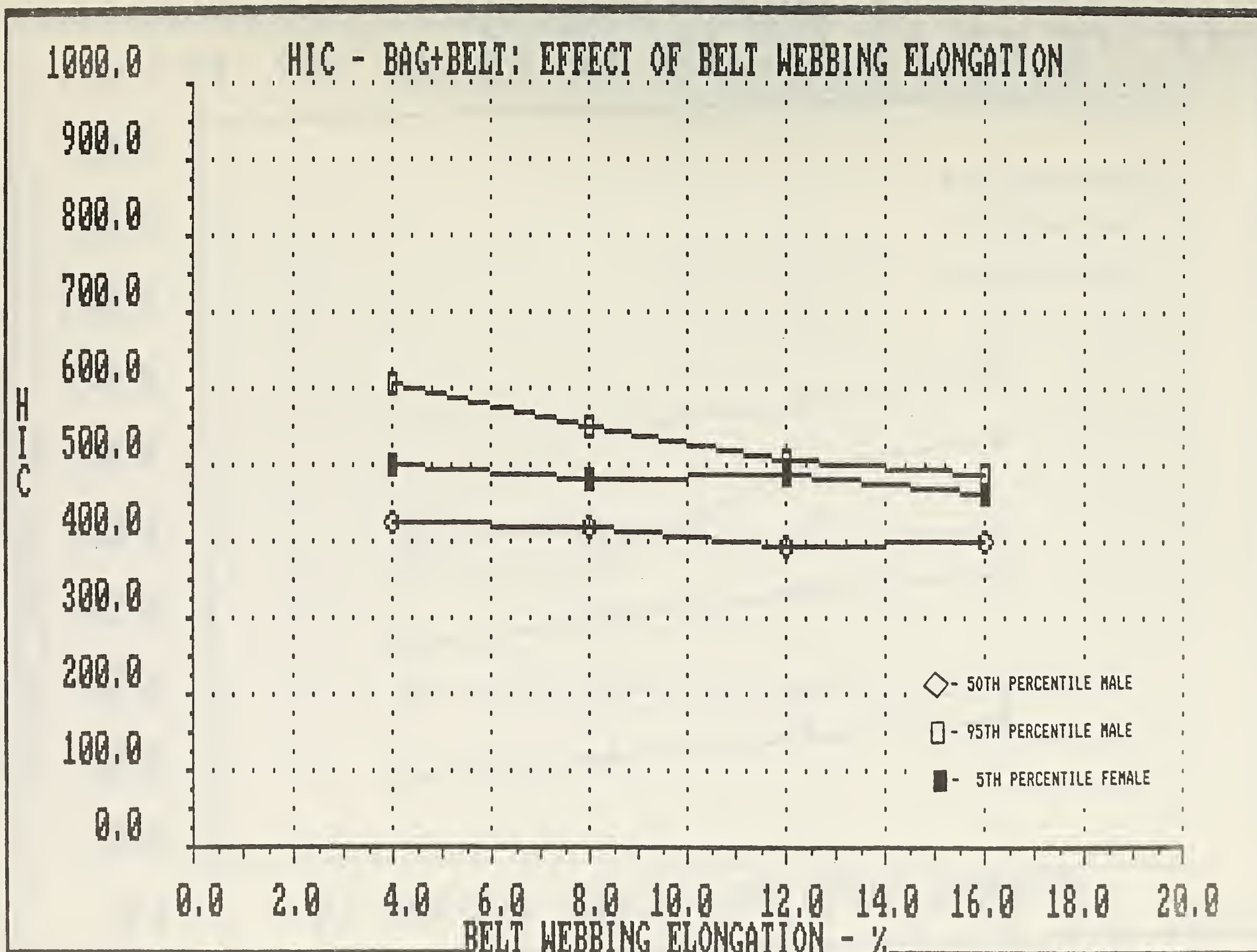
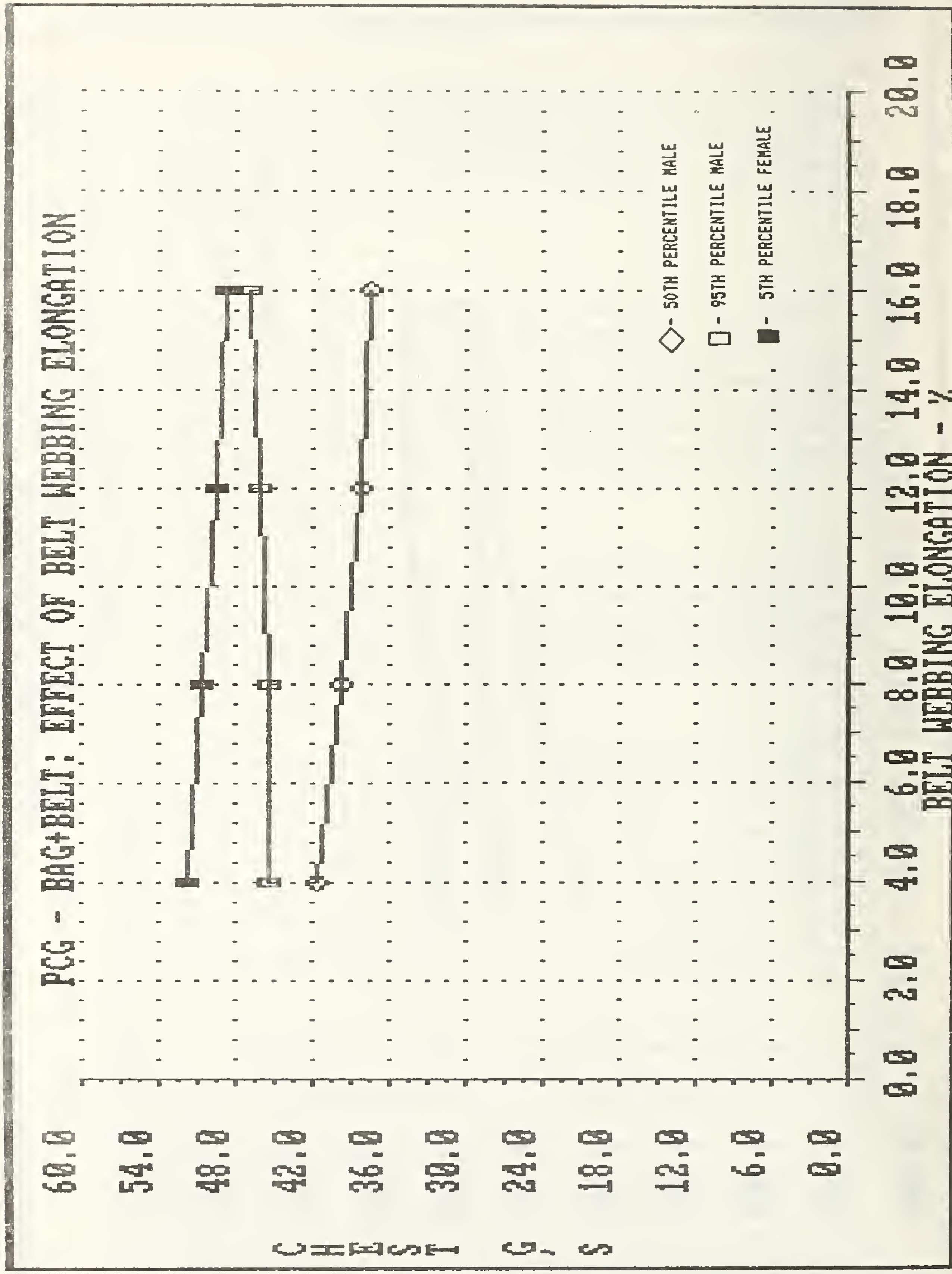

HIC - BAG+BELT: EFFECT OF BELT WEBBING ELONGATION
HIC
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
BELT WEBBING ELONGATION - %
- 50TH PERCENTILE MALE
- 95TH PERCENTILE MALE
- 5TH PERCENTILE FEMALE

FIGURE 31


PCG - BAG+BELT: EFFECT OF BELT WEBBING ELONGATION
CHEST G'S
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.0
0.0
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0 20.0
BELT WEBBING ELONGATION - %
- 50TH PERCENTILE MALE
- 95TH PERCENTILE MALE
- 5TH PERCENTILE FEMALE

FIGURE

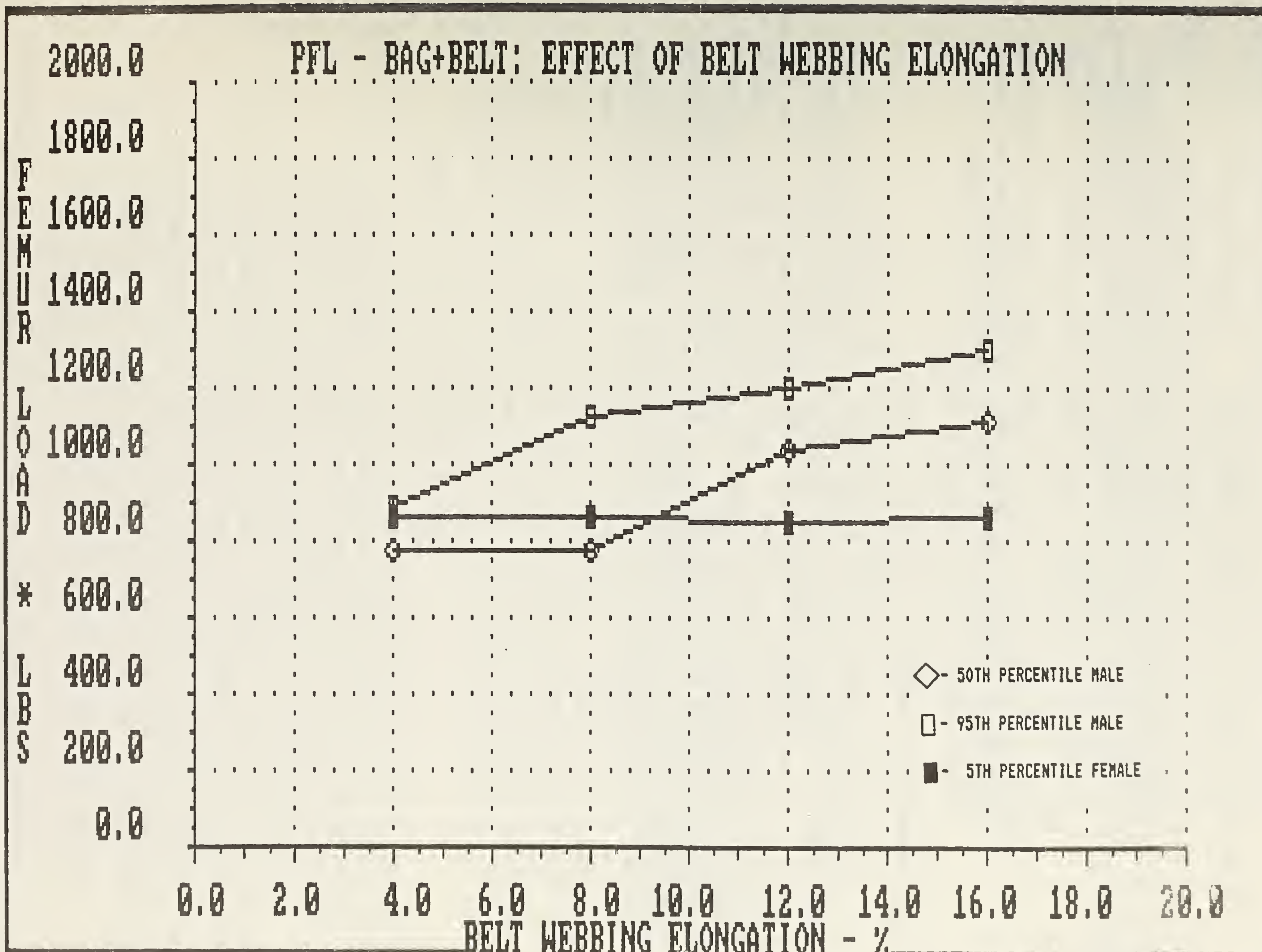

PFL - BAG+BELT: EFFECT OF BELT WEBBING ELONGATION
FEMUR LOAD * LBS
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
BELT WEBBING ELONGATION - %
- 50TH PERCENTILE MALE
- 95TH PERCENTILE MALE
- 5TH PERCENTILE FEMALE

FIGURE 33

harder impact with the airbag and less ride-down due to the lack of initial restraint.

The 50th and 5th percentile drivers demonstrate a slight decline in chest g's with an increase in webbing elongation since they are close enough that the softer belts exert less of a chest force before airbag contact is made. This means the softer belts allow the airbag to predominate and move more toward the airbag only case.

3. PFL - (Figure 33) the increases seen here for the 50th and 95th percentile males are because the softer belt restraint results in a harder impact and deeper penetration into the knee bolster.

6.3 Summary of Webbing Elongation Study

The trends observed here serve to confirm those that arose in the other parts of this airbag versus airbag plus three-point belt study - particularly the sensitivity to distance from the airbag. If we neglect femur load, the preferred elongation based just on this work would be 14% - the highest simulated. However if we give femur load a full weight, we would probably recommend keeping the elongation at 8.0%. In this case, increasing elongation beyond 8.0% compromises the PFL for the 50th and 95th percentile drivers even though minor head and chest injury reductions are possible for the 50th and 5th percentile drivers.

7.0 STUDY SUMMARY: BAG VERSUS BAG PLUS THREE-POINT BELTS

The goal of this study was to determine the advantages and disadvantages of airbags and airbags plus three-point belts as they affect driver injury measures **in frontal impacts.** Five major elements of automotive restraint design have been investigated:

1. Driver seat position - three seat positions

2. Airbag tethering - three airbag shapes (shape modification accomplished through tethering)

3. Sensing time - three sensing times

4. Pretensioning of three-point belts - three different degrees of belt pretensioning

5. Belt webbing elongation characteristics - four different belt webbing stretch characteristics

Three driver sizes were subjected to 35 mph frontal barrier crashes in a compact car. These driver sizes were: 50th percentile male; 95th percentile male; and 5th percentile female. The conclusions drawn below are strictly applicable to the vehicle, restraint environment and driver seated positions assumed for this study. It remains for future work to ascertain whether these conclusions are general or specific to the vehicle and restraint system parameters assumed as constant for this study. The conclusions listed below are the most important conclusions we were able to draw from the study. For more detailed conclusions, we refer the reader to the conclusions listed at the end of each of the five study area sections.

The primary conclusions are:

1. Airbag versus airbag plus three-point belts - almost in every case, the restraint type exhibiting lowest head and chest injury was the airbag acting alone as the restraint system. Throughout this study the primary injury measures (HIC and PCG) were significantly increased when belts were used in conjunction with an airbag restraint system. In many of the five specific areas investigated, the injury measures changed little over the range of variable values investigated - particularly for the airbag only restraint type. When there was a pronounced trend to these variables, it was almost always for the airbag plus belts restraint type.

   Conclusion #1 also applies to all of the ensuing conclusions.

2. Seat position - distance from the deploying airbag was consistently a major factor in the resulting driver injury measures. Basically, the 5th percentile female

fares much better as she is able to move rearward away from airbag. The forward-most seat position subjects her to serious forces from deploying airbag. Conversely, both the 50th and the 95th percentile males benefit from being closer to the airbag - particularly when belts are employed with the airbag. This is due to ride-down benefits outweighing the effect of airbag deployment forces.

With the belts and airbag operating together, HIC and PCG for the two male driver sizes increase as distance from the airbag increases.

3. Sensing time - this variable had significant influence on both the 5th percentile female and the 50th percentile male with or without the addition of belts to the airbag restraint. For these driver sizes injury measures tended to decrease as sensing time decreased. The 95th percentile male demonstrated negligible injury variation as sensing time changed with either restraint type.

4. Pretensioning - addition of pretensioning to belts that will be used in conjunction with an airbag appears to offer no real advantage. The nominal seating positions of the 95th and 5th percentile drivers demand excessively high pretensioning to overcome the complicating factors of their respective distances from the airbag.

5. Belt webbing elongation - the benefit of various belt webbing characteristics is overshadowed by the increase in injury measures that arise from the addition of belts to the restraint system. However if it is "a given" that belts will be in the vehicle and if femur load is not given as much weight as head and chest injury, an increase in belt webbing elongation from those currently in use appears to offer merit. A value of 14.0% looked best from this study.

   If femur load is given equal weight with head and chest injury, the webbing characteristics should be left as it is in the majority of current vehicles; i.e. in the 8% range.

6. Airbag plus belts versus femur injury - drastic reductions occur for the injury to the femur when belts are used in conjunction with an airbag. In this study the PFL's prior to the inclusion of belts were well within the acceptable range. Significant reduction resulted in all cases where belts were added. Since injury to the femur is not a critical issue if the force incurred is below the threshold limit, primary emphasis was given to the head and chest injuries.

If it is necessary to design a restraint system that must incorporate both an airbag and three-point belts, this study has shown that these variables are the most critical:

1. Distance - this turns out to be the key variable once all of the competing synergies are analyzed. When belts are employed with 95th and 50th percentile males, the distance from the airbag should be kept to a minimum consistent with comfort in order to maximize ride-down benefits. Generally, this minimizes the head rotational g's and the torso-belt induced chest g's prior to airbag contact. However the driver must not be placed too close to the airbag or another factor comes into play.

   Here the 5th percentile female is affected due to her proximity to the airbag. In this case she must have her distance from the airbag maximized to prevent the severe chest and head loads that can occur due to the deploying airbag. This is true for her even with the airbag only restraint type.

2. Airbag tethering (shape) - again there is competition between the needs of the small and the larger drivers. The most sensitive injury measures with airbag plus belts that were seen in this study are the HIC for the 50th percentile driver, the PCG for the 95th percentile driver, and the PCG for the 5th percentile driver. The former two would prefer a rounder, non-tethered airbag for maximum ride-down benefits as befits their greater mass and distance from the airbag. The 5th percentile female however, prefers a narrower, tethered airbag to limit airbag deployment forces. This conclusion is true for both restraint types - bag only or airbag plus belts.

3. Sensing time - this was basically the only variable that competed with driver distance from the airbag for potential effect. The 95th percentile driver was for the most part unaffected by sensing time changes. The other two driver sizes benefited from both lower head and chest injuries as sensing time was decreased. The response of the 5th percentile female was critically sensitive to sensing time variation. At the highest sensing time simulated, her HIC and PCG were quite high for both the airbag only and airbag plus belt restraint types.

This completes our study.