DOT HS-803 343

VEHICLE INTEGRATION AND EVALUATION OF ADVANCED RESTRAINT SYSTEMS

RESTRAINT SYSTEM ANALYSIS REPORT

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16. Abstract

This report describes the results of the sled testing and vehicle crash testing that were conducted in order to evaluate the performance of four advanced restraints systems in a compact size automobile. These results were then used to construct a crash survivability envelope for the front seat occupants of the subject vehicle in a variety of accident modes.

The vehicle chosen for this effort was the 1976 Volvo 244. The restraint systems chosen to be integrated into the Volvo were:

1. Advanced Driver Airbag System (Contract DOT-HS-5-01215)
2. Advanced Passenger Airbag System (Contract DOT-HS-5-01215)
3. Force-Limited Airbelt System (Contract DOT-HS-4-00917)
4. Force-Limited 2-Inch Belt System (Contract DOT-HS-5-01215)

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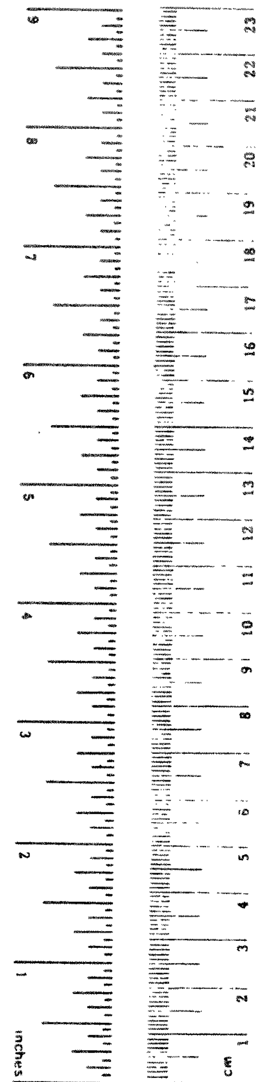
METRIC CONVERSION FACTORS

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

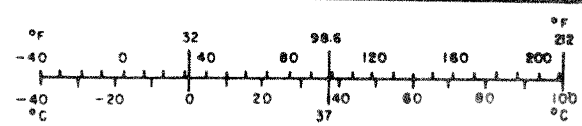


TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF TABLES

1.0 INTRODUCTION

The objective of this research program was to establish the occupant protection performance limits (crash survivability envelope) of four advanced restraint systems when integrated into a production, compact sized automobile undergoing crashes in a variety of accident modes representative of the modes that produce a high percentage of the total societal cost of accidents. The 1976 Volvo 244 was chosen as the compact size car for this program since, in an earlier program sponsored by NHTSA, the Volvo appeared to have a good combination of a crash pulse that was not too aggressive in side impacts, was not too "stiff" in frontal impacts, and had a passenger compartment with above average room in which to bring the occupants safely to rest.

There were four advanced restraint systems selected for use in this program. All four of these systems had been recently developed by Minicars Inc. of Goleta, California on previous NHTSA research programs. These four systems, selected to be integrated and evaluated in the Volvo were:

- Minicars RSV Phase II Driver Airbag System
- Minicars RSV Phase II Passenger Airbag System
- Minicars Airbelt (active system) Developed under NHTSA Contract DOT-HS-4-00917
- Minicars Force-Limited 2-Inch Active Belt adapted from the RSV Phase II rear seat restraint system

These systems will be described in greater detail in Section 5.0

The sled and vehicle crash test conditions were specifically chosen to determine the performance limits of the advanced restraints and the production Volvo structure. As such, a variety of accident modes were investigated in this program so as to simulate as much as possible real world type frontal collisions.

In order to evaluate the performance of each of the restraints in a manner that would permit direct comparisons in performance from one system to another for equivalent crash conditions, a common denominator of crash severity was selected. The method of selection and the results obtained from construction of a crash survivability envelope for each system will be discussed in Section 9.0.

Figure 1-1 shows a breakdown of the activities that took place as part of this program. As you look left to right across the page, the project milestones are presented in a rough chronological fashion. As nearly as possible, this report will adhere to a chronological account. In this way, the reasons certain things were done, the results of project decisions, and the methodology behind the program should be more apparent.

The program was primarily a restraints program in that the objective of the program, as previously stated, was to determine a crash survivability envelope for each restraint system. For this reason, the slant of this report will be toward restraint performance rather than vehicle performance. To emphasize both in this report would, we feel, detract from the overall thrust and the emphasis that was actually given in the program. With the foregoing established, let us now discuss the layout of the report.

A series of twenty-eight sled tests and nineteen full scale crash tests were conducted in this program to, first, "tune" the restraint systems and then, second, evaluate the restraint system performance. The tuning sled tests will be discussed in Section 5.0 and the vehicle crash tests in Section 7.0. Section 6.0 will discuss the integration of the restraint system into the vehicles. Section 8.0 will discuss the sled tests done to determine the survivability limits the driver system would have if used in conjunction with the standard Volvo steering column. Section 9.0 then summarizes the vehicle test results by presenting the crash survivability envelope.

A few words are in order concerning the philosophy and experimental nature of this program. The contractual work statement specified that four types of advanced restraints were to be integrated into a compact automobile which possessed a high degree of crashworthiness potential. As previously mentioned, the Volvo 244 was the automobile chosen by the NHTSA. The statement of work continued to specify that the selected vehicle with the advanced restraints installed would be crashed at speeds up to 50 mph to determine the performance envelope of the combined advanced restraints/vehicle structure occupant protection system. Based on the structural capabilities of even the

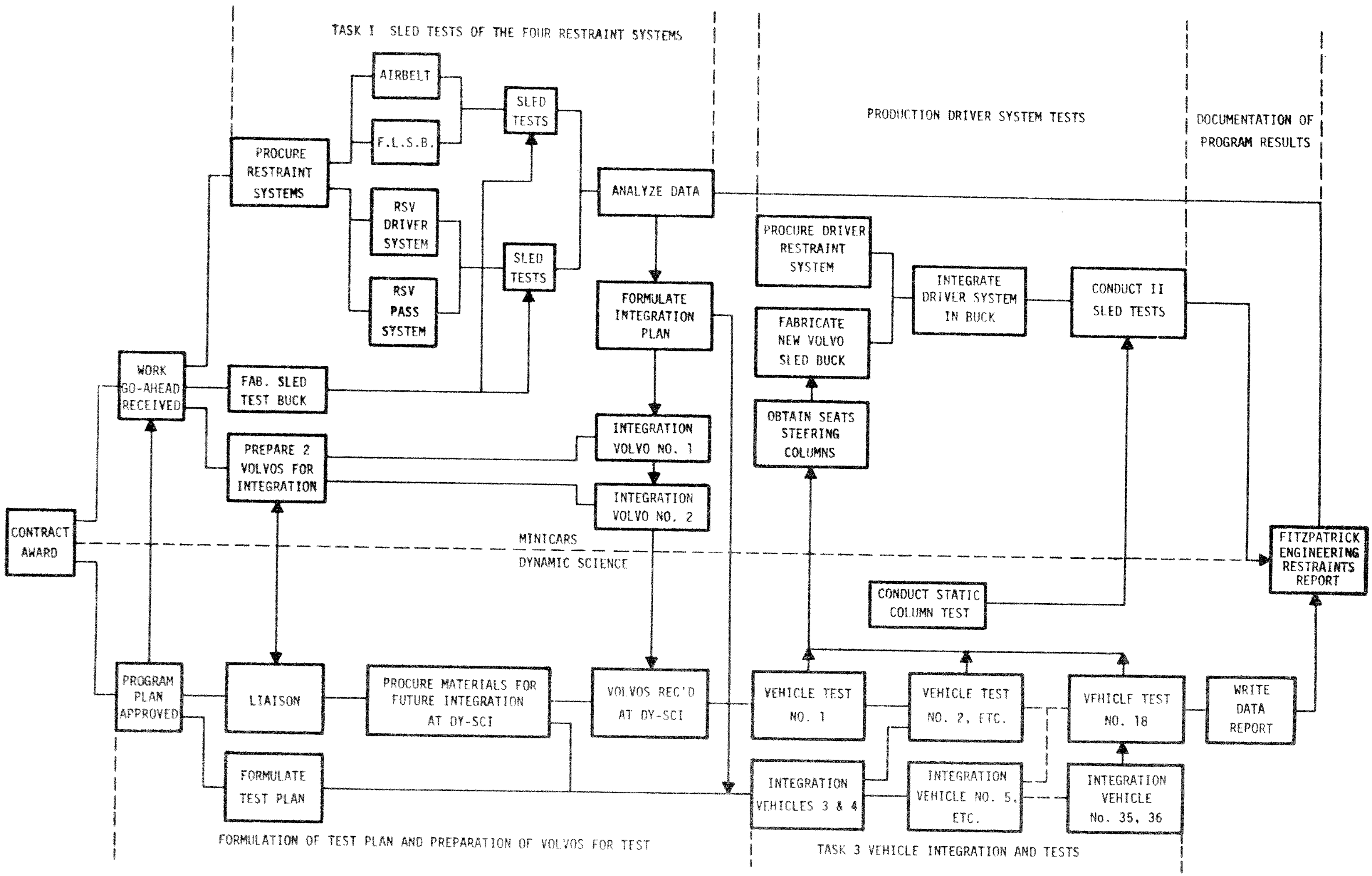


Figure 1-1. Program Development

better performing compact vehicle structures, the specification of the 50 mph goal for protection clearly indicated that some tests would have to be scheduled with the specific intent of exceeding the performance limits (specified by FMVSS 208 criteria) in order to define (bracket) the upper limit of performance for the integrated systems. This should be kept in mind as the program unfolds in the following pages.

A second point we would like to make is that the advanced airbag restraints to be tested in the Volvos in this program were those developed for the Minicar's Phase II RSV Program, and as such, the technical feasibility of the driver and passenger bag systems were demonstrated in that program. No additional developmental work on these systems was specified for this program, although, as will be discussed in Section 7.0, continuing improvements were made as they suggested themselves.

The force-limited airbelt was developed under Contract No. DOT-HS-4-00917, "Inflatable Belt Development for Subcompact Car Passengers," and the force-limited 2-inch belt was adapted from the Minicar's RSV rear seat restraint design. In both of the belt systems, low elongation, doubled-over, polyester webbing was used for additional strength, and no retractors were used. All of the restraint systems, airbag and belts, were in the early stages of development and should be considered as experimental systems.

Another developmental apsect of the belt systems is that the force-limiters, such as the roller tape devices used at the Volvo anchor points, have never been used in any production belt system, primarily because they are effectively excluded by the present FMVSS 209 standard. An entirely different production capability would have to be developed and appropriate rulemaking activity taken before force-limiting concepts would be adopted on a wide scale.

Both belt systems were run as passenger systems (except in Test No. 17) because no suitable production-oriented collapsible steering column was available that would not impact the belted occupant's head in these extremely high-speed crashes which were near the structural intrusion limits of the Volvo compartment.

With respect to the experimental reliability of all the systems, the hardware was research in nature and the uniform minimum requirements typical of production quality control were not maintained. The reason was because of the expense and time involved, and because, as in most pure R&D work, a deterministic decision was made to use the resources that would have been required to achieve high reliability instead to test under more varied conditions. Corrective measures were taken after each experimental anomaly, and subsequent tests were conducted only after reasonable assurances of success were in hand.

A final word is in order here concerning the number of tests run in each crash mode, both with respect to repeatability of the results and the hardware development which inevitably takes place during any such research program.

This program was of a basic research nature, and as such, it was deterministically decided, in consultation with the NHTSA, that the emphasis in the program would be placed on testing under as many varied conditions as possible, consistent with the relatively limited funds available to conduct nineteen crash tests. Subsequent programs to further develop these four advanced restraints would logically include hardware nearer to production, and also would require that each test condition be repeated two or three times in order to demonstrate the repeatability of the systems and allow meaningful evaluation of the capabilities of the system should any testing anomalies occur during any one test.

Again, since the program's objectives included determining the upper limit of the impact velocity at which the injury measures of FMVSS 208 could be met, we necessarily conducted tests which exceeded the injury criteria limits. However, we should note that the velocity limits at which the systems no longer could be repeatably relied upon to meet the injury criteria are substantially in excess of the FMVSS 208 limit of 30 mph.

With these thoughts in mind, let us now discuss the results of the program in summary fashion.

2.0 SUMMARY

The following is a very brief summary of the most important program results. As such it is intended to show at a glance, so to speak, the main things accomplished in the program and what the results were. Section 3.0 is a similar section in that the conclusions we drew, based upon these results, is presented. By referring to these two sections (Sections 2.0 and 3.0) a pretty good idea can be obtained on "what was done" and "what it meant". For any further understanding, one must refer to the other sections of this report where the complete program is discussed in detail.

A series of nineteen full-scale crash tests were conducted to evaluate the performance of four advanced restraint systems that were structurally integrated into the Volvo 244. These tests were of two main types. The first type consisted of car-to-car and car-to-barrier impact tests using only Volvo 244's as test vehicles while the second type of impact test configurations were car-to-car using Volvo 244's with Ford Torinos serving as bullet vehicles.

The advanced restraint systems tested were:

- RSV Driver Airbag System (DS)
- RSV Passenger Airbag System (PS)
- Force-Limited Airbelt (AB)
- Force-Limited 2-Inch Belt (FLB)

These systems had been developed under previous NHTSA research and development efforts (Ref. 1) and were selected to provide an indication of the limits of occupant protection performance criteria for small production vehicles.

There were three main areas of activity in the program. There was, first of all, the sled test phase where the restraint systems were "tuned" to the Volvo crash environment. Then, there was the integration phase where the "tuned" restraints were integrated into the Volvo dash area. Finally, there was the car crash phase where the results of the first two phases were evaluated in the vehicle crash environment. Since this last part of the

(1) DOT Contracts DOT-HS-5-01215 and DOT-HS-4-00917.

effort - namely the vehicle crash test phase - is the heart of the program in that the crash survivability envelope is based upon these results, it is this phase of the program that will be summarized in this section of the report.

The matrix of all nineteen of the vehicle crash tests is presented in Figure 2-1. These crash test conditions were chosen so as to determine the performance limits (crash survivability envelope) of each of the advanced restraints when functioning in the Volvo crash environment. (Figure 2-2 shows these test modes schematically.)(1) Table 2-1 presents the results of these nineteen crashes (details of each crash are presented in Section 7.0.

The results of these tests as presented in the table, provide the information needed to construct the crash survivability envelope. Details on how this envelope was constructed are presented in Section 9.0

The crash survivability envelope is presented in Figure 2-3. Figures 2-4 through 2-7 present another method of presenting the crash survivability envelope. Whereas, Figure 2-3 presented the restraint performance in terms of a survivability margin, Figure 2-4 through 2-7 present both restraint performance where critical and an estimate of structural performance where it is the critical factor.

Therefore, the upper solid line in the diagrams (Figures 2-4 through 2-7) represent either the upper restraint performance limits <u>or</u> the Volvo structural performance limits based upon which, in our opinion, would be the limiting factor for a given test mode. As such, Figures 2-4 through 2-7 include a subjective estimate of the velocity at which structural intrusion would be more critical than restraint performance. This is explained further in Section 9.0.

In addition, Figures 2-4 through 2-7 show <u>all</u> the valid data points in terms of percent of criteria limit in the "boxes" on the diagrams whereas in Figure 2-3 only the average of the data points for each mode was presented so as to be able to plot a single point for each test mode. We feel that when both presentations (Figure 2-3 and Figure 2-4 through 2-7) are studied together they complement each other and enable one to obtain a good overall "picture" of the restraint and vehicle survivability envelope.

(1) Note the non-sequential test numbers in Figure 2-1.

Figure 2-1. Test Matrix

TEST NO	TEST CONFIGURATION	IMPACT CONDITIONS SPEED[1] (MPH)	IMPACT CONDITIONS ANGLE (DEG.)	RESTRAINT CONFIGURATION[2] VEHICLE A OCCUPANTS L FRONT	VEHICLE A OCCUPANTS R FRONT	VEHICLE B OCCUPANTS L FRONT	VEHICLE B OCCUPANTS R FRONT
1	Volvo-to-Volvo Head-on	80.6	0°	DS	BC	FLB	PS
2	Volvo-to-Volvo Head-on	81.2	0°	DS	PS	AB	FLB
3	Volvo-to-Volvo Head-on	89.8	0°	DS	PS	AB	FLB
4	Volvo-to-Volvo Offset Left (25")	80.6	0°	DS	PS	AB	FLB
5	Volvo-to-Volvo Offset Right (25")	81.4	0°	DS	PS	AB	FLB
6A	Volvo-to-Barrier	46.1	0°	DS	PS		
6B	Volvo-to-Barrier	46.7	0°			AB	FLB
7A	Volvo-to-Barrier	48.1	0°	DS	PS		
7B	Volvo-to-Barrier	48.3	0°			AB	FLB
8	Torino-to-Volvo Head-on	77.0	0°	STD	STD	DS	PS
9	Torino-to-Volvo Head-on	78.6	0°	SWL	SWL	AB	FLB
10	Torino-to-Volvo Right Oblique	60.5	30°	STD	STD	DS	PS
11	Torino-to-Volvo Left Oblique	59.5	30°[4]	SWL	SWL	AB	FLB
12	Torino-to-Volvo Right Oblique	63.3	30°[4]	SWL	SWL	DS	PS
13	Torino-to-Volvo Left Oblique	65.8	30°[4]	STD	STD	DS	PS
14	Torino-to-Volvo Right Oblique	66.6	30°[4]	SWFL	SWFL	AB	FLB
16	Torino-to-Volvo Left Oblique	60.3	45°	None	None	DS	PS
17	Volvo-to-Volvo Head-on	84.2	0°	DS	PS	AB[3]	FLB[3]
18	Volvo-to-Volvo Offset Left (25")	81.9	0°	DS	PS	None	None

(1) Closing speed for car-to-car frontal impacts; both cars moving at the same speed. For oblique impacts, Torino velocity (Volvo stationary).

(2) DS = RSV Driver System, PS = RSV Passenger Airbag System, AB = Force-Limited Airbelt, FLB = Force-Limited 2-Inch Belt, BC = RSV Airbag/Collapsing Dash System, STD - Standard 3-Point System, SWL = Standard System with Web Locking Device, SWFL = Standard, Web Locking and Force-Limited.

(3) Advanced steering columns installed at these positions for this test.

(4) Major resultant acceleration vector, this number of degrees to centerline of target vehicle.

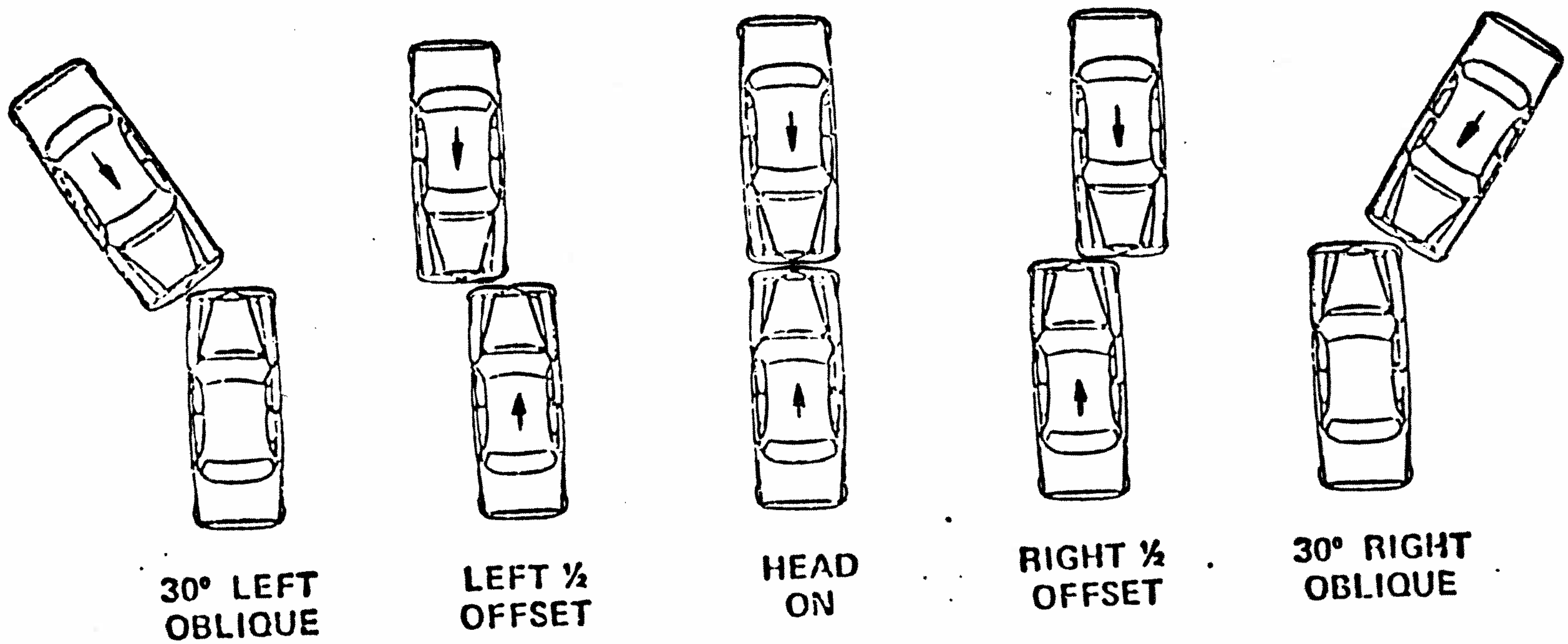


Figure 2-2. Typical Frontal Crash Modes

Table 2-1. Data Summary

TEST NO	RESTRAINT SYSTEM (1)	HEAD PEAK G (G)	HEAD HIC	CHEST PEAK G (G)	CHEST CSI	FEMURS LF (LB)	FEMURS RT (LB)	VELOCITY CHANGE (MPH)	REMARKS
1*	DS	No Data		69.7	736	333	781	45.1	Column rotated upward due to bending of transverse beam and fastener failure. Bad buckling occurred in floor pan of car.
	BC	92.6	1015	No Data		447	773	45.1	Stroking dash stroked = 1/2 inch Dash impacted by firewall.
	FLB	118.0	1599	99.6	1184	190	791	43.2	Force-limiters improperly installed so that L.I. tape pulled out of its fixture.
	PS	40.4	290	No Data		252	1082	43.2	Non-stroking version of passive restraint. Lost some gas since bag clamp pulled loose; however, injury measures still within specification. Severe floor buckling.
*Volvo-to-Volvo Head-on									
2*	DS	42.9	375	39.8	373	1284	1521	47.5	Good test
	PS	39.7	242	34.8	329	962	1351	47.5	Good test. From here on only non-stroking version of passive restraint used. Dash impacted hard by intruding firewall.
	AB	38.8	301	No Data		2504	3084	46.9	Force-limiter tapes improperly installed so that L.I. tape pulled out of its fixture.
	FLB	157.3	2080	122.8	1989	4128	2417	46.9	Force-limiter tapes improperly installed so that L.I. tape pulled out of its fixture.
*Volvo-to-Volvo Head-on									
3*	DS	48.4	471	46.4	459	1327	2336	50.0	Good test.
	PS	52.1	366	50.3	681	1441	1227	50.0	Good test.
	AB	81.7	681	51.2	538	1882	362	48.1	Good test. Lots of intrusion. Firewall against dummy's knees.
	FLB	76.4	991	56.9	491	2556	356	48.1	Good test. Firewall impact with left knee.
*Volvo-to-Volvo Head-on									
4*	DS	61.1	330	35.7	223	1407	2002	43.0	Good test.
	PS	122.2	1284	64.5	613	1583	1693	43.0	Bag seam open and some gas expelled due to improper seam stitching. Corrected for future tests.
	AB	30.4	255	30.1	224	1516	1021	41.0	Good test.
	FLB	38.3	311	27.2	200	520	152	41.0	Good test.
*Volvo-to-Volvo Offset Left (25")									
5*	DS	32.9	119	30.4	172	1570	2308	44.4	Good test.
	PS	33.4	170	33.6	216	973	1419	44.4	Good test. Increased seam strength by improved seam design.
	AB	28.4	205	36.4	212	91	92	42.6	Good test.
	FLB	82.5	596	40.0	262	2027	893	42.6	Good test.
*Volvo-to-Volvo Offset Right (25")									
6A*	DS	56.4	572	86.7	981	1947	2772	48.7	Stroking portion of column impacted by intruding firewall. Chest G's high due to crash pulse being more severe than expected.
	PS	85.4	1671	73.9	1313	3306	3794	48.7	Suspect that wrong inflator was used. Crash pulse more severe than anticipated with accelerations exceeding 60 G. Chest G's high as a result
6B*	AB	38.3	408	57.5	665	682	2615	49.0	Good test, however no dash installed.
	FLB	84.5	841	45.0	482	2960	693	49.0	Good test, however no dash installed.
*Volvo-to-Barrier									

(1) DS = RSV Driver Airbag System
AB = Force-Limited Airbelt
FLB = Force-Limited 2-Inch Belt
PS = RSV Passenger Airbag System
BC = RSV Airbag/Collapsing Dash Systems

Table 2-1. Data Summary (Cont.)

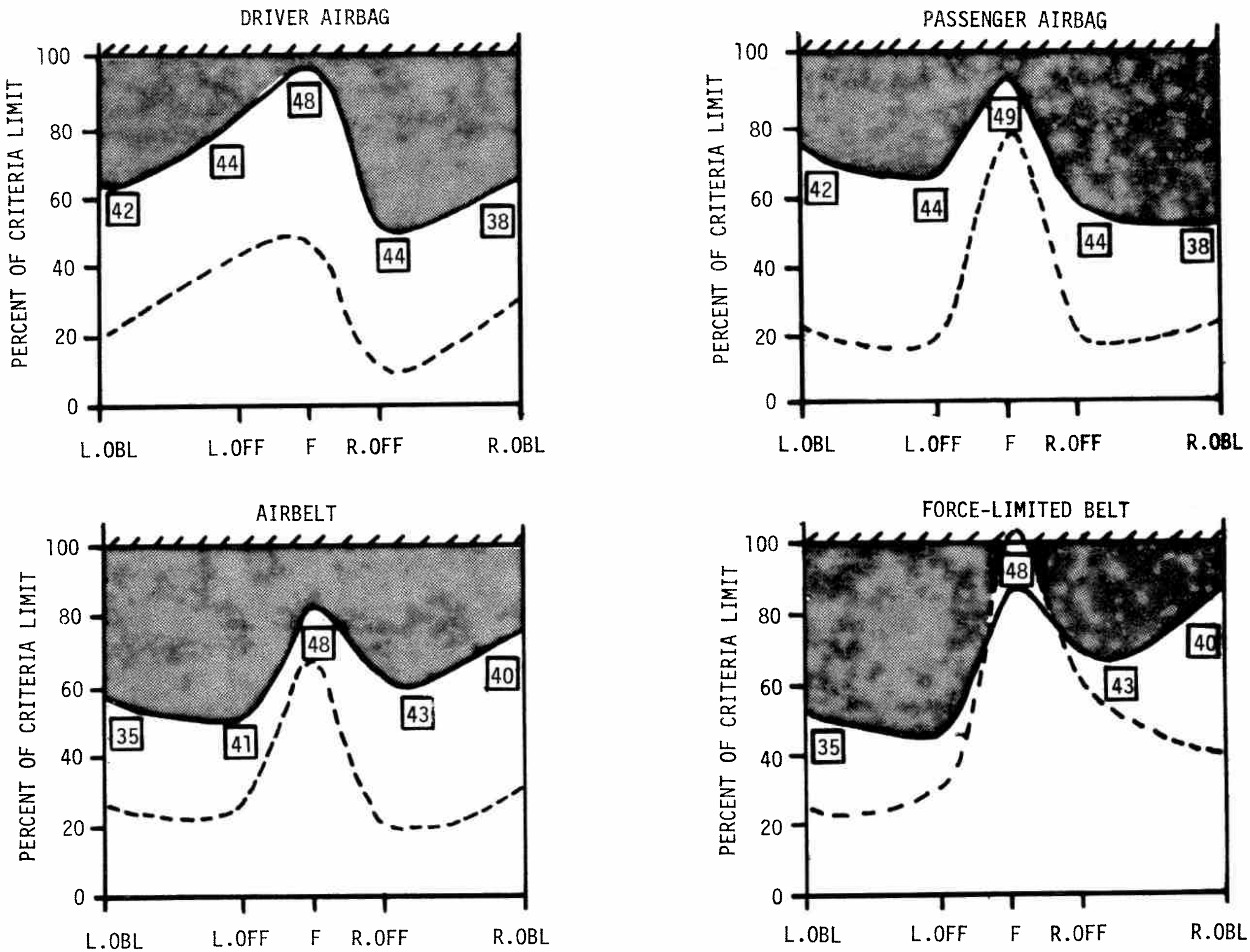
TEST NO	RESTRAINT SYSTEM (1)	HEAD PEAK G (G)	HEAD HIC	CHEST PEAK G (G)	CHEST CSI	FEMURS LF (LB)	FEMURS RT (LB)	VELOCITY CHANGE (MPH)	REMARKS
7A*	DS	71.6	674	82.0	1103	1856	2344	52.5	Improve column design, but column stroked full length and bottomed out energy absorber due to severe crash pulse.
	PS	91.4	1313	70.1	1018	1809	1457	52.5	Again, crash pulse very severe and dominating factor. Chest G's correspondingly high. Now suspect inflator in Test 6 was okay.
7B*	AB	68.1	1378	77.2	1049	2726	792	54.6	The lap belt force limiters were accidentally reversed during installation, resulting in lower inboard force-limiter tape stroking its full length before pulling out of its mount.
	FLB	152.3	3046	78.0	1161	2953	1230	54.6	The lap belt force-limiters were accidently reversed during installation, resulting in lower inboard force-limiter tape stroking its full length before pulling out of its mount.
*Volvo-to-Barrier									
8*	DS	55.1	550	59.8	623	1443	1590	46.5	Good test.
	PS	73.8	830	56.2	735	1033	1621	46.5	Good test.
*Torino-to-Volvo Head-on									
9*	AB	84.1	1061	51.6	632	1918	1379	49.9	Injury measures marginal. Severe crash pulse. Airbelt incorrectly positioned on shoulder, resulting in HIC exceeding criteria.
	FLB	81.3	1064	55.4	555	527	1703	49.9	HIC exceeded criteria limits.
*Torino-to-Volvo Head on									
10*	DS	41.3	333	38.0	184	1795	1250	34.9	Column rotated upward 8 degrees. Good test.
	PS	63.3	365	57.6	293	1092	501	34.9	First test in oblique mode. Injury measures within specification, however, seam opened up in airbag; strongly suspect that one of the old airbags with weak seams used inadvertently.
*Torino-to-Volvo Right Oblique									
11*	AB	34.9	247	33.5	225	325	138	35.1	Good test.
	FLB	33.7	236	29.6	166	656	972	35.1	Good test.
*Torino-to-Volvo Left Oblique									
12*	DS	33.6	233	37.9	212	1103	1440	40.2	Good test.
	PS	39.5	219	30.5	204	672	744	40.2	Lowered inflator load 20 gm to 440 gm charge to further increase safety factor on bag integrity. Good test.
*Torino-to-Volvo Right Oblique									
13*	DS	40.0	206	38.3	234	1699	1278	42.5	Good test.
	PS	38.3	195	42.3	264	No Data	523	42.5	Good test
*Torino-to-Volvo Left Oblique									
14*	AB	41.7	313	45.1	355	577	681	40.5	Good test.
	FLB	48.5	396	50.9	394	571	957	40.5	Good test.
*Torino-to-Volvo Right Oblique									
16*	DS	60.7	207	32.1	130	423	592	31.6	Good test.
	PS	117.3	1246	31.5	120	365	937	31.6	No dash padding over steel cowl structure. Dummy head hit steering wheel or dash on driver side late in the event (T=167 msec). Otherwise good test.
*Torino-to-Volvo Left Oblique (45°)									

(1) DS = RSV Driver Airbag System
AB = Force-Limited Airbelt
FLB = Force-Limited 2-Inch Belt
PS = RSV Passenger Airbag System
BC = RSV Airbag/Collapsing Dash Systems

Table 2-1. Data Summary (Cont.)

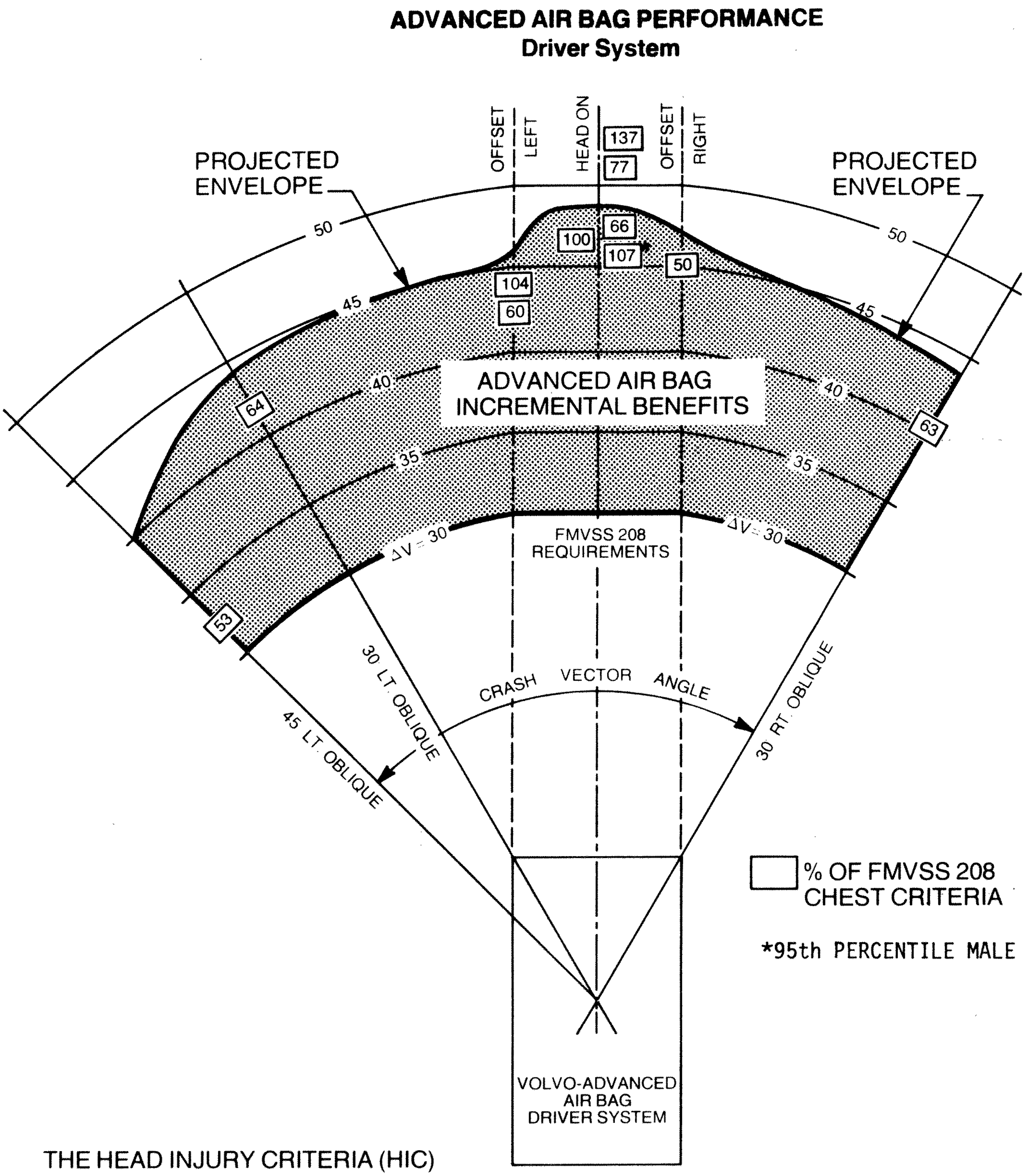
TEST NO	RESTRIAINT SYSTEM (1)	HEAD PEAK G (G)	HEAD HIC	CHEST PEAK G (G)	CHEST CSI	FEMURS LF (LB)	FEMURS RT (LB)	VELOCITY CHANGE (MPH)	REMARKS
17*	DS	43.4	319	64.3	608	No Data		45.8	95th percentile dummy. Chest g's slightly in excess of 60 g limit. Knees trapped between wheel rim and knee restraint.
	PS	75.7	712	44.3	425	No Data		45.8	5th percentile female dummy. Good test.
	AB	81.1	954	38.6	355	1397	1600	44.7	Good test. Steering column installed with this system for the first time. No head impact with steering wheel. Buckling of floor caused seats to tip forward.
	FLB	86.1	1179	52.2	509	1315	982	44.7	Steering column installed with this system for the first time. Dummy hit head on wheel rim.
*Volvo-to-Volvo Head-on									
18*	DS	74.4	545	62.1	570	1661	1309	44.1	Dummy torso rotated to the right and shoulder hit A-pillar causing high lateral g. Resultant chest g slightly in excess of criteria.
	PS	35.8	193	38.8	304	1211	1341	44.1	Good test.
	None	94.5	1167	72.9	669	2254	2419	46.4	Dummy unrestrained.
	None	107.5	1371	91.9	1300	872	2383	46.4	Dummy unrestrained.
*Volvo-to Volvo Offset Left (25")									

(1) DS = RSV Driver Airbag System
AB = Force-Limited Airbelt
FLB = Force-Limited 2-Inch Belt
PS = RSV Passenger Airbag System
BC = RSV Airbag/Collapsing Dash Systems



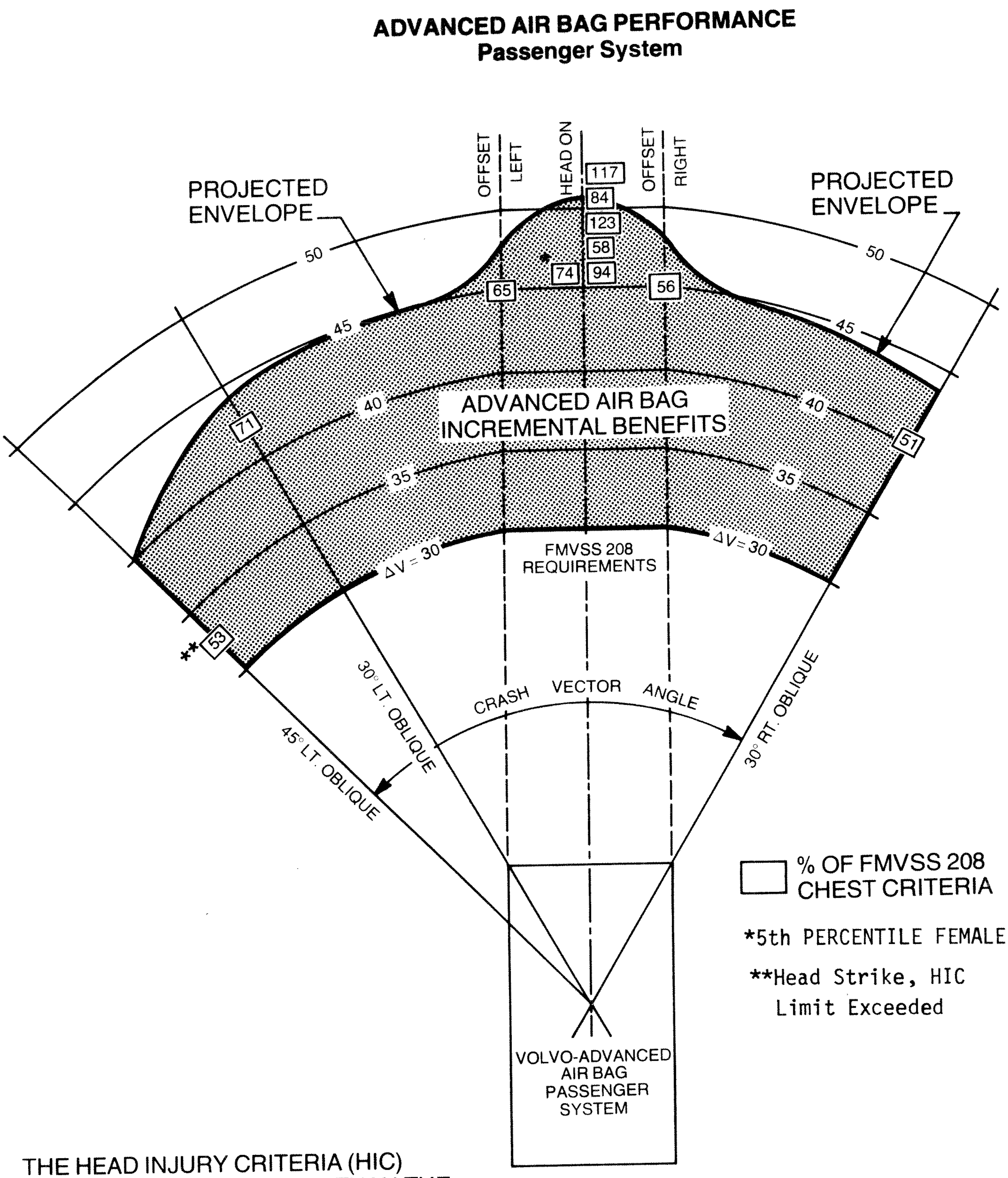
The percent of FMVSS 208 criteria limit and Delta V represent average values of the data for each test mode in which more than one test was conducted.

Figure 2-3. Survivability Envelope (Shaded Areas Represent Survivability Margin)



THE HEAD INJURY CRITERIA (HIC) WERE RELATIVELY LOWER THAN THE CHEST ACCELERATION IN EVERY CASE AND THUS, THE LATTER WERE USED TO ESTABLISH SYSTEM PERFORMANCE LIMITS

Figure 2-4. Crash Survivability Envelope - Driver Airbag System



THE HEAD INJURY CRITERIA (HIC) WERE RELATIVELY LOWER THAN THE CHEST ACCELERATION IN EVERY CASE AND THUS, THE LATTER WERE USED TO ESTABLISH SYSTEM PERFORMANCE LIMITS

Figure 2-5. Crash Survivability Envelope - Passenger Airbag System

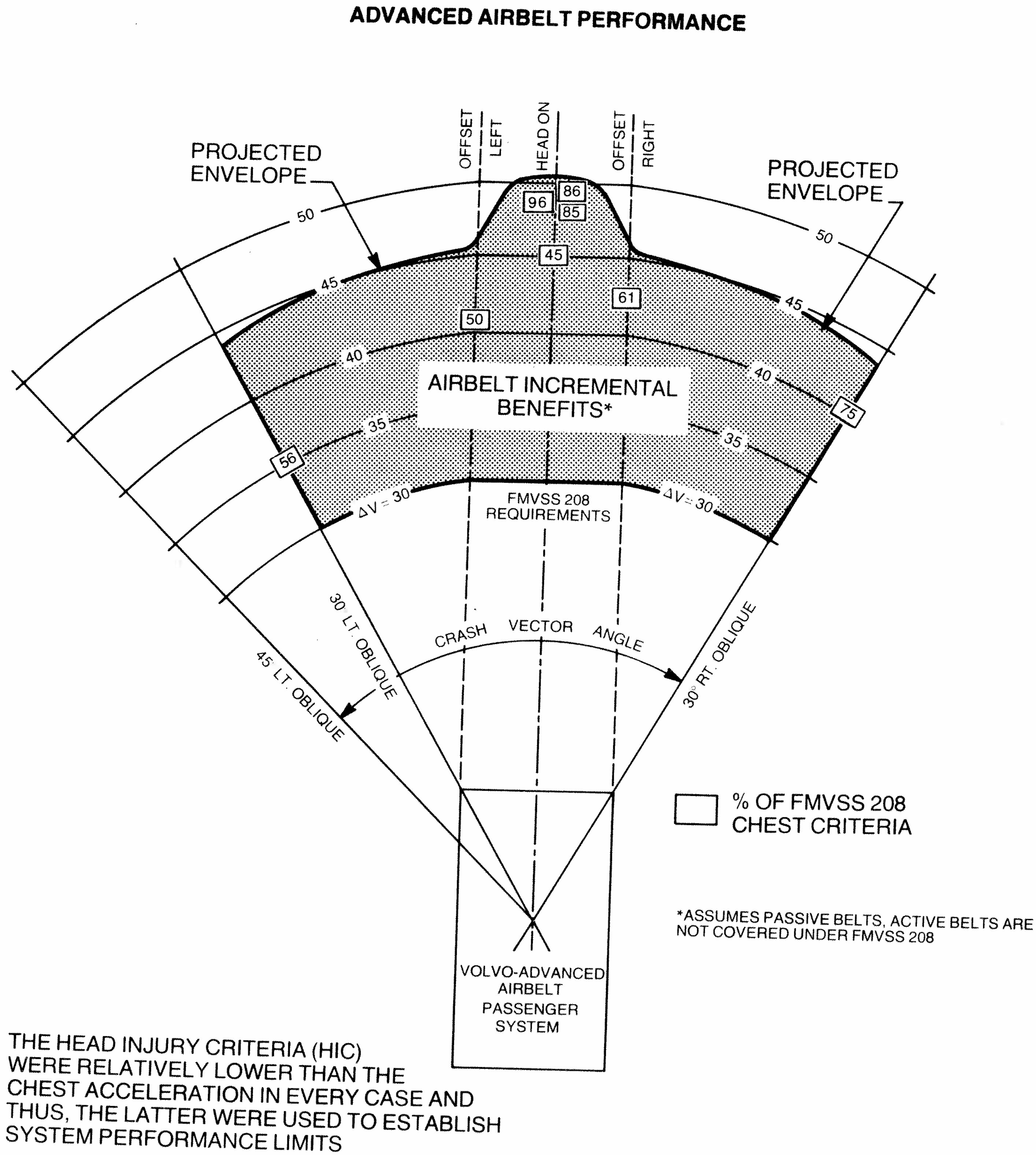


Figure 2-6. Crash Survivability Envelope - Airbelt System

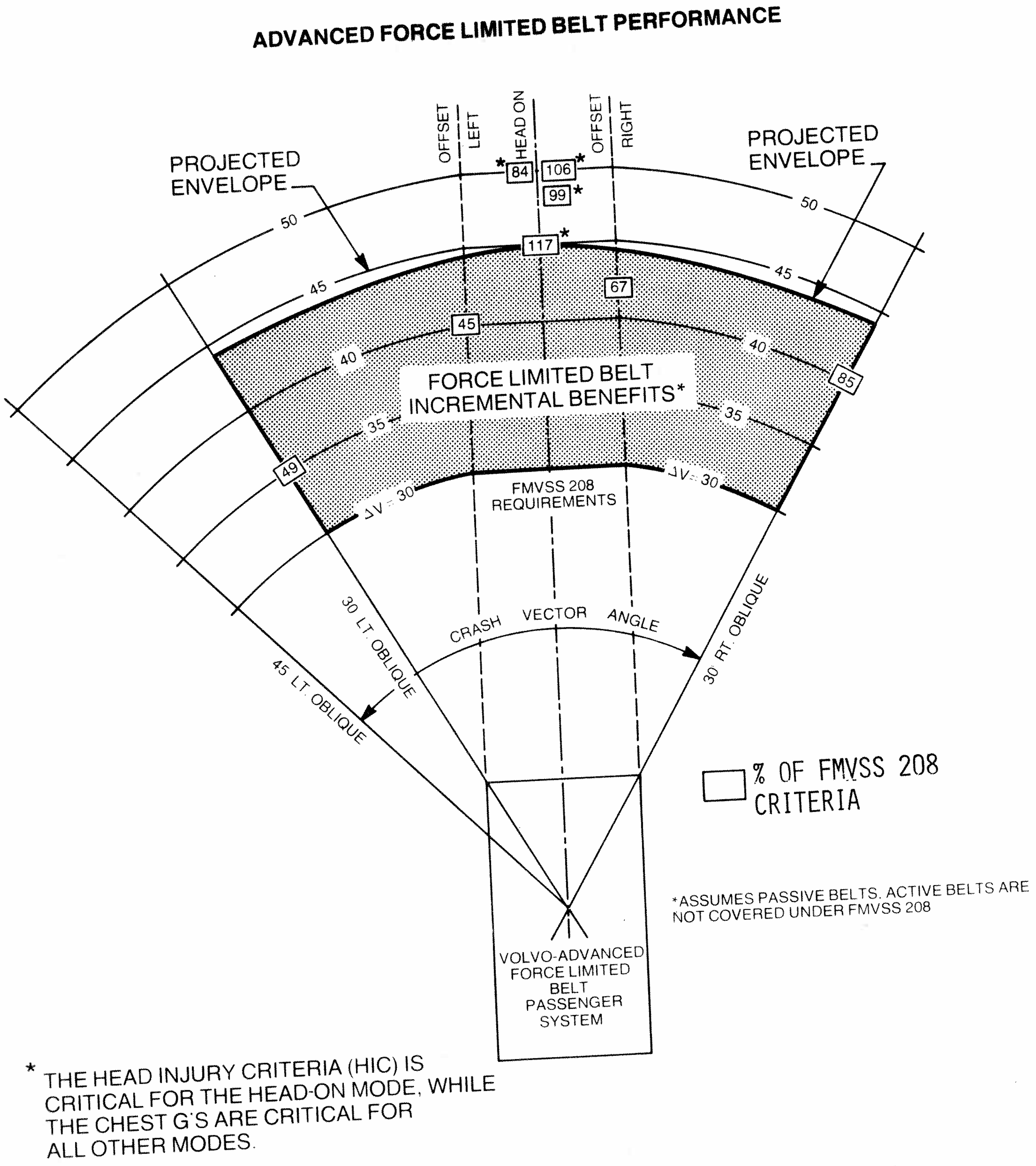
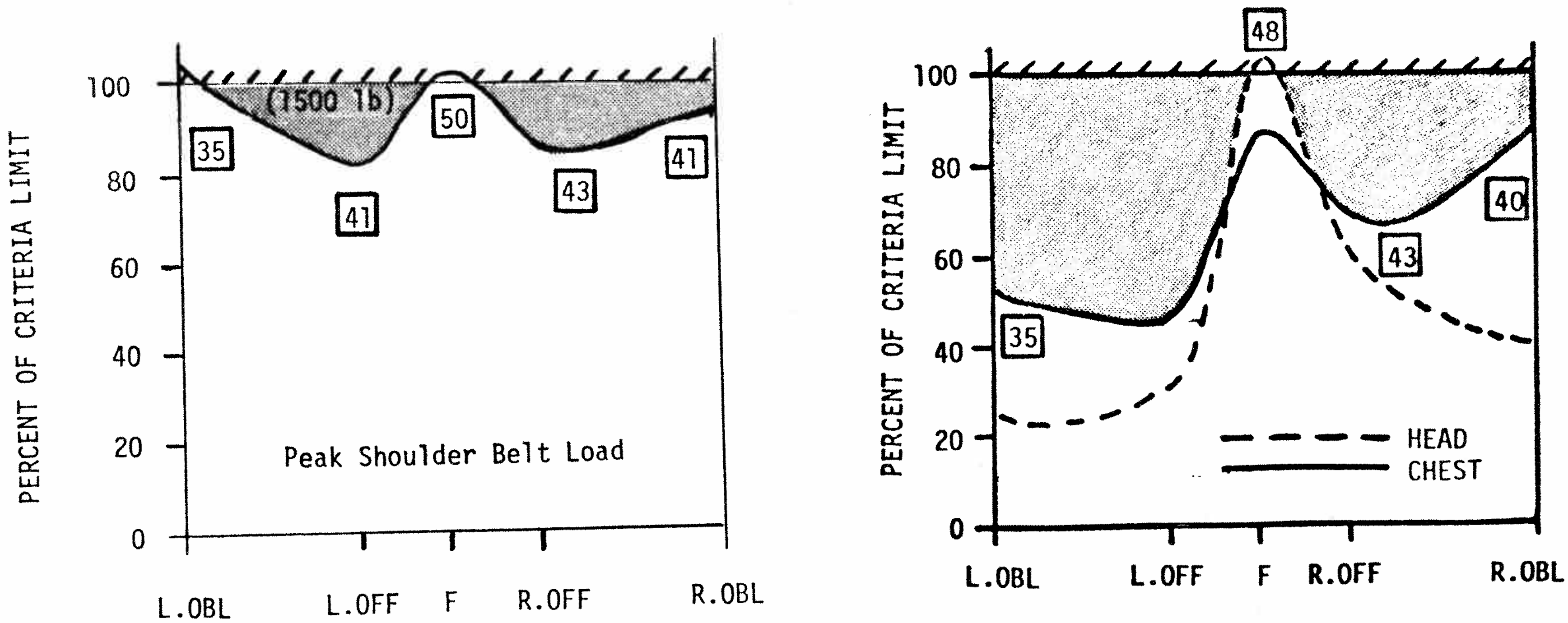


Figure 2-7. Crash Survivability Envelope - Force-Limited Belt System

One final piece of data we think is worthy of presenting here. Although peak shoulder belt load is not specified as part of the injury criteria which determines whether the system "passes or fails" in a given crash, it is, nevertheless, widely used as an "indicator" of how well the system performs. 1500 lbs is widely used as an upper, acceptable bound for the torso belt load and, as such, we present here Figure 2-8 which, in the same way as Figure 2-3, presents the "survivability margin" for the force-limited 2-inch belt if 1500 lb were the upper, acceptable bound for torso belt load.

As can be seen from the figure, if this criteria were used to judge system performance, there would be much less margin than was the case when either HIC or peak chest g's were used as the critical criteria (Figure 2-3).

With this brief summary of test results completed, let us now discuss what these results mean in terms of conclusions that may be drawn.



The percent of FMVSS 208 criteria limit and Delta V represent average values of the data for each test mode in which more than one test was conducted.

(Shaded Areas Represent Survivability Margin)

Figure 2-8. Force-Limited 2-Inch Belt - Survivability Margin

3.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the results presented in Sections 2, 7, 8 and 9, several conclusions may be drawn which will, in turn, lead to certain recommendations being made. It is the subject of this section of the report to summarize these conclusions and recommendations.

3.1 RESTRAINT SYSTEM DESIGN CONCLUSIONS

1. Of the four advanced restraints integrated and evaluated in the Volvos, the RSV passenger system seemed to be the nearest to being producible by present day inflatable restraints technology. It used a production inflator and manifold, and the bag itself can be stowed in the same size compartment used by production Volvo bags. As will be discussed in Section 4.0, the RSV passenger bag is a unique dual (upper and lower) bag design that has shown a great deal of promise for individually tailoring the head and chest restraint requirements. However, various production stitching designs still need to be investigated to ensure maximum reliability if the bag is to be produced in large numbers.

2. The next most producible system, in our opinion, is the Phase II, RSV driver system. The driver bag consists of a dual (inner and outer) bag which also has shown great promise for individually controlling the head and chest accelerations. The inner and outer bags taken individually, are of a standard driver bag design; only of different volumes, and are of the type which have been extensively used in production airbag systems. The driver system inflator is the same solid pyrotechnic unit GM used in their 13,000 airbag cars, with only a slight upload in charge. The most nonproducible aspects of the RSV driver system, by present-day automotive practice, are the steering column with a low angle of seven degrees to the horizontal and the heavy mounting structure required to hold it in place.

We understand the hardware associated with RSV steering column concept is currently undergoing a production engineering process, and when completed, shall be as producible as any steering column on the market today.

Also, the RSV dual driver bag was shown in supplementary sled testing in this program (see Section 8.0) to provide protection to 42 mph when used with the production Volvo column hardware. Higher speed performance can be anticipated in future development, should varying of the column collapse load be allowed.

3. The experimental belt systems were the least production-feasible restraint systems evaluated in the program. Both the airbelt and 2-inch belts were active systems, and were hard-mounted to the Volvo floor and B-pillar anchor points through force-limiters at each anchor point. The rationale was that in order to establish the theoretical limits of performance for the belt systems, no slack, such as that introduced by retractors or passive mechanisms, could be tolerated. These conditions for the belts were somewhat unrealistic from the standpoint of passivity or comfort features; however, a web locking device was tried in the Torino bullet cars and showed promise that such devices, sometime in the future, could permit the addition of retractors or passive mechanisms without degrading the performance of the belts.

3.2 PERFORMANCE CONCLUSIONS

4. After studying Figures 2-4 through 2-7 we see that using the present FMVSS 208 injury criteria, the restraint systems may be ranked in order of overall performance as:

a) Airbelt or right front passenger airbag system (a virtual tie)
b) Driver airbag system
c) Force-limited 2-inch belt system.

If however, the 1500 lb torso belt load were used as limiting criteria, we see from Figure 2-8 that there would be an even greater spread between the number two system (the Driver Airbag System) and the number three system (the Force-Limited 2-Inch Belt System) since, as shown in the figure, the survivability margin for the FLB system would decrease drastically.

5. On the average, three of the four restraint systems can be expected to "meet" the head and chest injury criteria for all accident modes at the speeds listed in Figure 2-3. Only the force-limited 2-inch belt fails, on the average, to meet the HIC requirement in the full frontal impact mode. For all other modes this restraint can be expected to meet the injury criteria at the velocities shown on the diagram.

6. The chest can be expected to be the critical anatomical area for the occupants restrained by the inflatable restraint systems while the head is the critical area for the occupants restrained by the force-limited 2-inch belt system.

7. Frontal impact is the critical test mode for all four restraint systems. Only accidents in this mode really exercised the systems near or above the criteria limits.

8. The critical delta V for each restraint system in the frontal mode is approximately:

System	Critical Delta V (Survivability Limit)
Airbelt System	> 50 mph
Right Front Passenger Airbag System	> 50 mph
Driver Airbag System	48-50 mph
Force-Limited 2-Inch Belt	< 48 mph

*9. The force-limited 2-inch belt system is "chest critical" for the offset and oblique modes and "head critical" for the frontal mode. All other systems are "chest critical" for all modes.

*Note: The above conclusion is based upon the same injury criteria being applied to each restraint. In this author's opinion the force-limited 2-inch belt should be judged with different chest criteria than the inflatable devices since the load is more concentrated with the 2-inch belt.

10. In general, it may be said that all four of the advanced restraints tested showed a performance level far above that required by FMVSS 208. When one considers this was accomplished in a production, compact size automobile the results are extraordinary.

11. Since all four of these basic systems show a great deal of potential for increased protection levels over that which is currently being experienced in production automobiles, the author feels there is a moral obligation to continue their development. These basic systems should now be "productionized" and then retested to become viable candidates for eventual installation in production vehicles. One such exercise done with the driver airbag system as part of this program was successful (Section 8.0) and there is no reason to believe further productionizing of the other three systems would not also be successful.

3.3 RECOMMENDATIONS

There are two primary recommendations that could be made after the results of the program are in and evaluated. One recommendation concerns the Volvo itself and the other the future development of the restraint systems. First let us discuss the Volvo.

The Volvo automobile proved to be a "good" vehicle in which to perform these tests since, first of all, it was of average size and weight and, therefore, represented, as well as any vehicle, the average vehicle on the road today. For this reason the performance levels obtained for the restraint systems can be widely applied and used as comparative data for vehicle classes above and below the weight and size of the Volvo.

Even though the restraint system test results obtained in the program were, on the whole, very much above average in that injury criteria were met in vehicle impacts much more severe than the "208" requirements, the Volvo crash pulse, although very good for 30-35 mph frontal impacts, is less than ideal for frontal impacts in the 45-50 mph range. It has been shown in a previous NHTSA program* that the "ideal" crash pulse for high speed frontal impacts for maximum crash efficiency with lowest injury measures is one in which the crash pulse rises relatively rapidly to the plateau g crush level and remains there or gradually declines thereafter.

In contrast, the Volvo pulse is very soft for the first twenty-five inches or so of crush. It then rises rapidly to a higher g plateau late in the event which is threatening to the vehicle occupants since crash pulse g's are directly linked to occupant g levels. This type of pulse also requires more room in the compartment for the occupants to come to rest.

For the above reasons, we recommend that the Volvo front end structure be redesigned somewhat to obtain a more idealized pulse shape. We feel this redesign, if carefully done, need not make the vehicle more aggressive in side impacts. However, a relative study of societal savings, if they were done, versus the possible loss one might give up in increased aggressiveness should this modification be undertaken, should precede the actual modification.

All in all, we feel the Volvo to be a relatively "safe" vehicle. In fact, past experience has shown that practically any other vehicle that would have been chosen for this program would also have had a less than ideal pulse shape for the very high velocities tested in this program.

The other recommendation we make concerns the restraint systems themselves. As related in the conclusions above, the overall performance of each of the four advanced restraint systems was generally much above that given by current production restraint systems. The only drawback is that, with the advanced belt systems in particular and the advanced airbags to a lesser degree, the restraint systems are not yet what one might term a "production" system. We therefore, have a situation where, on the one hand, we have promise of significantly improved restraint performance, but, on the other hand, it is not ready to be installed in vehicles on a mass basis. There is a promise of significantly reduced injuries and, therefore, societal cost of accidents but,

*Final Report, DOT Contract DOT-HS-113-3-742, "Development of an Advanced Passive Restraint System for Subcompact Car Drivers", Section 4.2.2.1.

frustratingly enough, insufficient data and development work to place them in vehicles on a mass basis.

For these reasons we recommend further development work to be planned and implemented by the NHTSA for at least the two systems requiring the least development work to place them in vehicles on a mass basis. These two systems are the driver and passenger airbag restraint systems. In our opinion, further testing, refining, and productionizing of these two systems would pay off in quickly obtaining two high performance, producible restraint systems for the driver and passenger that could be quickly implemented into production vehicles in the 1984 time frame.

4.0 PROGRAM METHODOLOGY AND SCOPE

Prior to our discussing the actual testing that took place in this program it will be informative to lay the groundwork, so to speak, for the main objectives of the program. In this section, then, our task is to:

1. Clearly state the objectives of the program and the criteria we used to determine the degree to which we accomplished our objectives,
2. Lay out the program methodology (approach) we feel provided the greatest promise in meeting these objectives,
3. Discuss briefly the program as related in Figure 4-1.

At this point it will be useful for the reader to refer to Figure 4-1 and continue to refer to it as the program methodology unfolds in the following pages. In this way we will briefly "talk through" the flow chart which depicts the program milestones. Once we have done this and we have a general idea of the "flow" of the program, we will begin a detailed discussion of the program in the subsequent sections of this report. Even in the detailed discussion to follow later, we will follow the basic approach outlined in the figure.

4.1 PROGRAM OBJECTIVES AND CRITERIA

The primary objective of this program was to evaluate the performance of four different types of restraint systems in the 1976 Volvo. By "evaluate the performance" we mean to determine a crash survivability envelope that reflects the performance capabilities of each restraint system when installed in the subject vehicle undergoing a crash mode that produces a significant percentage of the total societal cost of all vehicle accidents.

The criteria used to determine the crash survivability limits were established by NHTSA and are listed below:

- Head Injury Criteria (HIC) < 1000
- Peak Resultant Chest G's < 60 G's
- Peak Femur Loads < 2250 lb

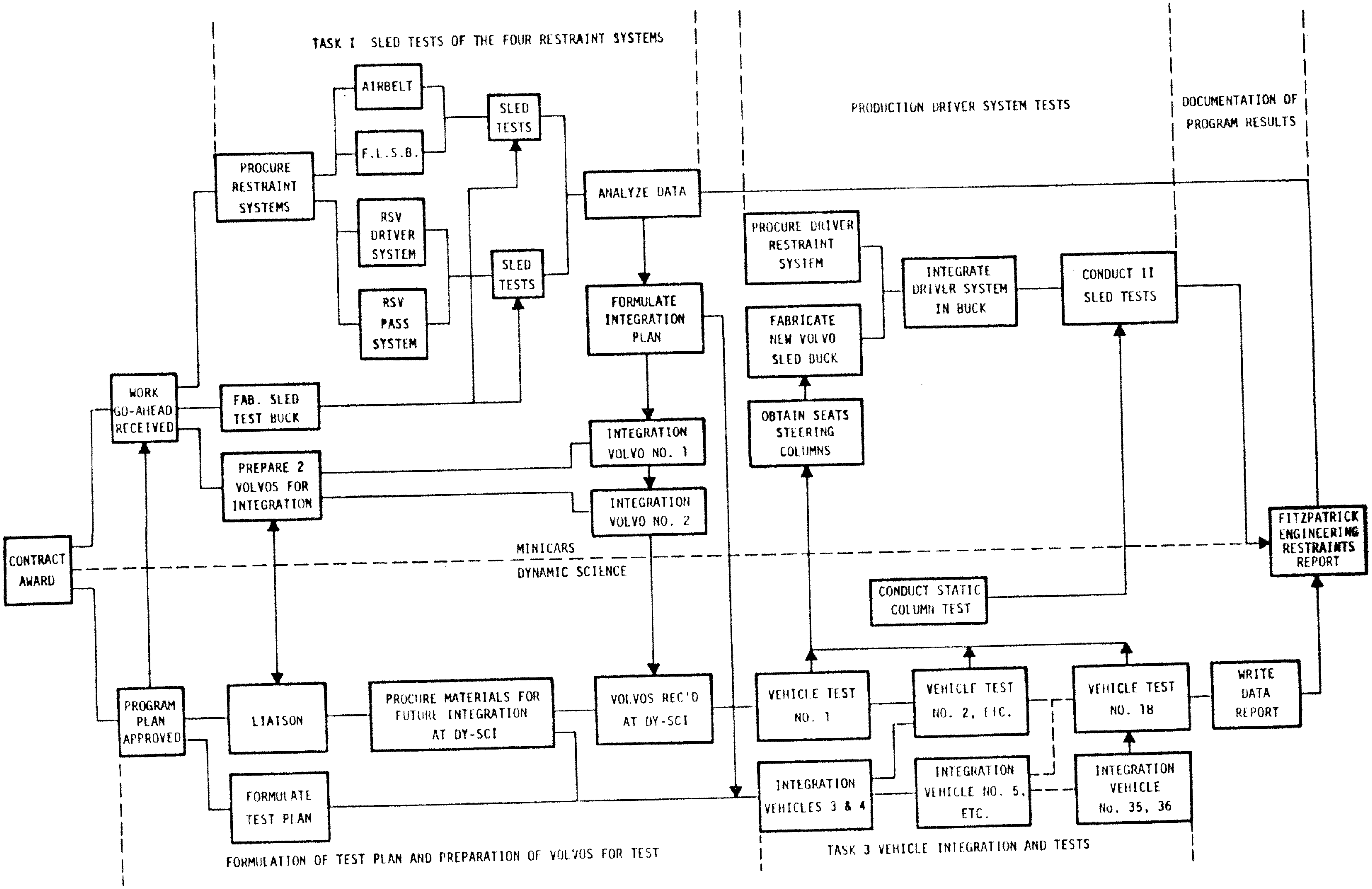


Figure 4-1. Program Development

4.2 PROGRAM DEVELOPMENT

Figure 4-1 is structured to provide a visual picture of the total program. Let us now discuss briefly the overall program development so that when we begin to discuss the detailed design, integration and testing of the various restraint systems, we will have an overall idea of how that specific task fits into the overall program development.

Following approval of the program plan, submitted by Dynamic Science to NHTSA, both Minicars and Dynamic Science began parallel efforts structured to culminate in a series of vehicle crash tests at Dynamic Science later in the program. This parallel effort is best visualized by the flow chart previously referenced. In the Figure, the Minicars effort is depicted by those events lying above the dotted line, while the Dynamic Science effort is depicted by those events that fall below the line.

Minicars portion of this initial effort consisted of procuring the necessary restraint hardware necessary to conduct a minimum of 6 sled tests and 19 full scale car crash tests with each of the 4 systems. Dynamic Science's efforts during these initial stages was in receiving the vehicles to be crash tested and beginning to strip the cars so they would be ready for later restraint integration and crash testing.

The purpose of the initial sled tests at Minicars was to take each of the four restraint systems; the Minicars RSV driver, front seat passenger and rear seat restraints plus the Minicars airbelt system and conduct several sled tests with each in order to "tune" the systems to the 1976 Volvo crash pulse (Figure 4-2). Since the crash environment of the Volvo is different than the Minicars RSV and the Ford Pinto (the vehicle that the airbelt was originally designed to operate in), this part of the program was an integral step in obtaining satisfactory performance in the Volvos crashed later in the program.

During the time these initial sled tests were being conducted, Minicars began the preliminary integration of each of the four systems into two 1976 Volvos. Since Minicars' personnel had developed each of these four restraints,

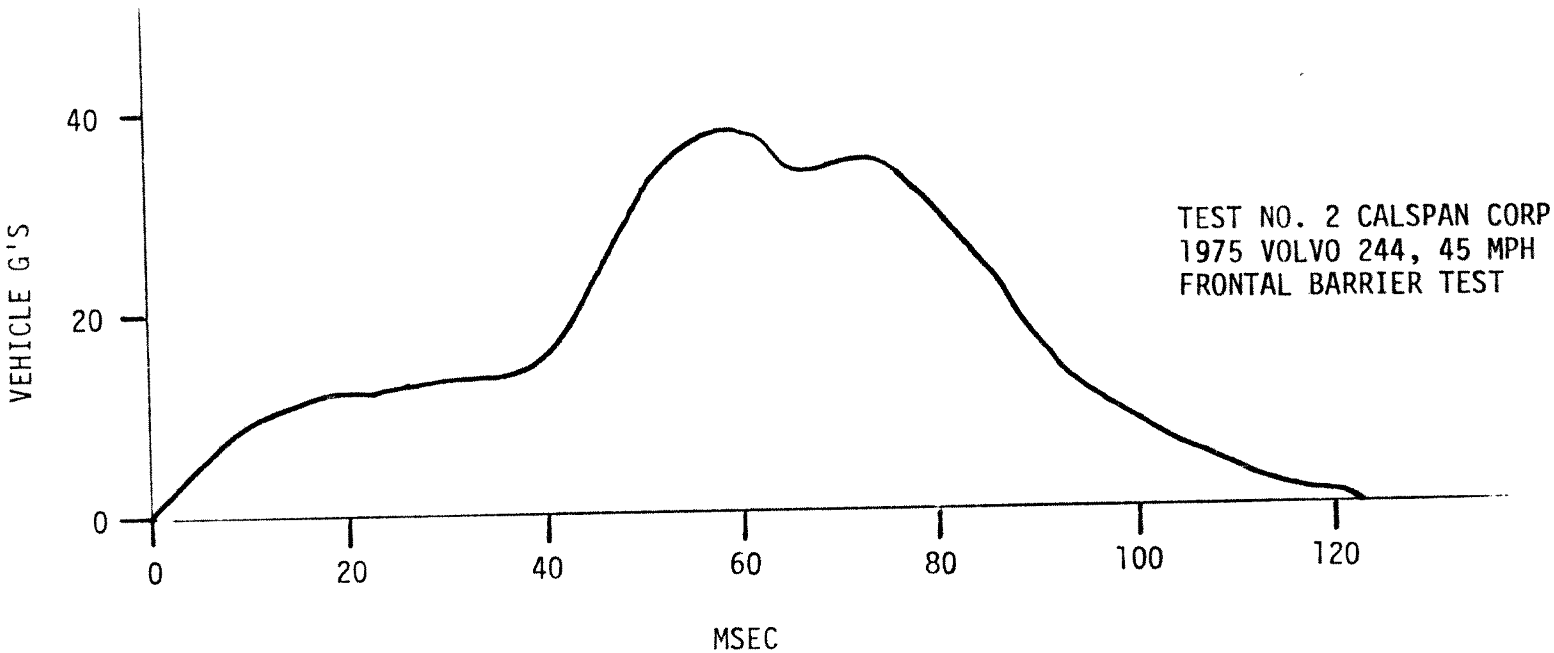


Figure 4-2. Volvo 244 Crash Pulse

it was convenient to conduct the integration in the first two vehicles at the facility of the restraint system supplier - Minicars. Once the integration methodology and technique had been worked out at Minicars, the cars were shipped to Dynamic Science. All future integration effort in this program, as well as the crash tests themselves, were conducted at Dynamic Science.

Once the restraint system hardware had been largely finalized through the knowledge gained in the tuning operation during sled testing at Minicars, final restraint system components were procured and shipped to Dynamic Science for installation in the Volvos.

At this point in the program, the emphasis switched from activity at the Minicars facility in Santa Barbara to the Dynamic Science facility in Phoenix. Here preparations were being made for the first of nineteen full scale vehicle crash tests with restraint systems installed. The long series of crash tests was begun on November 12, 1976 and culminated on October 7, 1977. During this time the Volvos were crashed in various accident modes that included crashes into other Volvos, Ford Torinos, and, in four cases, a fixed barrier.

Approximately three-fourths of the way into this full scale test matrix, a parallel effort was begun at Minicars to investigate the potential a more "production" driver system had in meeting the injury criteria at high speed. This more producible version was investigated since the Minicars RSV system used in the full scale vehicle crash test relied upon a steering column design that was, at that point in its development, rather developmental in nature with a column angle from horizontal of only 7 degrees. In this parallel sled test effort an actual Volvo column was used at its standard 23-1/2 degree angle from horizontal.

This brief summary,coupled with the flow chart (Figure 4-1), outlines the program and shows how the prime contractor (Dynamic Science) and the subcontractor (Minicars) worked together to complete the objectives of the program. With this in mind, let us now proceed in this following section to a more detailed discussion of the events outlined in the flow chart.

5.0 DISCUSSION — PHASE I SLED TESTS

Upon notification by Dynamic Science, Minicars began preparations for a series of sled tests to be conducted on the Minicars sled. In these sled tests each of the four systems - Minicars RSV driver, front seat passenger, and rear seat passenger systems plus the Minicars airbelt system - would be tested, adjusted, and tested again. The final objective of these tests was to obtain four restraint systems individually tailored to function optimally in the Volvo crash environment. At this point, we should discuss each of these four restraint systems in some detail so that in future reference to these systems the reader will be able to more fully comprehend the discussion.

5.1 RESTRAINT SYSTEM DESCRIPTION

The Minicars RSV driver, front seat passenger, and rear seat passenger systems were developed in NHTSA Contract DOT-HS-5-01215. As such, all three of these systems were designed to perform within the injury criteria limits at impact velocities up to 50 mph in the Minicars RSV. The airbelt, on the other hand, was designed to perform within these same injury specifications but in a Ford Pinto. Again, the velocity goal was 50 mph in frontal impacts.

In both programs the goals were met. Injury criteria were below criteria limits at the required velocities in the specific crash environment for which the restraint was designed. It was the goal of these sled tests then, to further "tune" these systems to operate in the Volvo crash environment. We will first describe the Minicars RSV driver restraint system, then, the Minicars RSV passenger restraint system, the Minicars RSV rear seat restraint system, and finally, the Minicars airbelt system.

5.1.1 Minicars RSV Driver Restraint System

The RSV driver restraint system is composed of an energy absorbing steering column, a column mounting system, a steering wheel assembly which houses the airbag and inflator, and a knee restraint (Figure 5-1).

Energy is absorbed during stroking by a rollerless tape mechanism. A continuous length of steel tape is attached at its ends to the right and left side interior walls of the forward tube and at its middle to the forward end of the aft section of the column (Figure 5-2a). As the column telescopes (Figure 5-2b), the tape loops roll off the sides of the forward section and onto the sides of the smaller aft section producing a static column collapse force given by:

$$F_c(x) = \frac{2\,\sigma_y t^2\, W(x)}{D + t}$$

where,

x = column stroke (in.)

σ_y = yield strength of the tape material (psi)

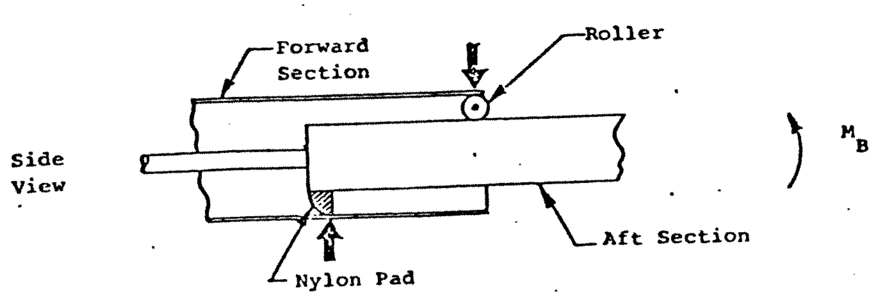
t = tape thickness (in.)

$W(x)$ = tape width at the loop as a function of column stroke

D = loop diameter (in.)

The parameters above have been set to result in a theoretical stroking level of approximately 1,750 pounds.

As with other steering columns, the RSV column is subjected to severe bending moments. The most severe of these is the counterclockwise* bending moment associated with the upward force at the steering wheel rim end of the column. To counteract this moment without introducing excessive friction, a roller is provided at the aft upper end of the forward section of the column to bear on the top flat of the aft column section. A nylon slide pad is provided on the bottom forward end of the aft section to bear on the lower interior surface of the forward column section as shown below.



*As viewed from the driver side of the vehicle.

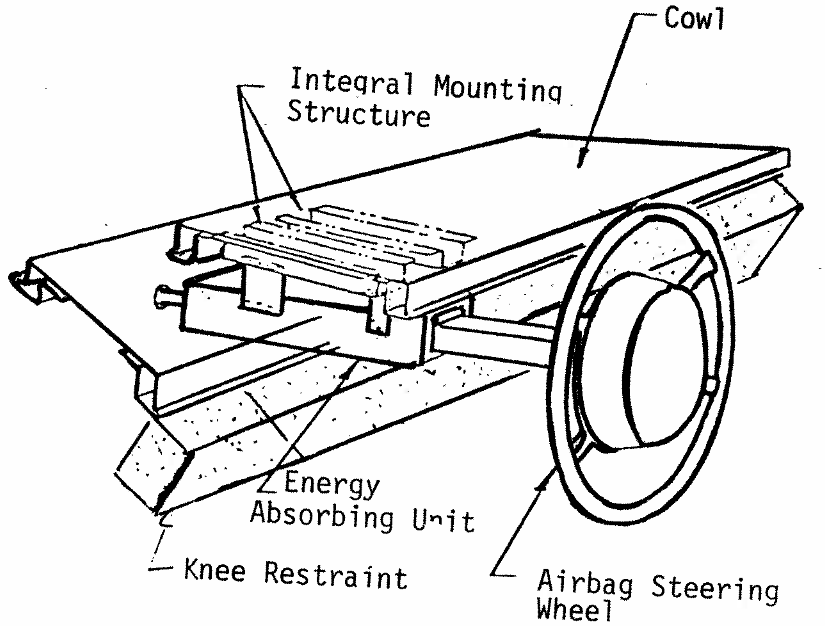


Figure 5-1. RSV Steering Column System

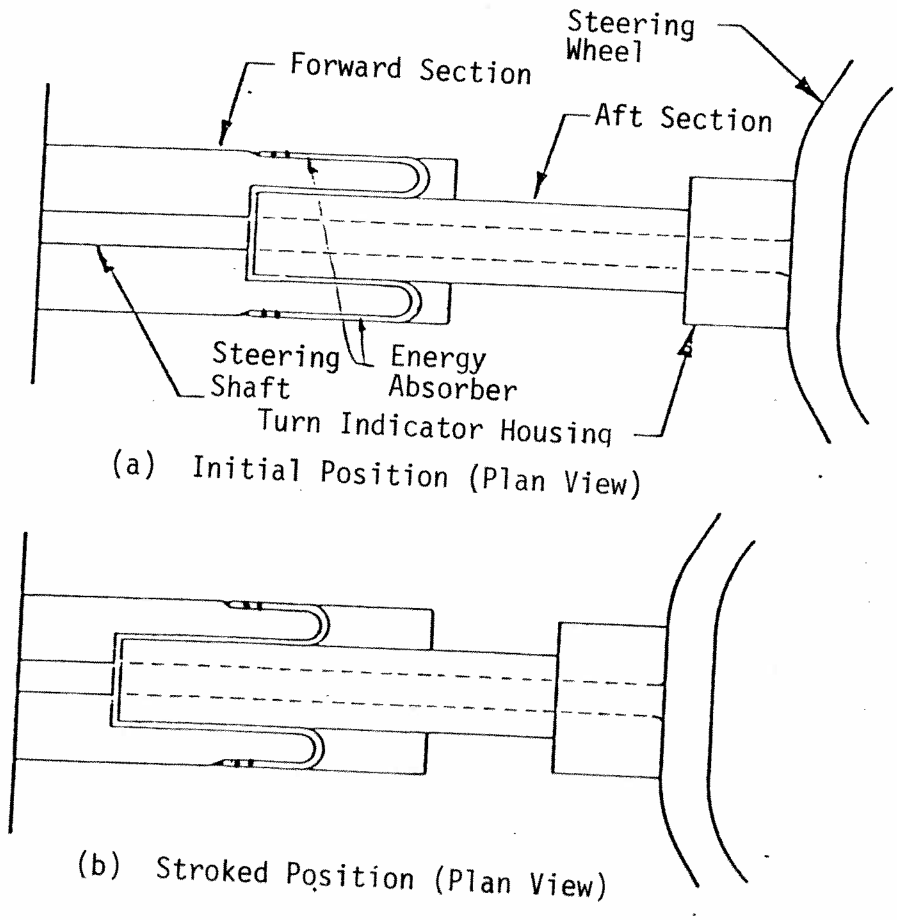
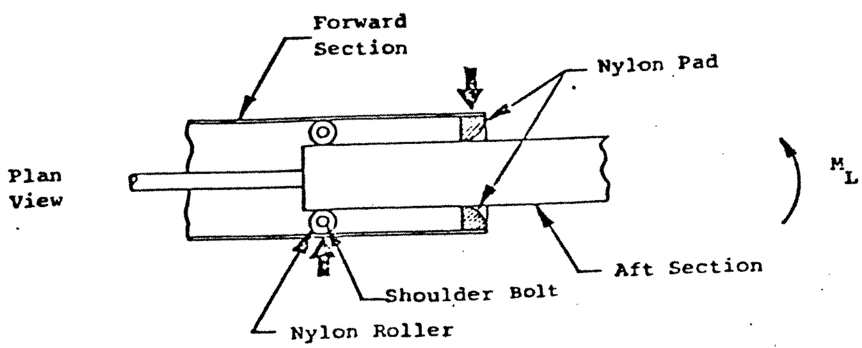


Figure 5-2. RSV Column EA Mechanism

Significant lateral bending moments arise when the vehicle is involved in an angular or offset frontal collision and/or when the driver is not directly behind the column at impact. To counter these lateral bending moments, nylon pads are provided on the forward section of the column at its aft end on the interior vertical walls of the tube. These pads bear against the right and left sidewalls of the column aft section. Two shoulder bolts, inserted vertically through the forward section of the column, contain nylon rollers which bear on the side walls of the aft column section as shown.



The steering shaft is a conventional (Ford) telescoping unit with splined aft end. Bearings for this shaft are provided at the firewall at the point it enters the aft section of the column and where it connects to the steering wheel. Also, attached to the aft end of the column is a Ford turn indicator/ignition/column lock assembly.

The steering wheel assembly is comprised of a wheel rim, inflator, reaction plate/retaining ring assembly, airbag configuration, and a bag cover as shown in the exploded view of Figure 5-3. The wheel rim is a General Motors Air Cushion Restraint System (GM ACRS) rim, a significantly more rugged rim than any other commercially available model. The wheel rim has four spokes, a diameter of 15-1/2 inches, and a depth of 4 inches. The inflator is an uploaded version of a unit manufactured by Thiokol Corporation to meet GM ACRS specifications with the inflator propellant charge being increased by about 10%.

The bag system is clamped to a large (9-3/4 in. diameter) reaction plate/ retaining ring assembly.

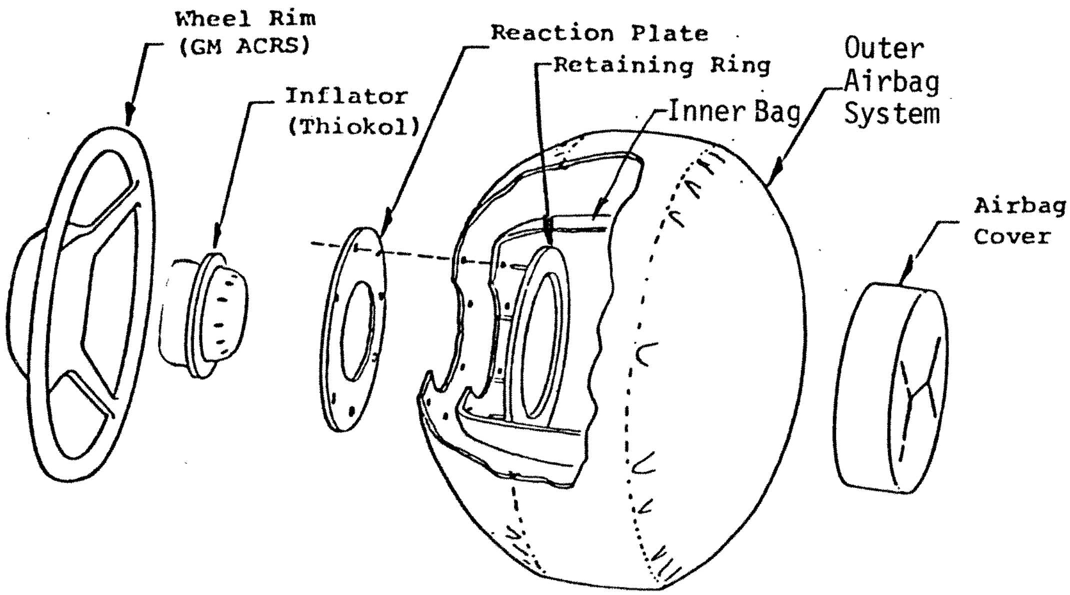


Figure 5-3. Steering Wheel Assembly Exploded View - Dual Airbag System

The RSV driver bag system is a dual-bag configuration. Both the inner and outer bags are cylindrical in shape (Figure 5-4). The inner bag volume is 1.0 cubic foot: the larger, outer bag has a volume of 1.7 cubic feet. The bags are constructed of low permeability plain weave nylon. Venting in both bags is accomplished solely by virtue of bag porosity.

The lower body energy of the driver is absorbed by the foam knee restraint, attached to a sheet metal backing plate on the lower dashboard (Figure 5-5). As can be seen, the backing pan is attached to the cowl and the firewall, and is oriented at about a 45° angle. The knee restraint consists of about 10 inches of rigid "DB" foam faced with a protective and decorative elastic foam-backed cover material.

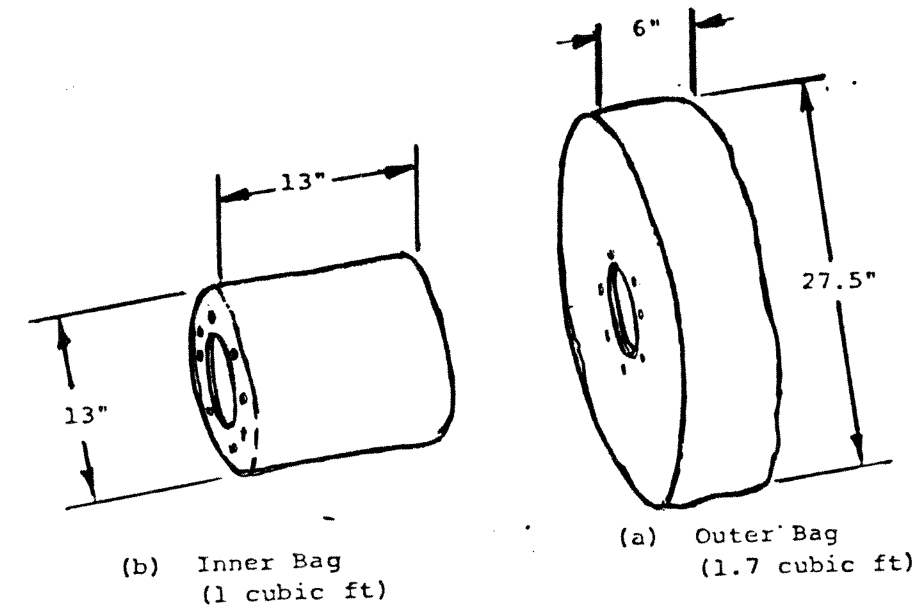


Figure 5-4. RSV Dual Airbag Configuration

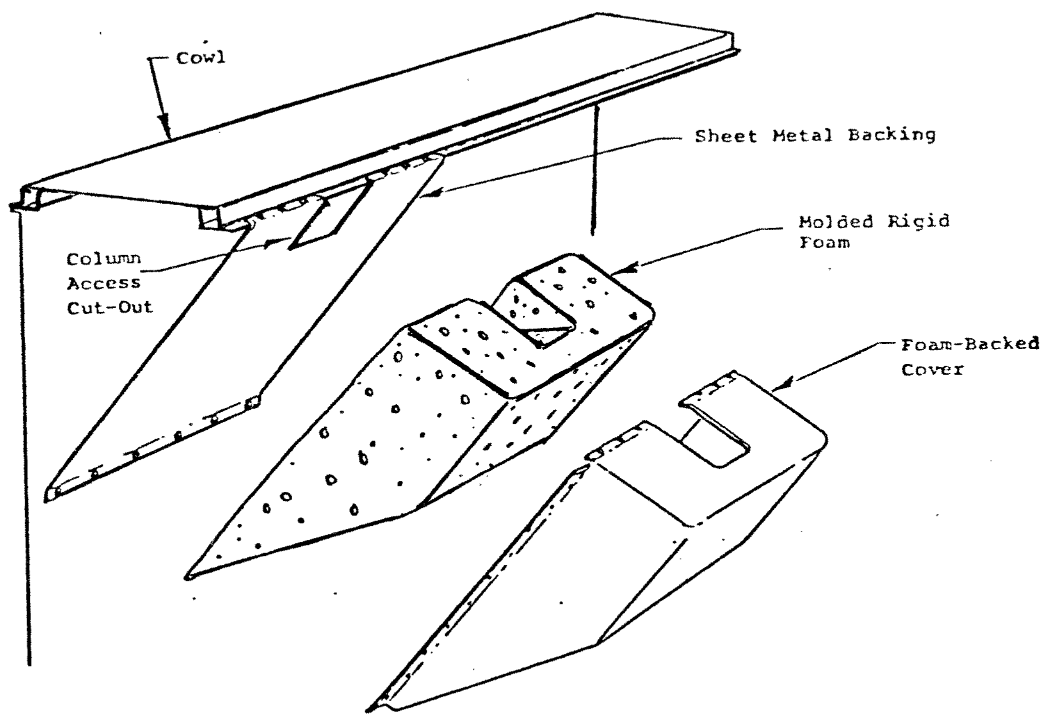


Figure 5-5. RSV Driver Knee Restraint

System-Operation

Operation of the RSV driver restraint system is best described by relating the sequence of events which occur during the most severe frontal impact condition for which the system is designed – a 50 mph barrier impact. A sequence of five sketches depicting critical moments in the frontal crash event is shown in Figure 5-6. Sketch (a) shows the occupant, restraint, and vehicle at the moment of bumper contact with the barrier.

Sketch (b) is at sensor switch closing which in this case occurs in the bumper switches at about 9 milliseconds into the event. At this point, the driver has moved forward only a fraction of an inch.

About 30 milliseconds into the event the occupant begins to experience deceleration from his restraint system, as shown in (c). The small inner bag, which receives gas directly from the inflator, can respond very quickly.

At about 80 milliseconds into the 50 mph barrier impact (d), the force exerted by the airbag system on the driver's chest exceeds the stroking force (about 1,750 pounds) of the steering column. Since the effective weight of the 50th percentile upper body is about 60-65 pounds in this situation, the force-limiting nature of the collapsible steering column produces chest deceleration levels of about 30 g during column stroking. The larger volume outer bag, inflated by the gas vented from the inner bag, captures and prevents the head from whipping forward.

Sketch (e) Column Stroking Ends – at about 100 milliseconds the driver reaches maximum forward translation in the compartment. The steering column has stroked about 4-1/2 inches and the knees have penetrated the lower dash about 6 inches (e). At this instant the occupant begins a very mild rebound into the seat.

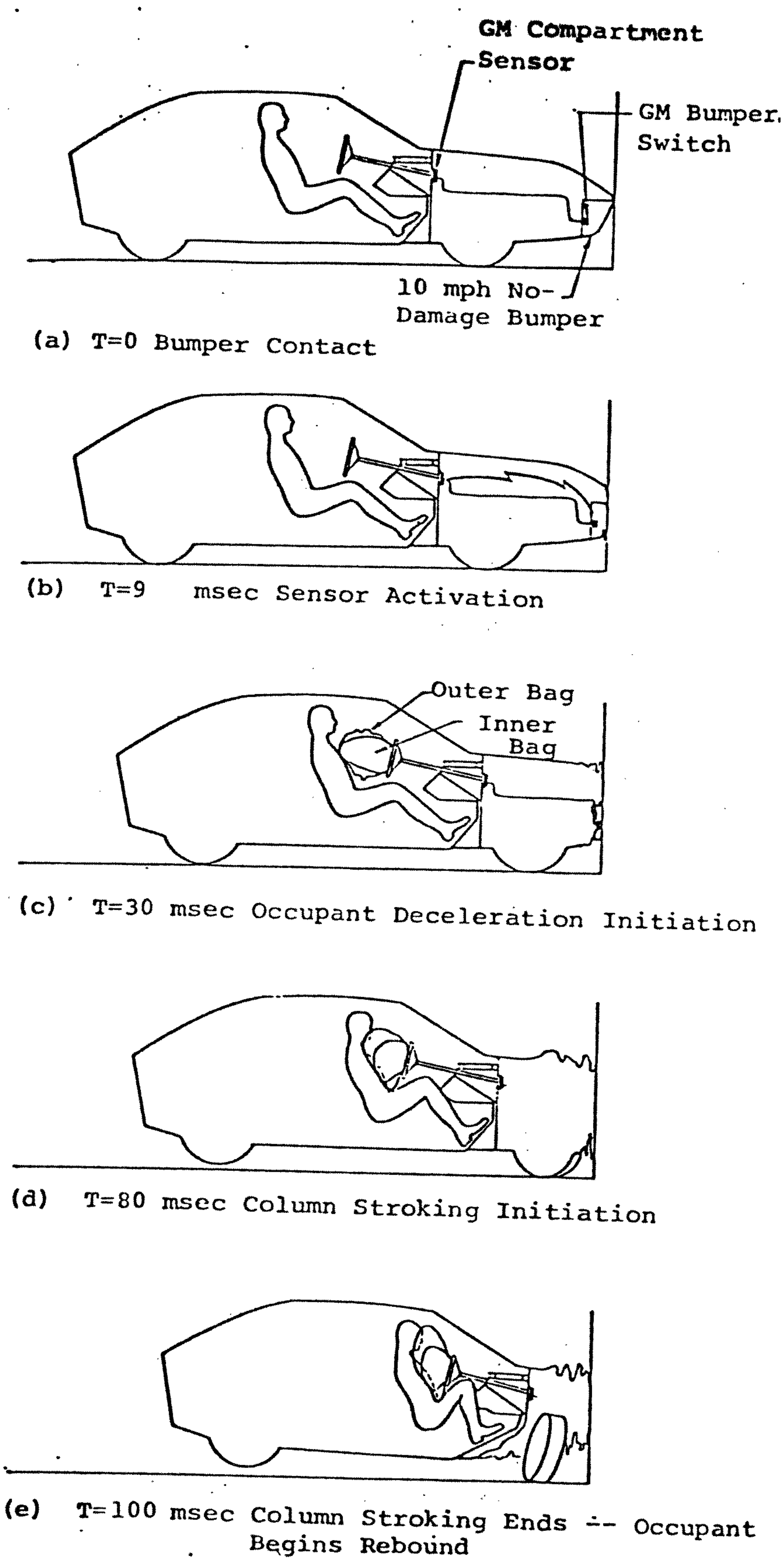


Figure 5-6. Driver Restraint Operation During Critical Moments in a 50 mph Barrier Impact

5.1.2 Minicars RSV Right Front Passenger Restraint System

Description

The restraint system selected for the RSV front passenger position, like the driver restraint, uses the dual airbag concept. Unlike the driver system, however, it was designed in accordance with two constraints not imposed on the design of the driver system. For the front seat passenger, it was necessary to develop a passive passenger restraint system which would not only meet the requirements for occupant protection, but would also maintain standard chest-to-dash distances so that ingress and egress and normal passenger movement in the compartment would not be hindered. It was also desirable that the system afford maximum protection for the out-of-position child in the front passenger seat and that the system be entirely mass-producible. The system is comprised of dual-chamber airbags, a Thiokol solid propellant gas generator, and a crushable knee bolster. (Figure 5-7).

System Operation

System operation commences approximately 9 milliseconds after bumper contact, at which time the bumper sensor signals the gas generator to initiate gas flow into the relatively small (3.8 cubic foot) torso bag (see Figure 5-8 for inflation sequence). Because of the small bag size, the bag fills very quickly. Chest g's begin to increase approximately 25-30 milliseconds after bumper contact.

Airbag. As the torso penetrates the lower torso bag, torso g's and torso bag pressure begin to increase. This increased pressure diverts a larger portion of the gas flow to a vent between the torso and head bags, causing the head bag to inflate. Approximately 50 milliseconds after bumper contact, the head bag is completely inflated. Since the head does not require support until after the torso has been somewhat retarded, the head bag need not deploy as rapidly as the torso bag. Thus, the dual-bag feature of the system enables the gas to be used twice — first to inflate the torso bag to

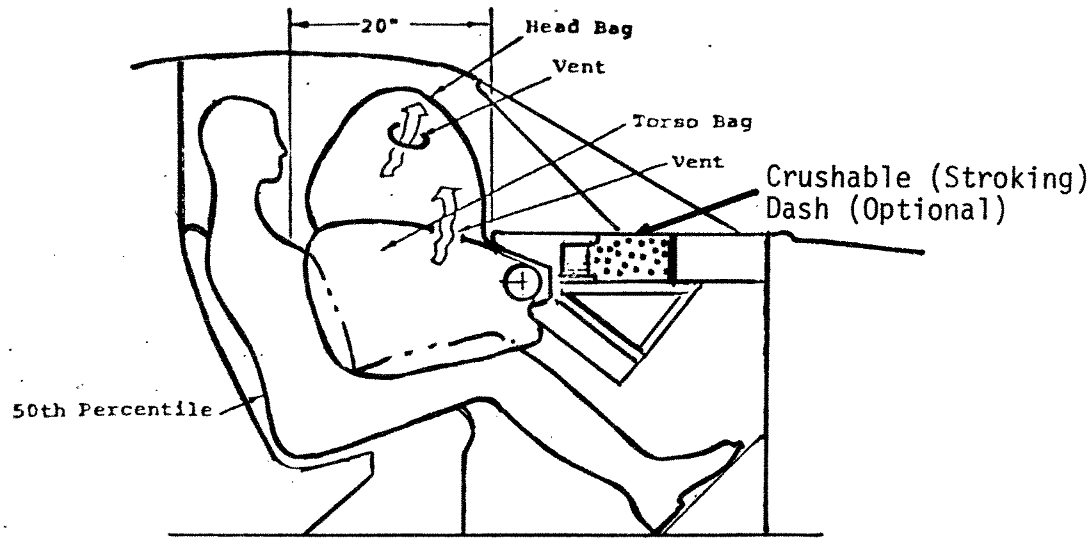


Figure 5-7. The RSV Passenger Restraint

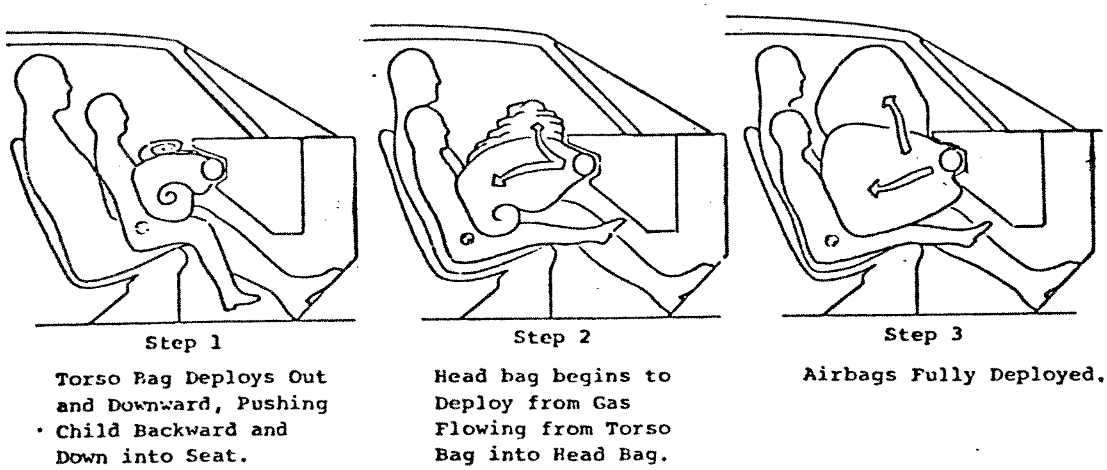


Figure 5-8. RSV Passenger Bag Inflation Sequence

slow the torso, and second to inflate the head bag to retard the head. Other advantages are inherant in the dual-bag system. For example, because the chest has a higher mass-to-area ratio than the head, it requires a higher bag pressure. This requirement is ideally satisfied by the dual bag system since the volume and venting features of the two bags can be individually tailored to satisfy these differing head and chest requirements. Another very important advantage is that the inherently quick response time of the small torso bag that, when coupled with the tailoring characteristic previously cited, combine to provide a very stroke-efficient airbag system.

The inflated RSV passenger bag is shown in Figure 5-9. As can be seen, the membrane separating the two bags acts as a tension member to prevent the restraint bag from presenting a spherically-shaped bag front to the passenger at initial contact. With a membrane tensile force at the bag center, the bag front is nearly flat. This causes chest g's to increase more rapidly early in the event (since the area of chest contact is increased) with a correspondingly higher percentage of passenger energy absorbed in the efficient "ride down" mode.

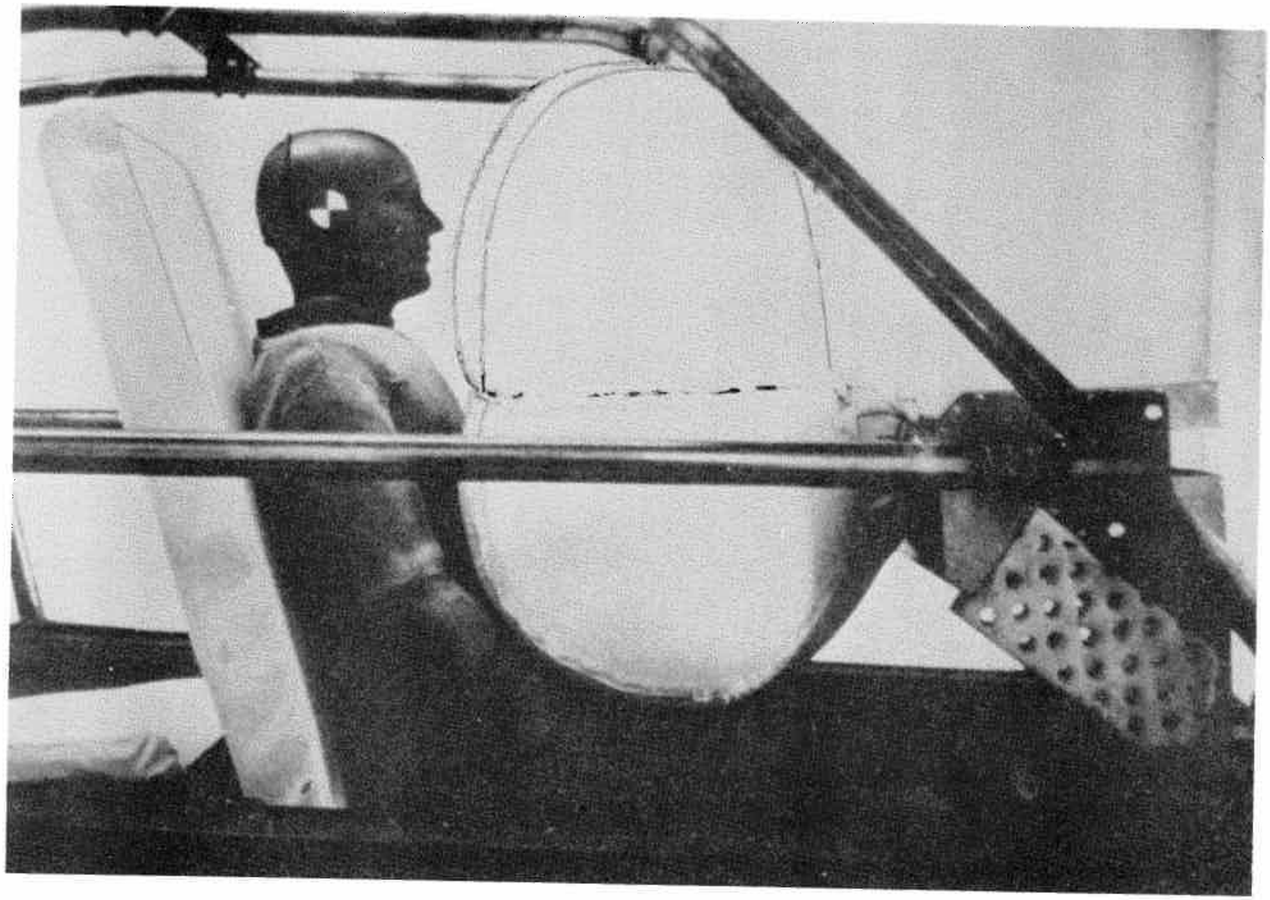


Figure 5-9. Inflated RSV Passenger Airbag

5.1.3 The Minicars RSV Force-Limited Belt System

The force-limited belt system installed in the Volvos was a three-point design. The standard Volvo anchor locations were used and a force-limiter was installed at each anchor location. Figure 5-10 shows the system installed on a 50th percentile male dummy prior to a typical car crash test. No retractor was used with this system; belt adjustment was entirely manual. The philosophy behind the system design was to ascertain, via crash testing, the maximum velocity to which an advanced force-limited belt system could be expected to protect vehicle occupants. Because of this philosophy, no attempt was made to "productionize" the system.

The force-limiter design is simple and easy to implement. The Minicars system incorporates a small, lightweight, "add-on" mechanism at each anchor location. The mechanism itself is a stamped metal piece with two flanges pierced by a 0.25 inch diameter pin (Figure 5-11).

5.1.4 The Minicars Airbelt System

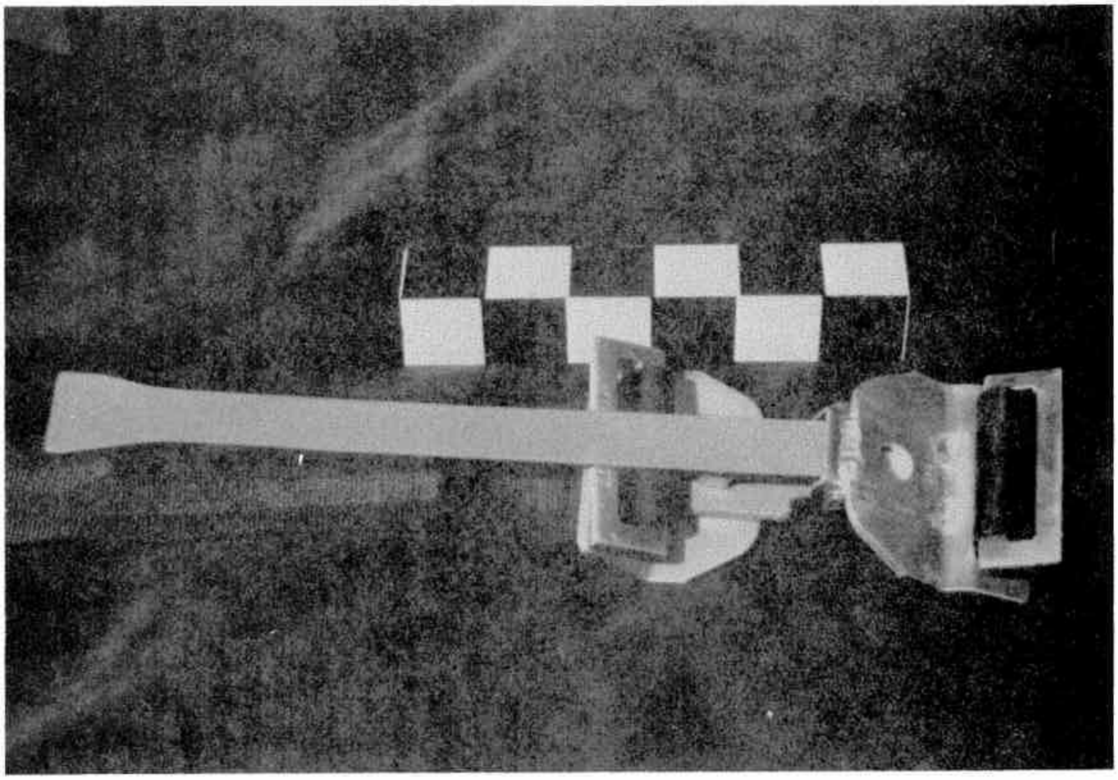
The airbelt design used in the test series was basically the airbelt system derived by Minicars in Contract DOT-HS-4-00917 and as reported in DOT report number DOT-HS-801-719.

The only modification to this basic design was in the force-limiter. The original force-limiter used in Contract DOT-HS-4-00917 was rather large and heavy. Since a newer version of this basic force-limiter was available, (Figure 5-11), we substituted the newer, lighter, more producible version for the later tests of the Volvo crash test series.

The airbelt system is a three-point design and consists of an inflatable torso belt, a conventional lap belt, an inflator, and force-limiters at each of three anchor positions (Figure 5-12).

Figure 5-13 shows a rendition of the airbag portion of the airbelt. Running longitudinally along two sides of the inflated cylinder are lengths of conventional seat belt webbing. This webbing is continuous, as shown in the figure, and is of double thickness at the ends for added strength.

Figure 5-10. Minicars RSV Force-Limited Belt System



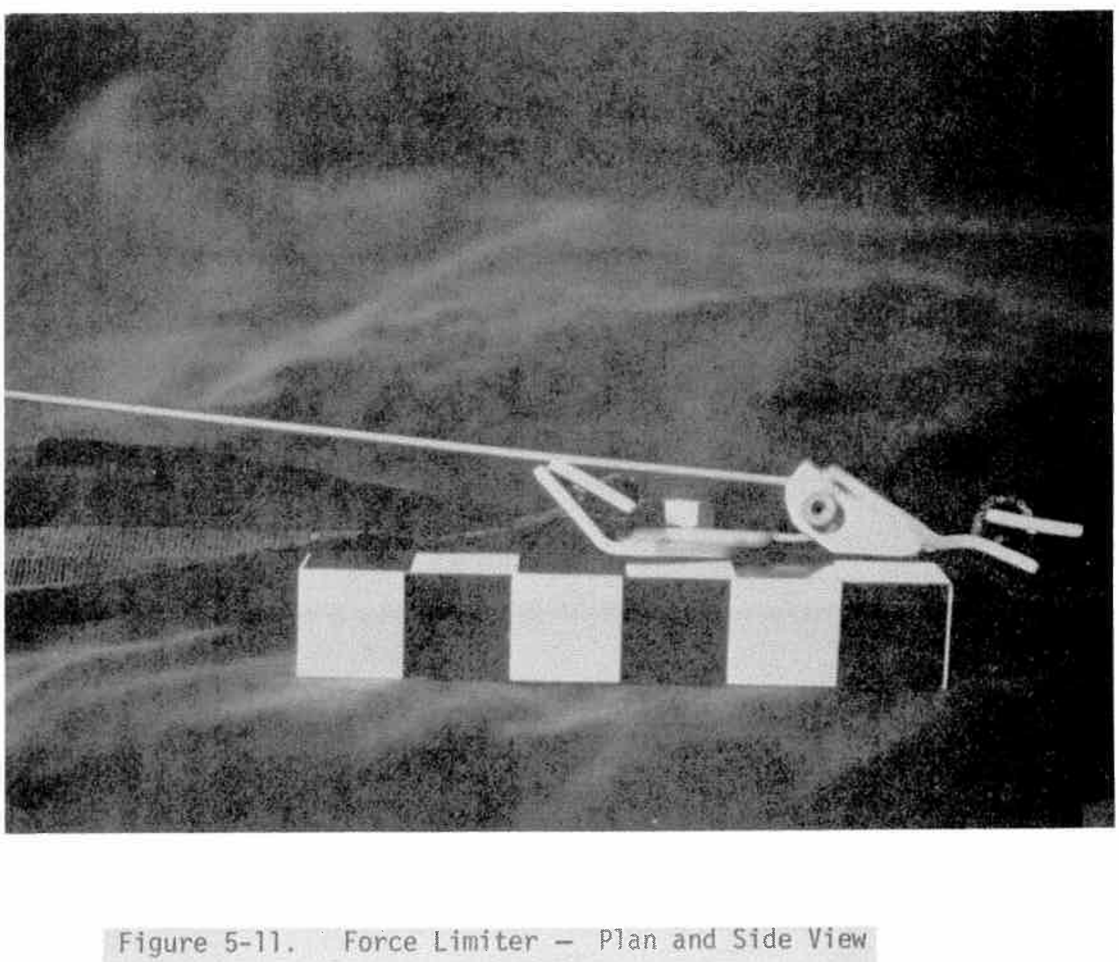


Figure 5-11. Force Limiter — Plan and Side View

Figure 5-12. The Airbelt Restraint System

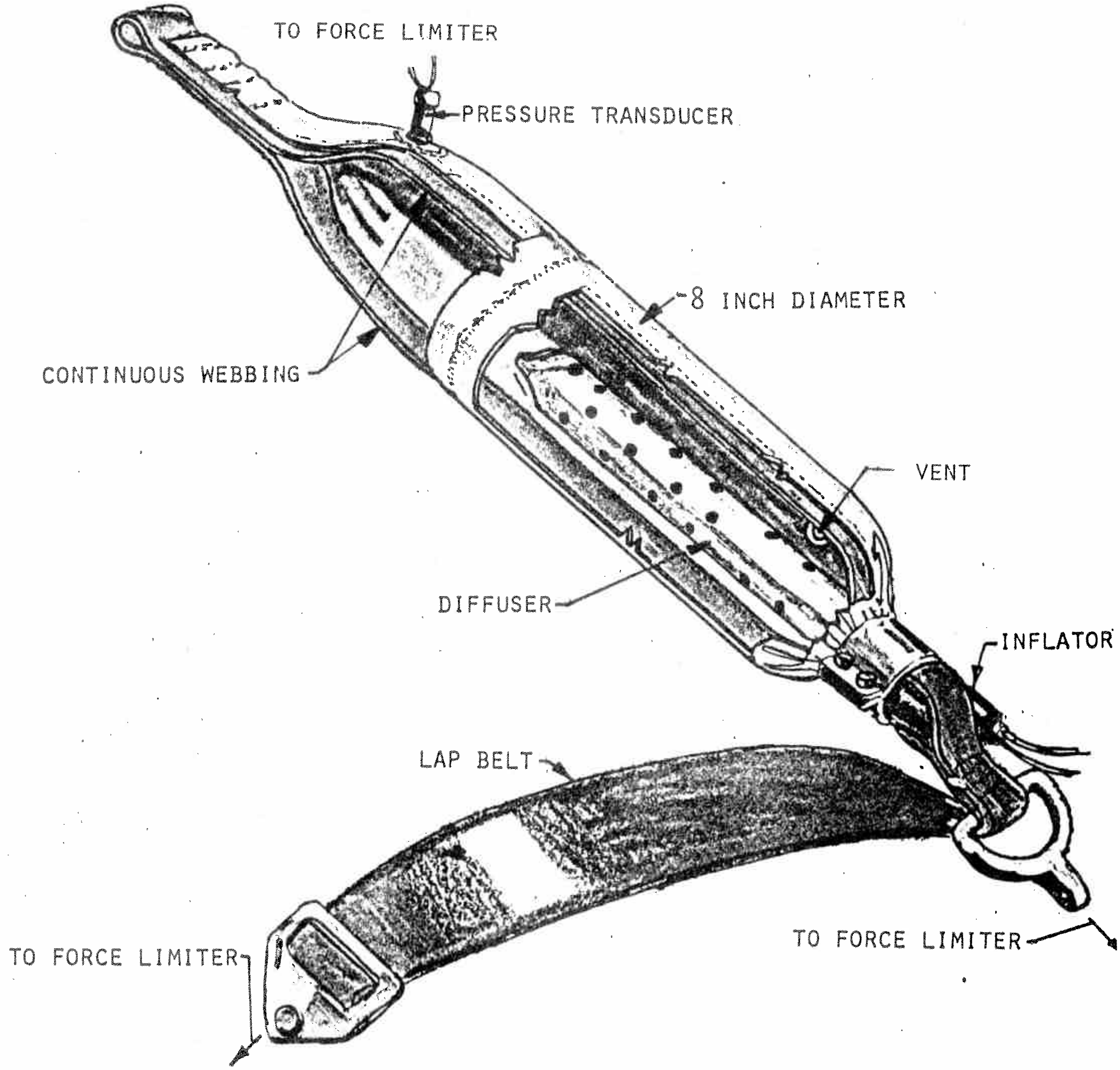


Figure 5-13. Airbelt Schematic

Located in the airbag portion of the airbelt is a 5/8 inch diameter vent which attenuates rebound by dissipating a portion of the stored compressive energy in the gas. Inside the airbag and attached to the inflator is a diffuser. The purpose of the diffuser is, of course, to distribute the incoming gas to various areas of the bag in order to prevent a large local, hot gas jet from burning a hole in the bag.

The inflator is of the pyrotechnic type rather than the stored gas type in order to properly phase the gas flow into the airbelt. Figure 5-14 shows a picture of the inflator.

The force-limiter used in the test series is identical to that described under the force-limited belt and will not, therefore be repeated here.

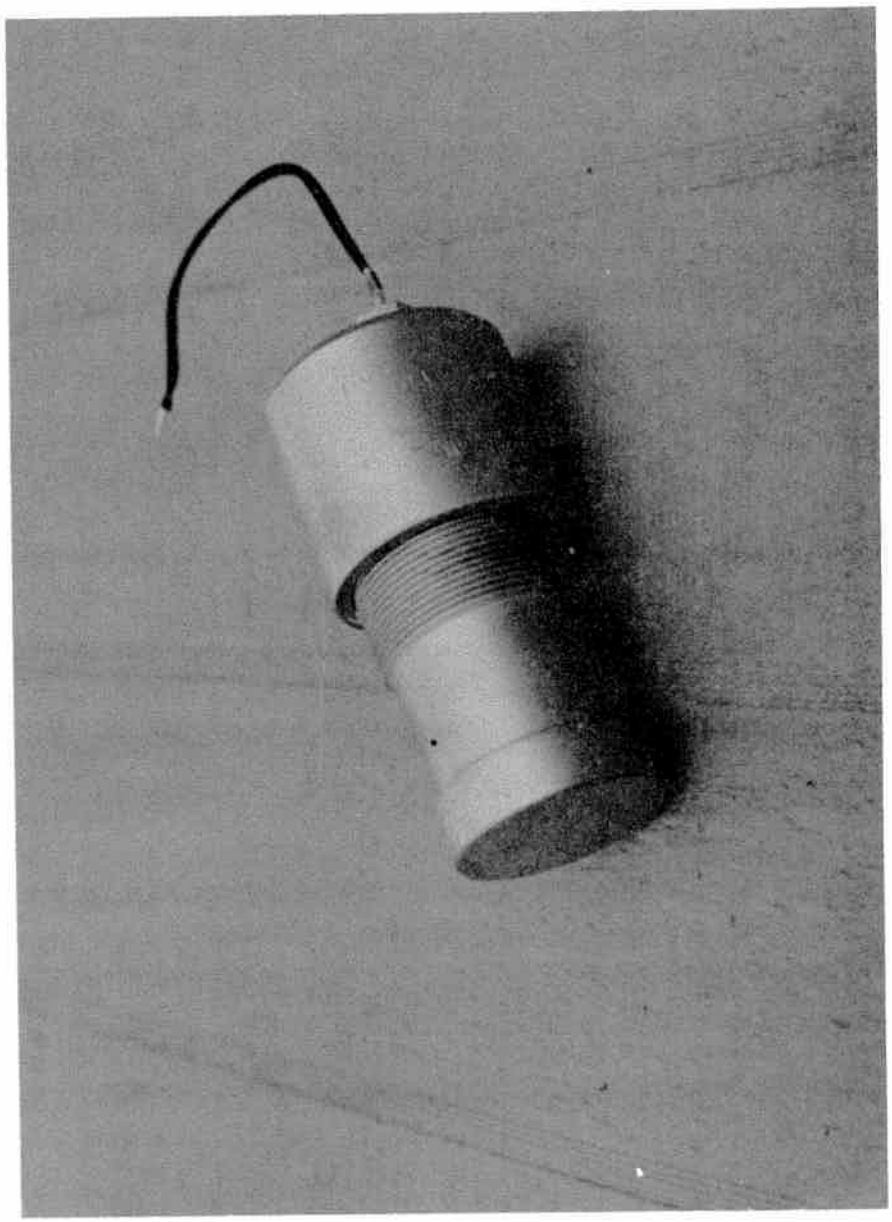


Figure 5-14. Airbelt Inflator

5.2 SLED TEST SET UP

Integral to conducting the sled tests is procuring the test hardware and fabrication of a sled test buck. Fabrication of the sled buck was straightforward and need not be discussed in detail here.

Procuring the restraint components was also straightforward with one exception. The inflator vendor for the airbelt system (Allied Chemical Co.) had ceased to manufacture the copper oxalate propellant that was used in the previously conducted airbelt program (DOT-HS-4-00917). The airbelt gas generator charged with a new propellant (sodium azide) proposed by Allied was many times more expensive than the old generator. In addition, Allied Chemical Co. proposed a significant amount of preliminary tailoring of the new propellant prior to shipping units to Minicars for test. This also was an extra, rather expensive item. Since the additional cost proposed by Allied, over what was originally bid by Minicars to Dynamic Science, was substantial, Minicars and Dynamic Science mutually agreed that obtaining another bid was in order.

Thiokol Chemical Company was forthcoming with a second bid. Of the two bids, Thiokol's bid was by far the lesser of the two. Since Thiokol has proved themselves a reliable, competent vendor on previous NHTSA programs and since Thiokol proposed to do the propellant charge weight tailoring without extra expense, Minicars and Dynamic Science mutually decided to select Thiokol as the supplier for the airbelt gas generator. Since Thiokol was already the gas generator supplier for the Minicar's RSV driver and passenger restraint systems, Thiokol now was involved in all three of the inflatable restraint systems selected for use in this program.

The crash pulse to be simulated on the sled was, as previously mentioned, the 1976 Volvo pulse. Since Calspan crashed several Volvos on a previous NHTSA program, Volvo crash pulse information was available for use in this program. NHTSA forwarded this information to Minicars and arrangements were made to obtain this pulse shape. Figure 5-15 shows the crash pulse.

The buck was completed and a series of pulse tailoring runs were initiated to match the sled pulse to the Volvo pulse. On August 25, 1976 after three pulse tailoring runs, we were ready to begin the restraint systems tests.

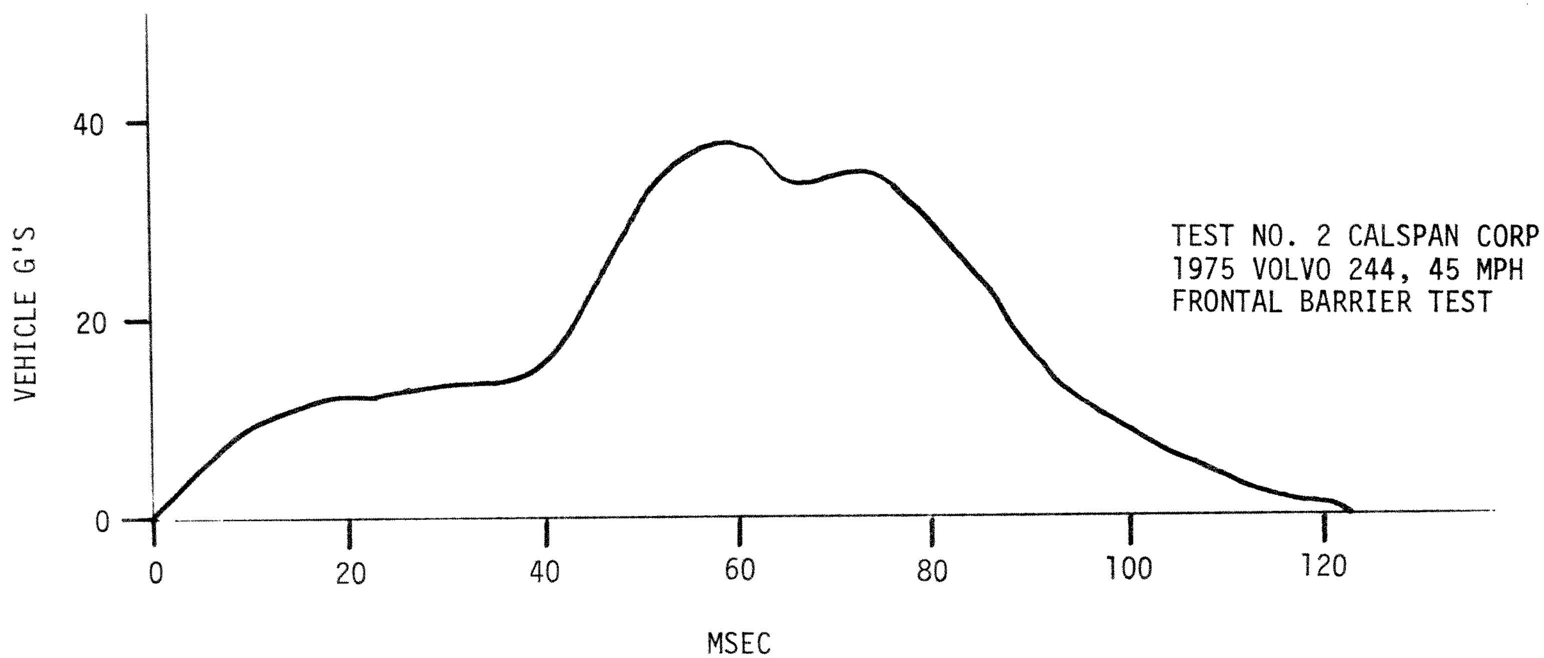


Figure 5-15 Volvo 244 Crash Pulse

5.3 SLED TEST RESULTS

In all, twelve tests were conducted in this series - 6 each with the two belt systems and 6 each with the Minicars RSV airbag systems. In all the tests the 50th percentile male was simulated. Of the six tests with the FLB (force-limited belt) system, the first three were conducted with the Volvo retractor in the system and the last three without the Volvo retractor installed. This change was made in keeping with the philosophy of the program which was to establish theoretical limits of performance for the belt systems; i.e., no slack such as that introduced by retractors or passive mechanisms could be tolerated (see Section 1.0). The results of these tests are summarized in Table 5-1. Tests 1, 2, 3 and 12 were pulse tailoring sled runs and, as such, no data is presented.

In general, it may be said that the restraints performed very well with a minimum of tuning required to make the system "work" in the Volvo crash environment. The reason little tuning was required was due to the similarity of the Volvo crash pulse to the Minicars RSV crash pulse for which three of the restraint systems were previously designed. Figure 5-16 shows a comparison of the two pulses.

As stated above, in general, the restraint systems performed very well. There were, however, two specific instances where a problem did arise but in these cases a minor adjustment was sufficient to remedy the problem. Two examples of this were in Runs 8 and 10 where the steering column stroke was abruptly terminated and the chest g's were excessive.

In Run No. 8, the column itself deformed causing the column stroking to cease. Following this run, we reinforced the column locally where the deformation occured and solved the problem.

In Run No. 10, the driver seat bottom was deformed to the point where the femurs no longer were in the proper position for normal trajectory into the knee restraint. Because of this, the knee trajectory was high so that the knees became jammed between the wheel rim on one side and the knee restraint on the other. This caused the column to cease stroking resulting in correspondingly high chest g's. Following this run the seat was repaired to prevent this problem from reappearing.

Table 5-1. Sled Test Results

VOLVO SLED TESTS

SUMMARY OF INJURY MEASURES - 50TH PERCENTILE MALE

A = airbelt
F = force limited Volvo belt system
D = RSV driver system
P = RSV passenger system

Sled Run #	Velocity -mph- / Type	HIC	Peak Res. Chest g's (-3 msec)	CSI	Peak Femur Loads L	Peak Femur Loads R	Peak Torso Belt Load -lbs-	Remarks
4-A 4-F	40 Frontal	381 928	34 48	256 332	NA NA	NA NA	NA 1500	
5-A 5-F	44 Frontal	415 High	42 70	416 698	NA NA	NA NA	NA 1600	Force limiter broke and dummy impacted dash
6-A 6-F	44 Frontal	627 1226	40 50	324 436	NA NA	NA NA	NA 1530	Repeat of Test #5
7-A 7-*	48 Frontal	390 715	37 35	390 353	NA NA	NA NA	NA 1600	* Removed Volvo retractor and excess webbing from system
8-D 8-P	38 Frontal	612 857	64 52	594 619	1900 1300	1480 1420	NA NA	Column bound up and ceased stroking
9-D 9-P	45 Frontal	544 673	45 47	535 550	1650 1400	1300 1630	NA NA	
10-D 10-P	49 Frontal	607 655	68 40	628 434	1580 1250	— 1000	NA NA	Knees interfered with column stroke
11-D 11-P	49 Frontal	504 722	44 49	480 605	1480 1370	1340 500	NA NA	Removed force limiter from dash
13-A 13-F	37 30°L oblique	341 1343	40 45	425 373	NA NA	NA NA	NA 1250	Head strike on floor due to excessive lateral movement across compartment by torso.
14-D 14-P	39 30°L oblique	— 296	60 85	589 990	450 400	400 650	NA NA	Lost head S.I. Acc. Passenger Chest impact on wheel rim
15-A 15-F	40 28°R oblique	144 179	32 55	178 406	NA NA	NA NA	NA 300	Inflatable portion of belt gave good support against lateral movement.
16-D 16-P	40 28°R oblique	324 high	50 high	398 high	600 500	1500 500	NA NA	Leaky inflator caused hole to be burned in bag which triggered bag rip.
17-D 17-P	40 28°R oblique	349 773	39 58	292 585	1100 1050	1320 850	NA NA	Repeat of 16 with inflator fixed. Extra door padding added.

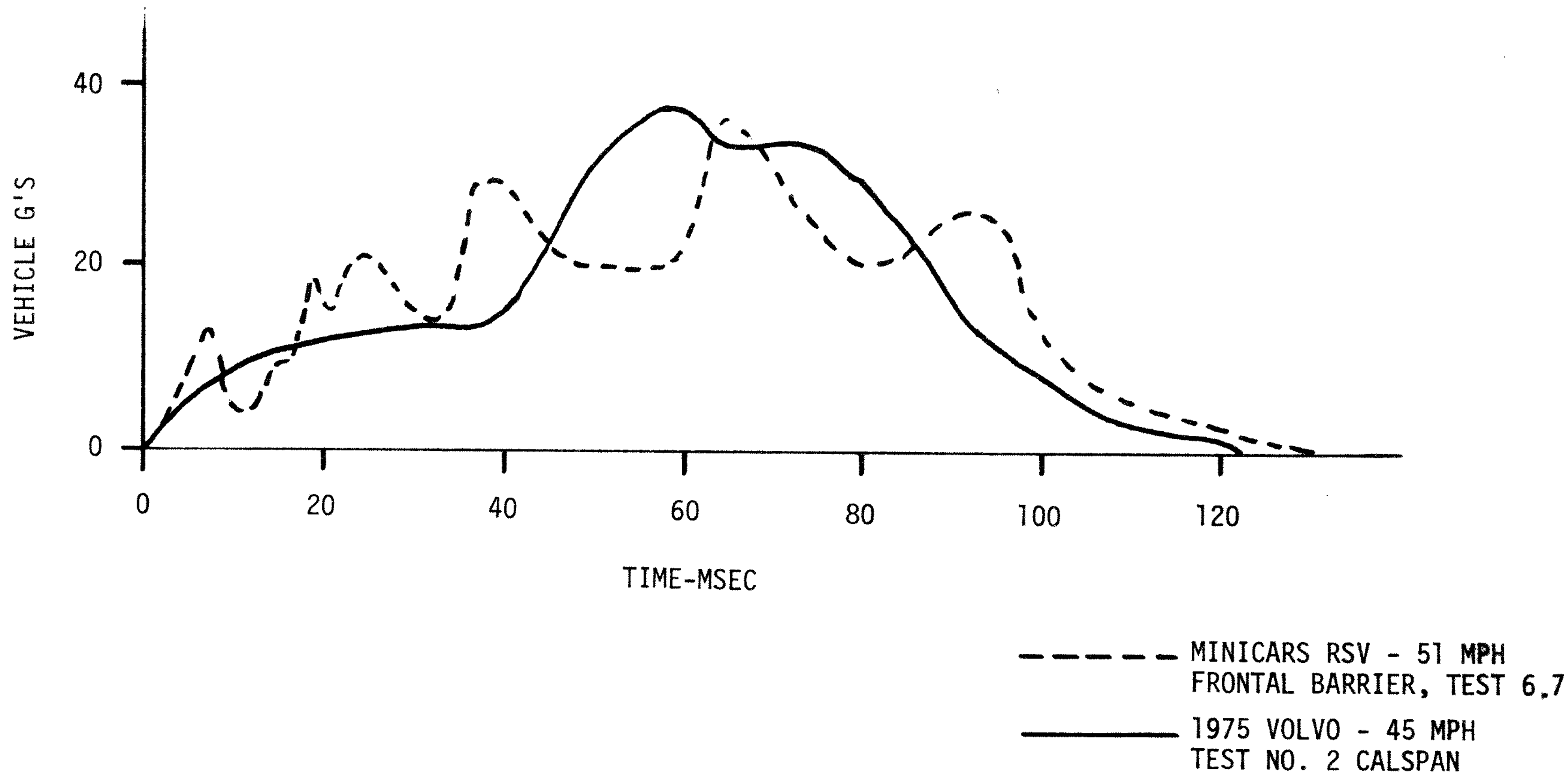


Figure 5-16 Crash Pulse Comparison - Frontal Impact

5.4 SLED TEST CONCLUSIONS

To sum up, the following general conclusions may be drawn:

1. All restraint systems performed well up to 50 mph frontal impact with the exception of the force-limited Volvo belt system with retractors. This system was HIC critical at about 40-42 mph (Runs 4-F and 6-F).
2. Significantly improved results were obtained with the force-limited Volvo system when the original retractor and single layer webbing was removed and double layer webbing was substituted for it (Run 7). This reduced the stretch in the system thereby allowing the force-limiters to operate more effectively.
3. The airbelt restraint system seems to result the lowest overall injury measures.
4. The force-limited Volvo system did not adequately restrain the passenger dummy for far side oblique impacts (Run 13-F). The dummy would slip out of his torso belt and rotate about his waist until his head impacted the floor near the driver dummy's right foot.

   The airbelted dummy, however, did not experience this phenomenon for the equivalent impact as the inflated portion of the torso belt provided sufficient support to the torso to keep the torso against the seat back (Run 15-A).
5. The airbag systems performed well in oblique impacts except for the case of the right front passenger in a far side (11 o'clock) oblique impact (Run 14-P) and except for the bag rip in Run 16-P. In Run 14-P his torso impacted the steering wheel rim.

   In Run 16-P the bag ripped due to a leaky inflator blowing gas out of the end of the inflator and burning a hole in the bag.

This weak spot triggered a severe bag rip which allowed the under inflated bag to privide inadequate support. Thus, the passenger impacted the door and A-pillar very hard. On the next run (Run 17) the inflator was fixed so it could not leak and paper honeycomb door padding was added to take up the space where the door had bulged out in the previous run. In this run things improved considerably with all injury measures within the criteria limits.

6. The Minicars RSV right front passenger restraint system worked well in spite of the fact that very little stroking action of the collapsible dash was obtained. In fact, even in a case (Test No. 11) where we eliminated the stroking features, the injury criteria was easily met. The worth of retaining the stroking feature was judged to be questionable.

All in all, the restraints performed very well with overall performance obtained to approximately 50 mph. One additional comment is in order, the oblique tests simulated on the sled were somewhat conservative for the following reason. All of the energy of the sled simulated crash was necessarily dissipated with no vehicular rotation resulting in a more abrupt stopping of the buck than would actually occur. In normal, real-world vehicle crashes a portion of the energy is dissipated through vehicular rotation which results in more overground stopping distance.

For detailed data traces on these sled tests, refer to appropriate progress reports.

6.0 VEHICLE INTEGRATION AT MINICARS

Upon completion of the sled tests we had "tuned" the four restraints systems to the point that we felt: 1) further tuning would not result in significantly improved results, and 2) the results we had obtained were completely satisfactory with good promise shown for the upcoming vehicle crash tests. Now that this phase of the program was completed we had the information necessary to integrate the systems into the first two vehicles which had been scheduled to be crashed at Dynamic Science as the first crash test of the program.

Since Minicars personnel had developed the restraint systems, they were more familiar with the installation and operation of the four systems than were Dynamic Science personnel. For this reason it was decided that restraint integration guidelines and methodology would be formulated by Minicars at the Minicars facility for the first two vehicles. Once the methodology was established, Dynamic Science personnel would travel to Minicars for a first-hand look at how the integration was accomplished so they could follow the same procedures on the future integration effort to be conducted at Dynamic Science - the crash test site.

Let us now discuss this integration effort in some detail. The objective here was to integrate four restraint systems into the two furnished Volvos to be used in the first crash test at Dynamic Science.

As requested by NHTSA in their letter of October 15, 1976, the restraint systems were installed in the manner described below:

Car 1 (green 1976 Volvo)

Driver	-	Minicars RSV driver restraint system
	-	Minicars RSV passenger restraint system

Car 2 (orange 1976 Volvo)

Driver	-	Force-limited 3-point belt (steering column removed)
Passenger	-	Minicars RSV passenger restraint without stroking feature.

As requested by NHTSA in the above referenced letter, the force-limited 3-point belt system consisted of 2 layer polyester webbing connected to force-limiters at all three anchors. The anchor points used were the anchor points already in the Volvo. Also as requested by NHTSA, no retractors were used.

The reason two versions of the RSV passenger restraint system were installed rather than including the airbelt system in the first two test vehicles was that the sled testing showed that virtually no additional benefit was afforded by the stroking feature of the collapsing dash. By installing the passenger restraint systems both ways - that is, with and without the stroking feature in the first two vehicles, we would, after the first test, have data which would indicate once and for all whether the stroking feature was justified.

One of the primary problems facing the installation of the restraint systems into the two Volvos was how to compensate for the significant intrusion into the occupant compartment that would occur in the rather severe crash environment that was contemplated in the vehicle crash tests. Previously conducted tests on another NHTSA contract at Calspan Corporation had indicated that intrusion could be substantial in high speed impacts. Figures 6-1 and 6-2 show the results of Test No. 2, a 45 mph frontal barrier test, conducted by Calspan under contract DOT-HS-5-01099. This condition was considered as a baseline test which would be used as a design condition for integrating the advanced restraints into the Volvo 244. To further assist in this integration, another 1975 Volvo that had been crashed at Calspan in a 50 percent offset mode was shipped by Calspan, at the request of NHTSA, to Minicars.

For the first two vehicles modified, the configuration of restraint systems was as follows: In the first car (the green Volvo), the RSV Driver Airbag and RSV Dual Airbag Collapsing Dash were installed while in the second car (the orange Volvo) the RSV Dual Airbag system was mounted at the passenger's position and the force-limited belt was at the driver's position. The steering wheel was removed since a passenger restraint system was being tested. The Dual Airbag was just the RSV Airbag Collapsing Dash without the energy absorbing collapsible mechanism.

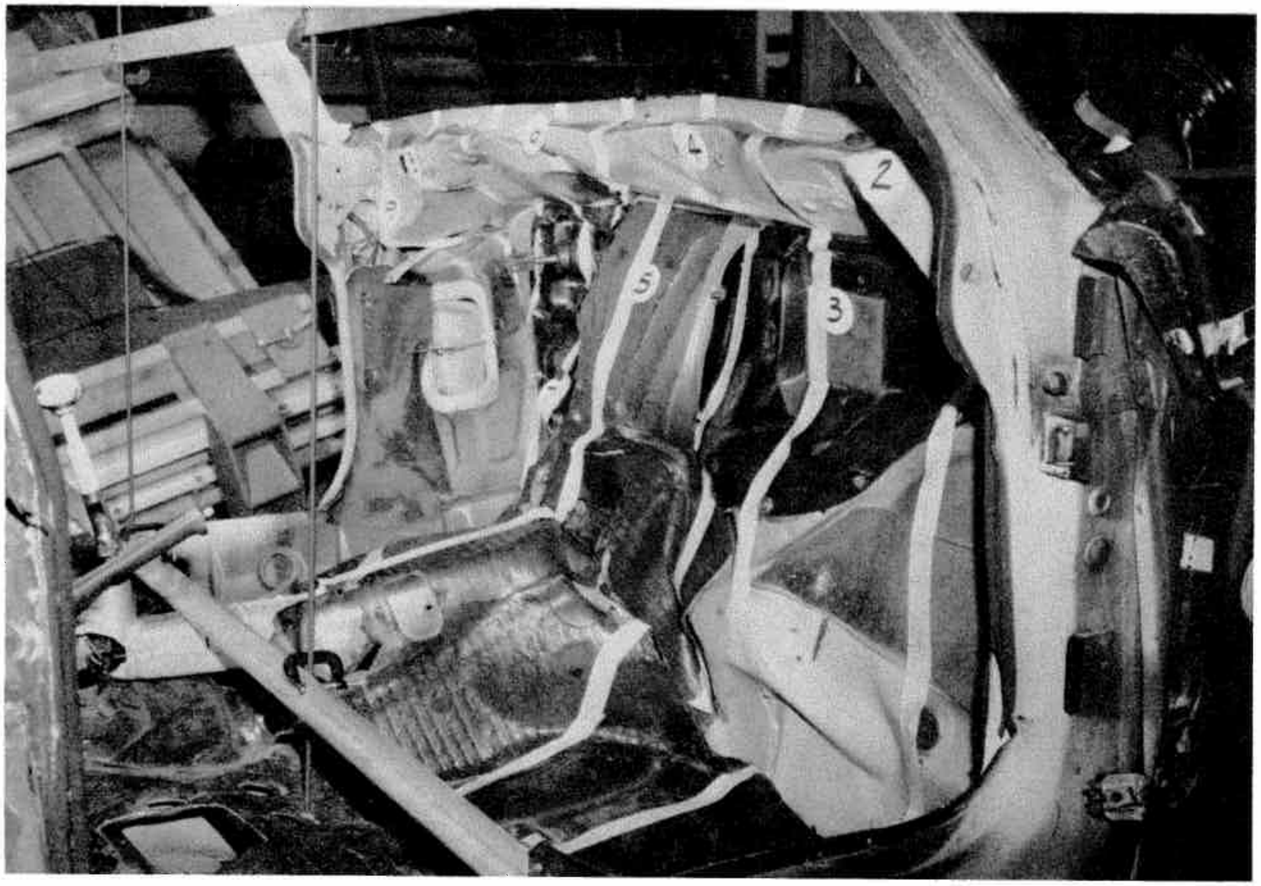


Figure 6-1. Vehicle Intrusion, Passenger Side - Calspan Test No. 2

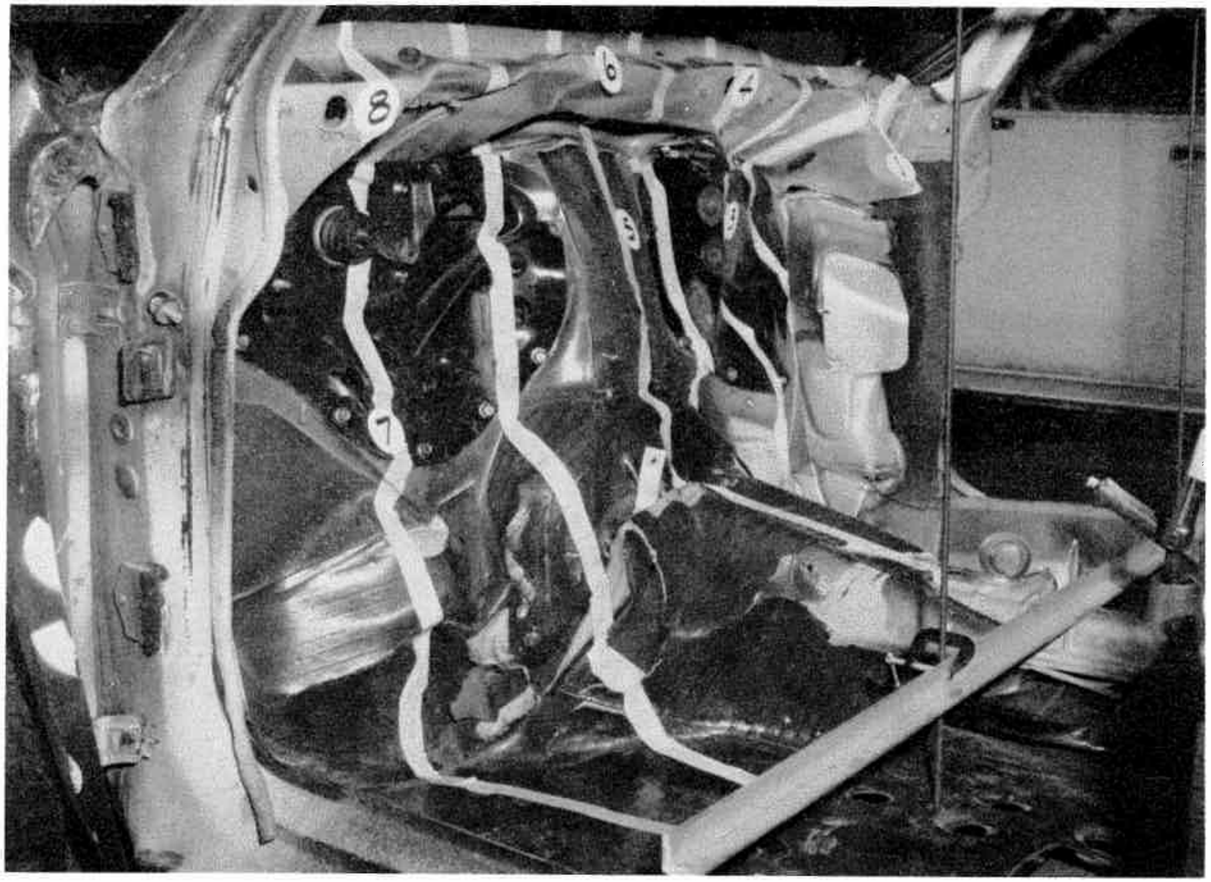


Figure 6-2. Vehicle Intrusion, Driver Side - Calspan Test No. 2

The three inflatable restraint systems are passive systems and as such required modification to the dash, console, and firewall area of the occupant compartment. Since the RSV Dual Airbag in the second Volvo was a non-stroking device and because installation in the driver's position was a Force-Limited Belt, the modifications to the two vehicles were slightly different.

The first step in modifying the vehicles was to remove the dash and console from the front portion of the Volvo's interior, to cut away the cowling directly behind the windshield and upper firewall. Figure 6-3 illustrates the condition of the vehicle at this stage. The next step was to reinforce the upper sections of the A-pillar to provide a secure end support for two cross-beams to which the RSV Driver Airbag and the RSV Airbag-Collapsing Dash are attached. Conditions at the end of this stage are illustrated in Figure 6-4. The two cross-beams were structural steel tubing whose sizes were:

- Forward Beam: 1-1/2 x 1-1/2 x .075
- Aft Beam: 2 x 2 x .09

For the Dual Airbag System without the collapsing mechanism, similar modifications were also incorporated with the exception being that only the aft beam was installed.

The next step was to weld the supporting brackets for the RSV Airbag-Collapsing Dash and mount the steering column for the RSV Driver Airbag. The status of the structure at this phase of the installation is shown in Figures 6-5 and 6-6. Finally, the frame for the RSV Airbag-Collapsing Dash was placed in position and the support pan for the driver's knee restraint was fastened between the aft beam and the firewall. The modification is essentially complete at this point and Figures 6-7 and 6-9 illustrate the installation at this stage of the integration effort.

The modifications to the second Volvo were quite similar; however as previously mentioned, only the aft beam was installed, and the RSV Dual Airbag was hard mounted to it as shown in Figure 6-10. After the braces for the airbag

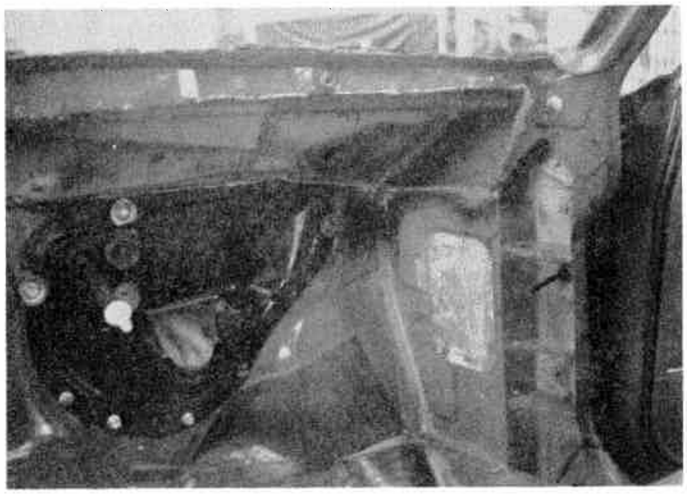
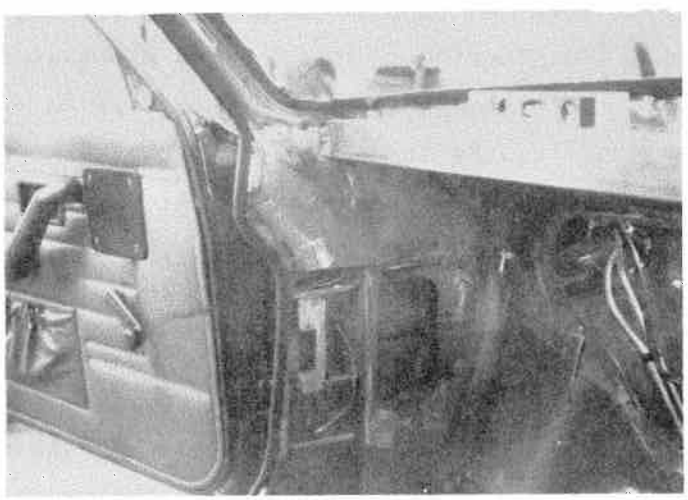


Figure 6-3. Dash Removed and Cowling Cut Away



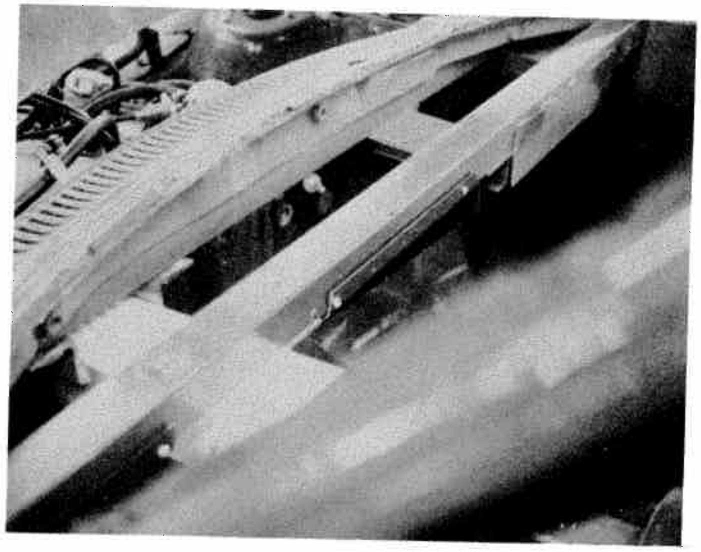


Figure 6-5. Transverse Tubing Welded in

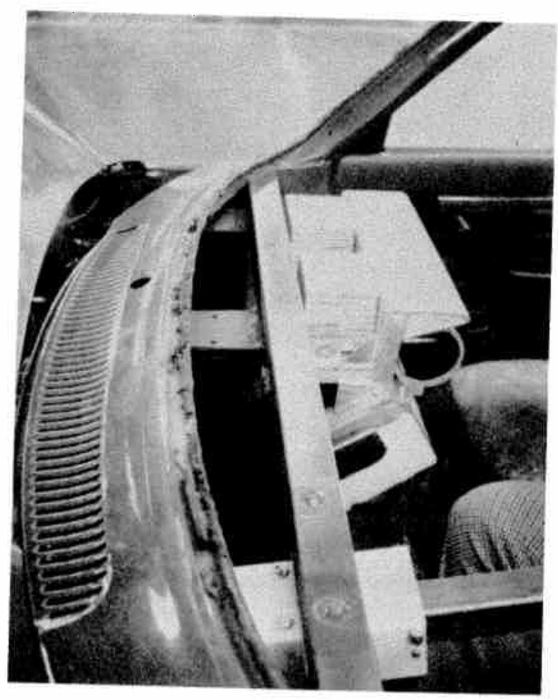


Figure 6-6. Restraint Systems Installed

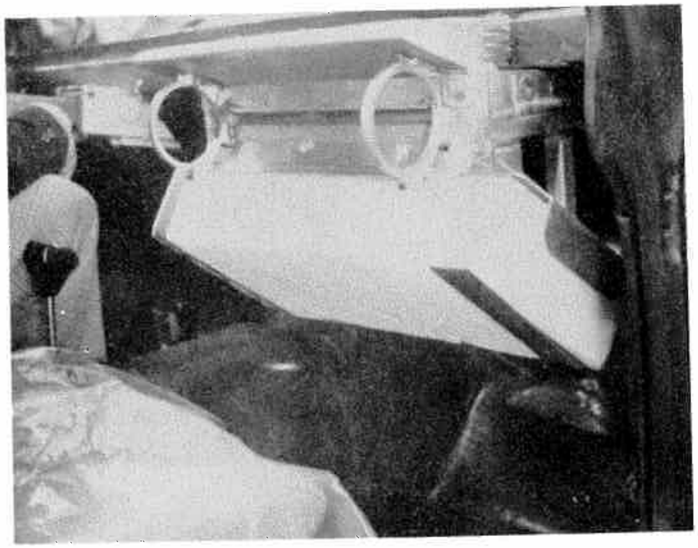


Figure 6-7. Passenger System Installed

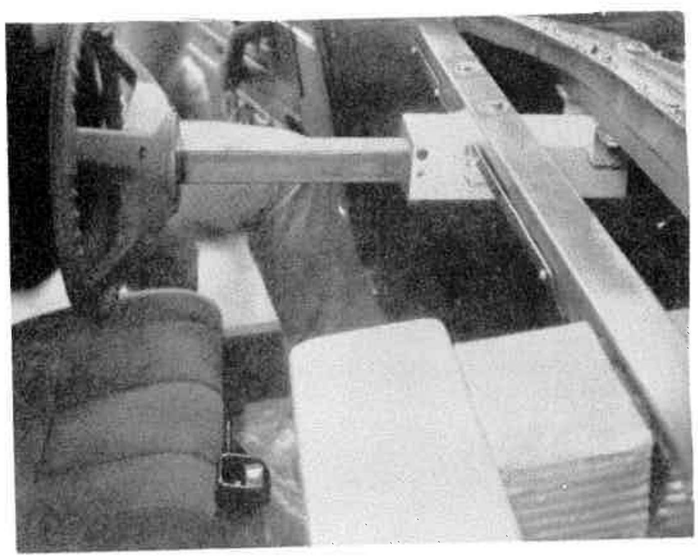


Figure 6-8. Driver System Installed

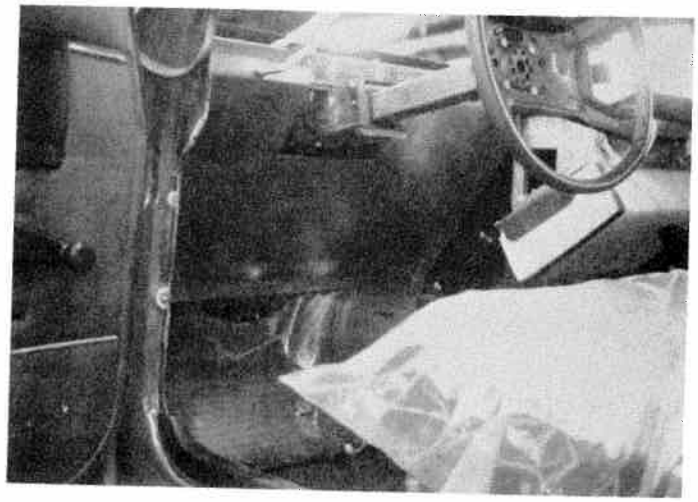


Figure 6-9. Driver Knee Pan Installed

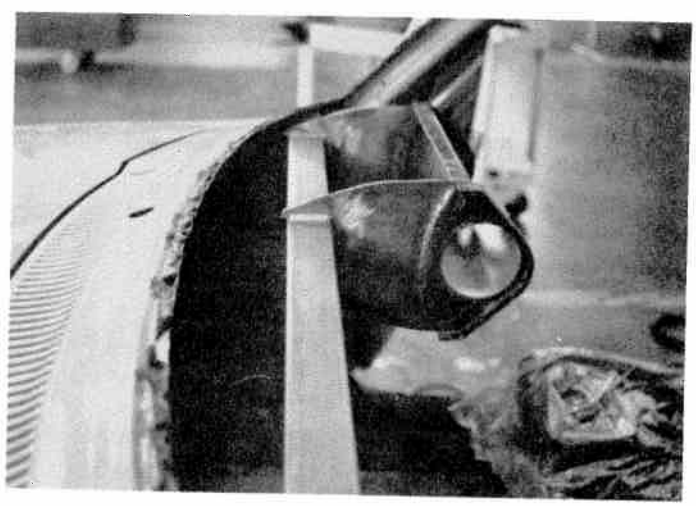


Figure 6-10. Passenger "Hard Mount" System Installed

had been welded in place, the pan supporting the knee restraints were installed. The final step in completing this installation was to replace the dash panel over the added structure as shown in Figures 6-11 and 6-12. Once this was completed, installation drawings of this initial structural integration were made (see Figures 6-13 and 6-14).

This effort completed the integration effort conducted at Minicars. On October 29, 1976 the orange Volvo (S/N VC 24445-E1131-479) was shipped to Dynamic Science to be readied for crash testing. On November 1, 1976, the green Volvo was shipped for similar disposition.

Figure 6-11. Dash Panel Replaced

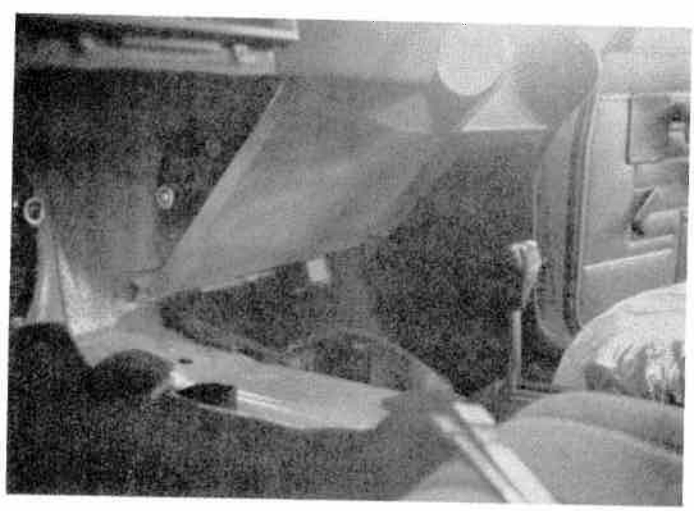
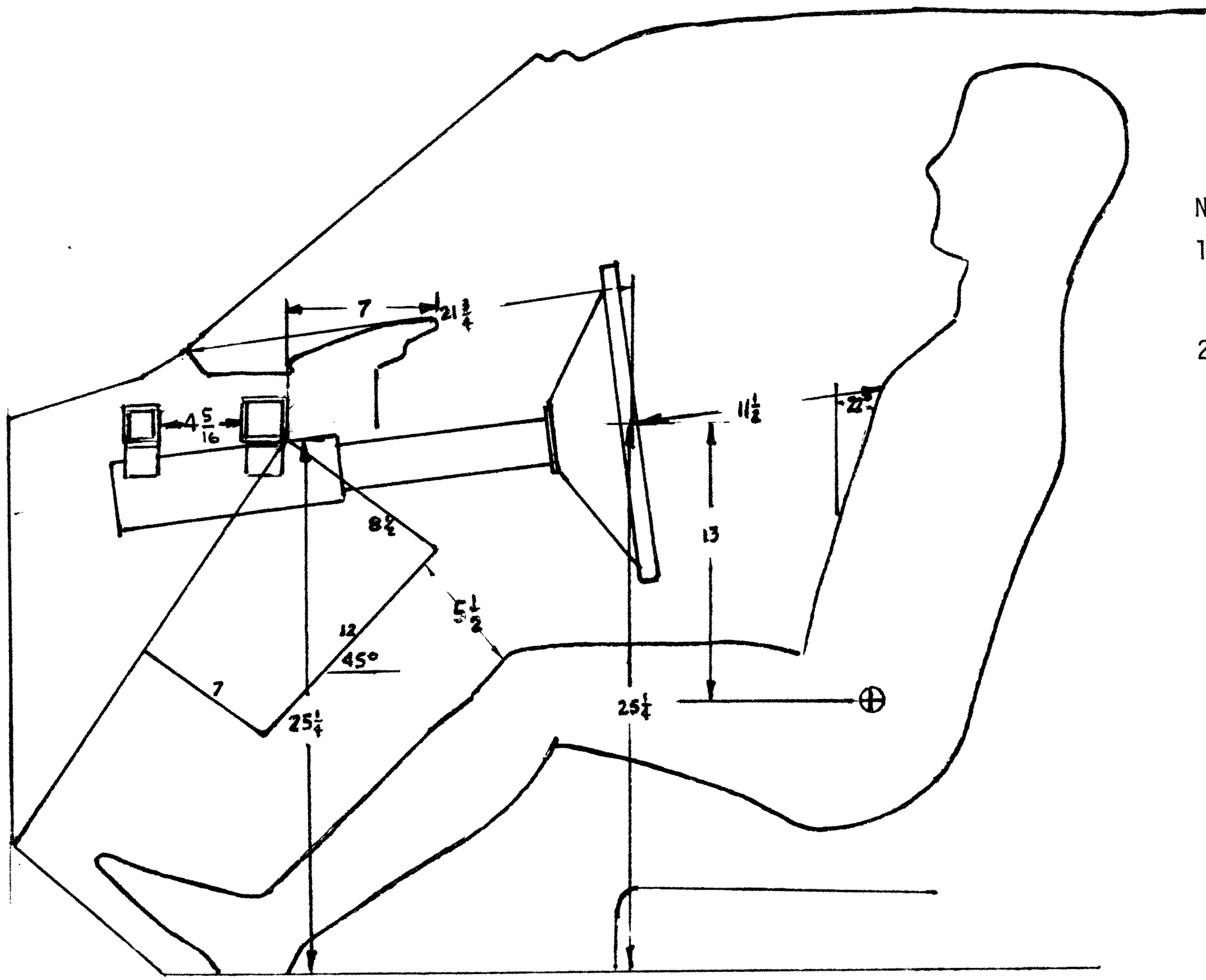


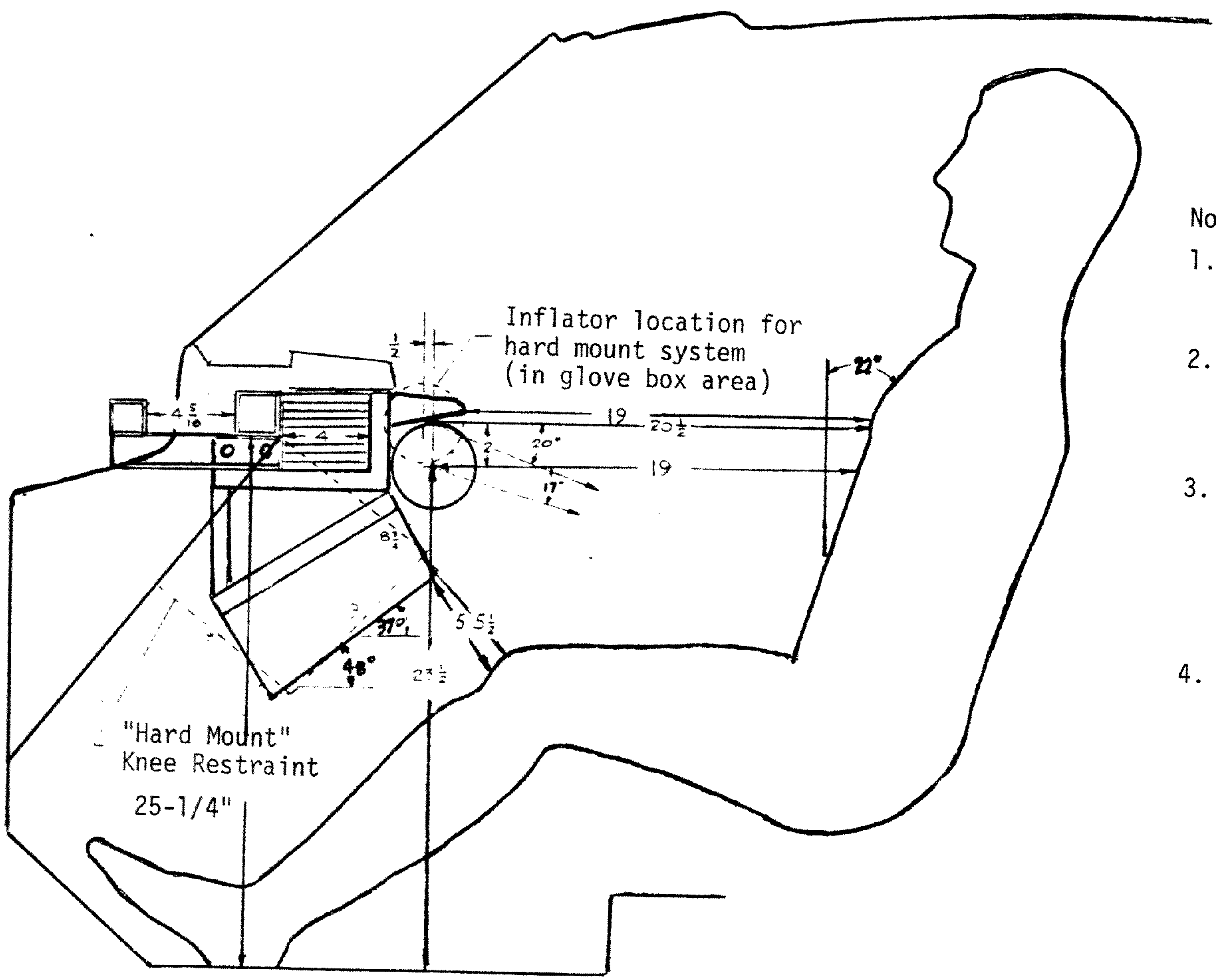
Figure 6-12. Knee Pan Installed for "Hard Mount" System



Notes:

1. Seat fore-aft adjustment 0-1 inch rear mid seat position
2. Seat vertical adjustment in lowest position both fore and aft.

Figure 6-13. RSV Driver System in 1976 Volvo



Notes:

1. Seat fore-aft adjustment 0-1 inch rear of mid-seat position.
2. Seat vertical position in lowest position both fore and aft for stroking version only.
3. Seat vertical position for hard mount system is at mid position at forward adjustment point and also at mid position for aft adjustment point.
4. Dotted lines represent "Hard Mount System".

Scale 1/4

Figure 6-14. RSV Passenger System in 1976 Volvo

7.0 FULL SCALE VEHICLE CRASH TESTS

We have now discussed all of the pre-crash test tasks we conducted in order to meet the program objectives discussed in Section 4.0. We will now discuss the crash tests themselves. The order in which we will do this is the following. We will first present the test matrix of the total test series of nineteen full scale car crash tests. This will be informative as to overall test scope and the crash test modes conducted. We will then, test-by-test, discuss the test objective, any test set up changes, test results, and the test conclusions. Following the test-by-test discussion, we will attempt to define a crash survivability envelope for the various test modes.

In all, nineteen full scale vehicle crashes with the Volvo were scheduled in which the performance of each of the four previously described restraint systems were evaluated in the Volvo 244. Of this total of nineteen tests, eleven were either Volvo-into-Volvo tests or Volvo into fixed barrier tests. The remaining eight tests were Ford Torino into Volvo tests with the Torino being the "bullet" (moving) vehicle. The test matrix of vehicle tests in which the Volvo, and therefore, the advanced restraint systems previously described were involved is shown in Table 7-1. There was one test (Test No. 15) where two Torinos with standard belt systems were crashed into each other, but since neither of the four advanced restraints or the Volvo was involved, this test is not reported here.

As previously mentioned the four advanced restraint systems tested in this series were:

- Minicars RSV Driver Restraint System (DS)
- Minicars RSV Passenger Restraint System (PS)
- Minicars Force-Limited Airbelt (AB)
- Minicars Force-Limited, 2-Inch Belt (FLB)

In addition, and also as previously mentioned, for a single test (Test No. 1) a version of the Minicars RSV passenger restraint system that employs a collapsing dash (BC) was substituted for the airbelt (AB) system.

*The results of the Torino tests are not the subject of this report and are reported elsewhere.

Table 7-1. Test Matrix

TEST NO	TEST CONFIGURATION	IMPACT CONDITIONS SPEED(1) (MPH)	ANGLE (DEG.)	RESTRAINT CONFIGURATION(2) VEHICLE A OCCUPANTS L FRONT	R FRONT	VEHICLE B OCCUPANTS L FRONT	R FRONT
1	Volvo-to-Volvo Head-on	80.6	0°	DS	BC	FLB	PS
2	Volvo-to-Volvo Head-on	81.2	0°	DS	PS	AB	FLB
3	Volvo-to-Volvo Head-on	89.8	0°	DS	PS	AB	FLB
4	Volvo-to-Volvo Offset Left (25")	80.6	0°	DS	PS	AB	FLB
5	Volvo-to-Volvo Offset Right (25")	81.4	0°	DS	PS	AB	FLB
6A	Volvo-to-Barrier	46.1	0°	DS	PS		
6B	Volvo-to-Barrier	46.7	0°			AB	FLB
7A	Volvo-to-Barrier	48.1	0°	DS	PS		
7B	Volvo-to-Barrier	48.3	0°			AB	FLB
8	Torino-to-Volvo Head-on	77.0	0°	STD	STD	DS	PS
9	Torino-to-Volvo Head-on	78.6	0°	SWL	SWL	AB	FLB
10	Torino-to-Volvo Right Oblique	60.5	30°	STD	STD	DS	PS
11	Torino-to-Volvo Left Oblique	59.5	30°(4)	SWL	SWL	AB	FLB
12	Torino-to-Volvo Right Oblique	63.3	30°(4)	SWL	SWL	DS	PS
13	Torino-to-Volvo Left Oblique	65.8	30°(4)	STD	STD	DS	PS
14	Torino-to-Volvo Right Oblique	66.6	30°(4)	SWFL	SWFL	AB	FLB
16	Torino-to-Volvo Left Oblique	60.3	45°	None	None	DS	PS
17	Volvo-to-Volvo Head-on	84.2	0°	DS	PS	AB(3)	FLB(3)
18	Volvo-to-Volvo Offset Left (25")	81.9	0°	DS	PS	None	None

(1) Closing speed for car-to-car frontal impacts; both cars moving at the same speed. For oblique impacts, Torino velocity (Volvo stationary).

(2) DS = RSV Driver System, PS = RSV Passenger Airbag System, AB = Force-Limited Airbelt, FLB = Force-Limited 2-Inch Belt, BC = RSV Airbag/Collapsing Dash System, STD - Standard 3-Point System, SWL = Standard System with Web Locking Device, SWFL = Standard, Web Locking and Force-Limited.

(3) Advanced steering columns installed at these positions for this test.

(4) Major resultant acceleration vector, this number of degrees to centerline of target vehicle.

For details of the development of each of these systems we refer to the respective reports summarizing the respective development efforts. For all but the airbelt system, refer to the Minicars RSV Phase II Final Report, Contract DOT-HS-5-01215. For the airbelt System (Contract DOT-HS-4-00917), the report number is DOT-HS-801-719.

To reiterate, the objective of the test series was to determine the performance capabilities of each of the four restraint systems when installed in a typical compact sized vehicle and crashed in accident modes that represent the more common vehicle crash modes and, therefore, those with highest societal cost.

In the Volvo-to-Volvo and Volvo-to-barrier tests, the airbag restraint systems were installed in one car (Car A) are the force-limited belt and airbelt in the other car (Car B). We commonly referred to these vehicles as the "Bag Car" and the "Belt Car" respectively. In the Torino-Volvo tests, the advanced restraints were installed only in the Volvo, the vehicle of primary interest. For a particular test the Volvo was set up to be either a "Bag Car" or a "Belt Car".

In all tests, except Test No. 17, a 50th percentile male dummy (Part 572) was used. In Test 17 with the "Bag Car" a 95th percentile male dummy was placed in the driver position and a 5th percentile female dummy in the passenger position.

A final word is in order here regarding the number of tests run in each crash mode, both with respect to the repeatability of the results and the hardware development which inevitably takes place during any such program that is primarily of a research nature.

Since the program was of a basic research nature, it was decided in consultation with the NHTSA, that the program emphasis would be placed on obtaining test data from as many test modes as possible consistent on obtaining reliable information that was considered representative of a given test mode and consistent with the funds allocated to the program. Subsequent programs to further "productionize" these four advanced systems would obviously include hardware nearer to production, and also would require that each test condition be repeated a sufficient number of times in order to demonstrate the statistical significance of the results from any given test mode. In this way one could evaluate the data with a relatively greater amount of confidence so that meaningful conclusions regarding the restraint performance for each test mode could be made. The resulting crash survivability envelope from such a program would be extremely useful since any test anomalies could be effectively filtered out due to the larger number of tests in each crash mode.

One final reminder; since the program objectives include determining the upper limit of the impact velocity at which the injury measures of FMVSS 208 could be met, we necessarily conducted some tests that exceeded the injury criteria limits. However, we would like to make clear that the velocity limits at which the systems could no longer be repeatably relied upon to meet the injury criteria are substantially in excess of the FMVSS 208 limit of 30 mph.

7.1 VEHICLE TEST NO. 1

7.1.1 Test Objective and Set Up

The first test of the series was scheduled as a full frontal test at 80 mph between the two Volvo 244's which had the restraint systems integrated at Minicars as described in Section 6.0. In all tests subsequent to this test, the restraint integration took place at Dynamic Science which was the site of all of the vehicle crash tests. The objective of this first test was to ascertain whether the four restraints listed below would enable a 50th percentile male to meet the injury criteria in a full frontal car-to-car test at a closing velocity of 80 mph. The restraint system configuration for Test No. 1 was:

Occupant	Vehicle A	Vehicle B
Left Front	RSV Driver Airbag	Force Limited 2-inch Belt
Right Front	RSV Airbag/ Collapsing Dash	RSV Passenger Airbag

The vehicles used for these tests were both 1976 Volvo 244's. Vehicle A was structurally modified in the dash panel and A-pillar area, as described in Section 6.0, to minimize occupant compartment intrusion and accept the restraint systems that were installed in it. These modifications consisted of:

- Reinforced A-posts
- Two steel tubes across upper dash
- Two sheet metal knee restraint support pans (for the left and right front occupant positions) attached between firewall and rear steel tube.

Vehicle B was also modified for the same purpose although not as extensively. The modifications in Vehicle B were:

- One steel tube across upper dash
- Sheet metal pan between firewall and steel tube.

Following the completion of these modifications, the dash was reinstalled in both vehicles over the steel tubes back in its original position.

7.1.2 Test Results

The impact conditions for Test No. 1 were:

Configuration	Closing Speed	Velocity Change (mph) Vehicle A	Velocity Change (mph) Vehicle B
Volvo-to-Volvo Head-on	80.6 mph	45.1	43.2

As is the case in many first tests of a series, some anomalies occurred that detracted from the overall success of the test. For the driver system in the bag car, the threaded fasteners holding the steering column forward support broke loose from the cowl, thereby allowing the column to rotate upward from its initial 7 degree angle from horizontal to 14 degrees. The increase in this angle placed the airbag higher on the chest than normal resulting in less effective torso mass being brought to bear on the column with a concomitantly low amount of column stroke of only one-quarter inch. This resulted in chest g's that were in excess of the criteria limit. This rather high placement of the bag on the chest was aggravated by the fact that the floor pan of the car buckled severely downward in this first test. After the test, it was visually apparent that, due to the floor pan buckling, which was most severe at the vehicle centerline, both front passenger seats were tipped inboard until the seat head restraints practically touched. As will be described in Test No. 2, the floor pan was subsequently reinforced and the threaded fasteners were eliminated as a mounting technique for the column.

Summarized below are the injury measures received by the driver of the airbag car.

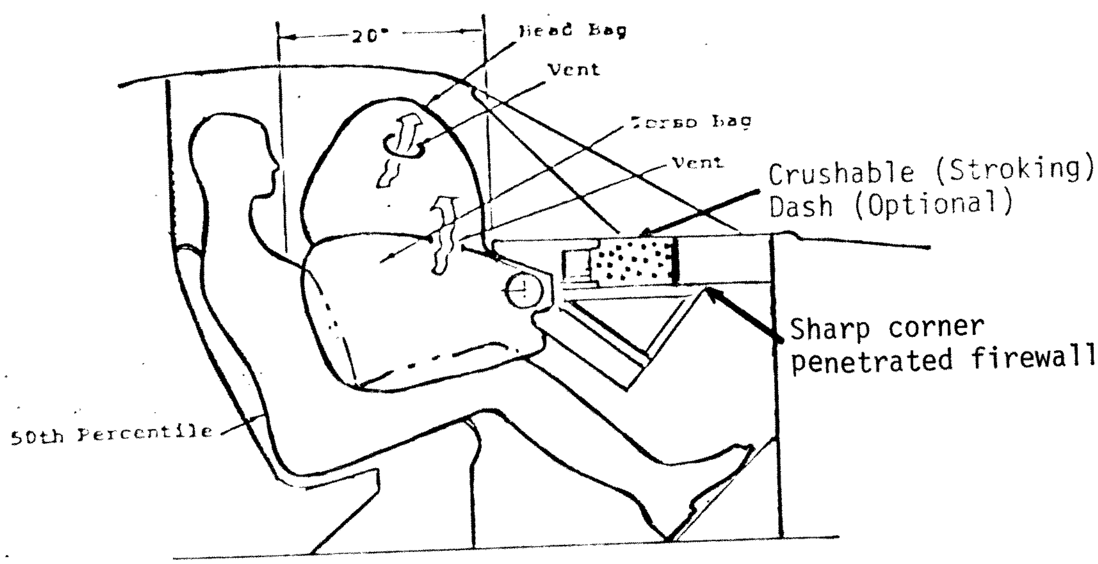
Driver Airbag Restraint System (DS)

HIC = 388

Peak Resultant Chest g's (-3 msec) = 69.7 g

Femur Loads: Left = 333 lb, Right = 781 lb

On the passenger side, the intruding firewall impacted the stroking dash. In fact, the firewall split completely open on the passenger side when this impact occurred.



The reason the firewall split open and the stroking dash was impacted was that for the stroking version of the Minicars RSV passenger restraint system, the dash unit extends approximately 9 inches closer to the firewall than it does with the non-stroking version and is, therefore, correspondingly more vulnerable to intrusion. In the Minicars RSV, the vehicle for which this particular restraint was designed, there is a much greater distance from the front of the bumper face to the firewall, plus the crash pulse is more efficient so that firewall intrusion is much less of a problem.

Summarized below are the injury measures for the passenger of the airbag car.

Passenger Airbag - Collpasing Dash Restraint System (BC)

HIC - 1015

Peak Resultant Chest g's (-3 msec) = No data

Femur Loads: Left = 447 lb, Right = 773 lb

In the other vehicle the restraints were, in the driver position (no column installed), the force-limited 3-point belt and in the passenger position, the Minicars RSV passenger restraint system with a fixed (noncollapsing) dash.

For the belted occupant, the injury measures were very high since the lower inboard force-limiter was accidently installed where the lower outboard force-limiter should have been installed. Since the lower inboard anchor position has to react a much higher load than the lower outboard anchor position due to the juncture of the torso and lap belts occurring at the lower inboard position, this accidental reversal put the lower force, force-limiter in the place where the higher force, force-limiter was required.

The net result was the lower inboard limiter pulled completely out of its mount allowing the dummy to impact the dash and windshield header.

Summarized below are the injury measures for the FLB restrained dummy.

HIC - 1599

Peak Resultant Chest g's (-3 msec) = 99.6 g

Femur Loads: Left - 190 lb, Right - 791 lb

Peak Shoulder Belt Load - 660 lb

For the Minicars RSV passenger restraint system with fixed dash the results were clouded by the fact that the longitudinal chest acceleration was lost in the middle of the event; however, no anomalies were present in the chest data up to the time (64 msec) in the event at which the transducer failure was experienced.

Summarized below are the injury measures for the passenger.

Minicars Passenger Airbag with Fixed Dash (PS)

HIC = 290

Peak Resultant Chest g's (-3 msec) = no data

Femur Loads: Left = 252 lbs, Right = 1082 lbs

7.1.3 Test Conclusions

1. Structural reinforcement of floor pan will be required for future high speed crash tests.
2. Present method of mounting column to cowl is not adequate - threaded fasteners will be eliminated and welded construction used in future tests.
3. There is too much intrusion to use passenger airbag system with collapsing dash any further. We conclude that fixed dash passenger system (PS) is preferred in future tests.

7.2 VEHICLE TEST NO. 2

7.2.1 Test Objective and Set Up

Due to the anomalies that occurred in the first test, certain changes were made to the airbag restraint systems and associated vehicle structure prior to the start of Test No. 2. First, in Vehicle A, a beam was installed that ran under the floor pan between the B-posts. This was done in an effort to prevent the severe buckling of the floor that occurred in the last test. In addition, since the collapsing dash passenger system had been eliminated from further consideration, the aft most transverse beam between the A-posts was moved aft two and one-half inches. In other respects the vehicle structure was unchanged. Second, the threaded fasteners used to mount the column to the two transverse beams running between the A-posts were replaced by a welded connection. Figure 7-1 shows a typical airbag test car set up.

Vehicle B was structurally unmodified in the dash and A-pillar area; however, the components under the dash were removed and the dash reinstalled in its original position. In addition, as in Vehicle A, a steel tube was installed between the B-pillars underneath the floor pan. Figure 7-2 shows a typical belt car test set up. The restraint system configuration for Test No. 2 was:

Occupant	Vehicle A	Vehicle B
Left Front	RSV Driver Airbag	Force-Limited Airbelt
Right Front	RSV Passenger Airbag	Force-Limited 2-Inch Belt

Again, the vehicles used for these tests were both 1976 Volvo 244's.

7.2.2 Test Results

Since several anomalous things happened in Test No. 1, it was decided to repeat Test No. 1. The only major change was that, as previously stated, the airbelt system was substituted for the passenger airbag system with collapsible dash (BC).

The impact conditions for Test No. 2 were:

Configuration	Closing Speed	Velocity Change (mph)	
		Vehicle A	Vehicle B
Volvo-to-Volvo Head-on	81.2 mph	47.5	46.9

In this test things went much more as planned. The driver and passenger systems in the bag car (Vehicle A) performed very well with injury measures substantially below the criteria limits. Test results for these two systems are summarized below:

Figure 7-1. Pre Test, Test No. 2 - Airbag Car

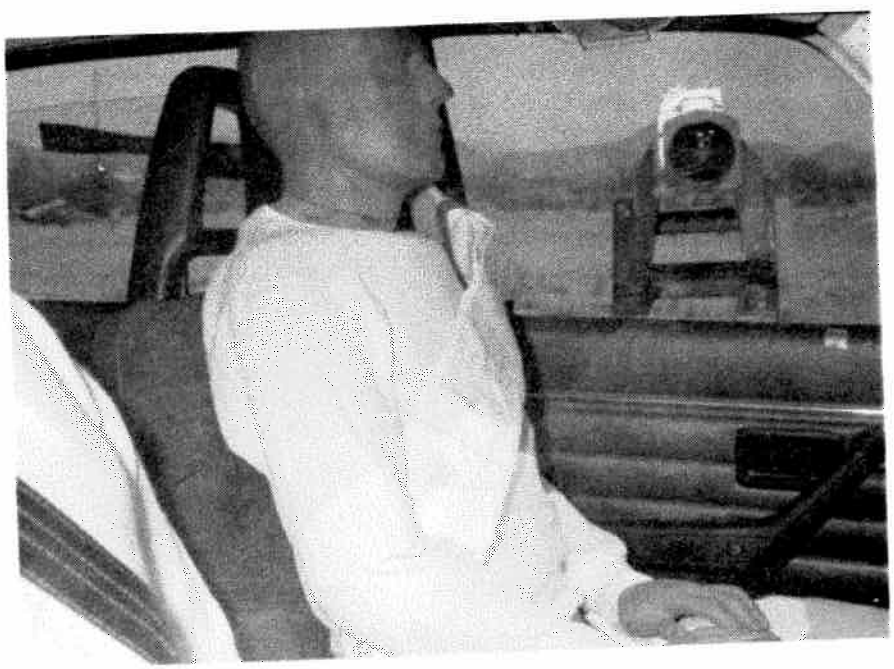


Figure 7-2. Pre Test, Test No. 2, Belt Car

Driver Airbag Restraint System (DS)

HIC = 375

Peak Resultant Chest g's (-3 msec) = 39.8 g

Femur Loads: Left = 1284 lb, Right - 1521 lb

Passenger Airbag Restraint System (PS)

HIC = 242

Peak Resultant Chest g's (-3 msec) = 34.8 g

Femur Loads: Left = 962 lb, Right = 1351 lb

Considering the fact that the vehicle velocity change was a very high 47.5 mph and the fact that the restraints were installed in a compact size vehicle, the results are extraordinarly good.

In Vehicle B, the belt car, things did not go quite so well. Again however, there was a reason. This time the force-limiters were installed in the correct locations - that is, the lower inboard force-limiter was installed where it was supposed to be, etc. However, the force-limiting elements on the lap belt were inadvertently loaded incorrectly (see Figure 7-3) resulting in force levels several times less than what they should be.

Summarized below are the injury measures for the occupants of Vehicle B.

Airbelt Restraint System (AB)

HIC = 301

Peak Resultant Chest g's (-3 msec) = no data

Femur Loads: Left 2504 lb, Right 3084 lb

Force-Limited Belt System (FLB)

HIC - 2030

Peak Resultant Chest g's = 123 g

Femur Loads: Left = 4128 lb, Right = 2417 lb

Peak Shoulder Belt Load = No data, transducer improperly installed

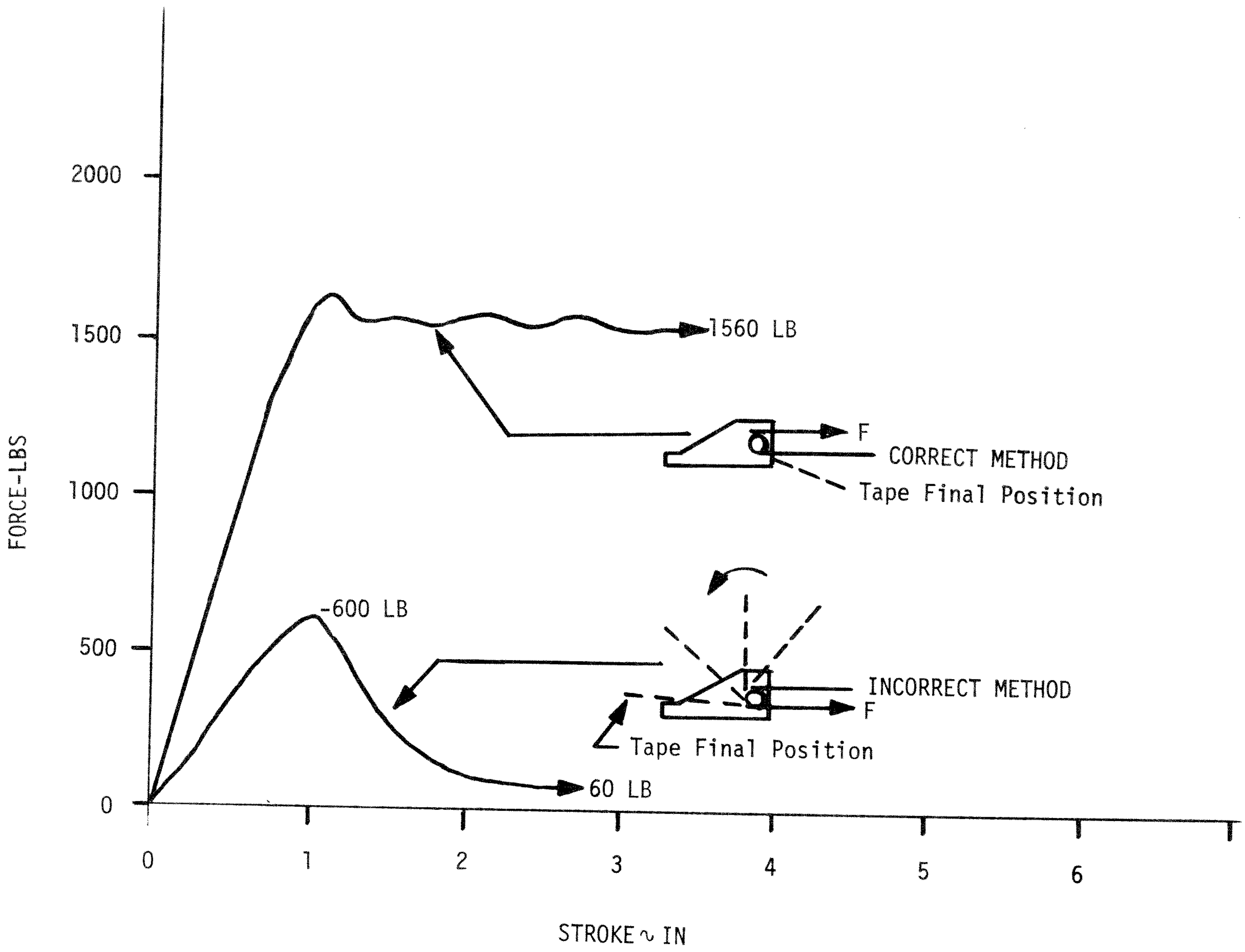


Figure 7-3. Force-Limiter Force Versus Stroke for Two Loading Methods

Since the force-limiter levels on the lap belt force-limiters on both dummies were so low, both dummies submarined badly and bottomed their head and chest on the dash resulting in the high injury measures shown above (see Figure 7-4 for the final positions of the dummies).

7.2.3 Test Conclusions

1. The addition of the beam between the B-posts under the floor pan eliminated the floor buckling problem.
2. The advanced airbag systems in Vehicle A demonstrated extraordinary potential since the injury measures were very much below the criteria limits of the high vehicle delta V of 47.5 mph.

7.3 VEHICLE TEST NO. 3

Upon completion of Test No. 2, a full frontal Volvo-into-Volvo test at 81 mph closing velocity, we were anxious to see if a further increase in test speed and crash severity would result in injury measures that would exceed the criteria limits. Since our objective was to ultimately determine a crash survivability envelope, we were interested in working right up to and possibly slightly beyond the criteria limits.

7.3.1 Test Objective and Set Up

The vehicles used for this third test were both 1976 Volvo 244's. Vehicle A was structurally modified in the dash, A-pillar, and B-pillar areas in the same manner as described before to preserve occupant compartment integrity and to accept the restraint systems that were installed in it. These modifications consisted of:

- Reinforced A-pillars
- Two steel tubes across the upper dash (same as Car A, Test 2)
- One continuous sheet metal pan across the vehicle attached between firewall and rear steel tube to support the knee restraint.
- Steel tube under floor pan between B-pillars.

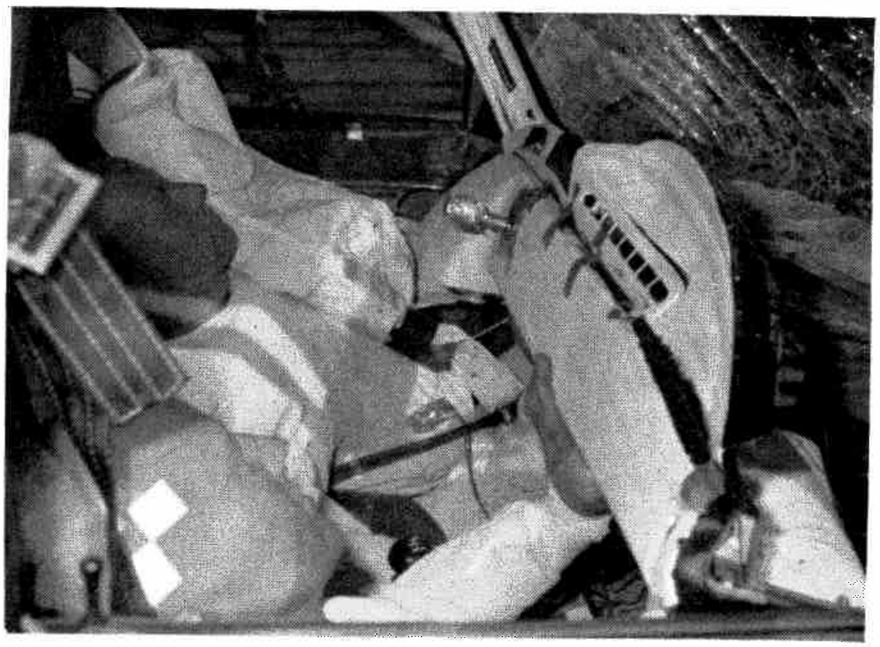


Figure 7-4. Post Test, Test No. 2, Belt Car

Vehicle B was structurally unmodified in the dash and A-pillar area; however, the components under the dash were removed and the dash padding was reinstalled in its original position. In addition, as in Vehicle A, a steel tube was installed between the B-pillars underneath the floor pan.

The restraint system configuration was:

Occupant	Vehicle A	Vehicle B
Left Front	RSV Driver Airbag	Force-Limited Airbelt
Right Front	RSV Passenger Airbag	Force-Limited 2-Inch Belt

Our objective in this test was to ascertain whether the injury measures received in a 90 mph closing velocity impact between two Volvos would exceed the criteria limits. Figures 7-5 through 7-7 show the systems prior to test.

7.3.2 Test Results

The impact conditions for Test No. 3 were:

Configuration	Closing Speed	Velocity Change (mph) Vehicle A	Velocity Change (mph) Vehicle B
Volvo-to-Volvo Head-on	89.8 mph	50.0	48.1

The conditions for this test were the most severe of any we are acquainted with where instrumented dummies were evaluated in a production automobile. The vehicle change in velocity for the airbag car was 50 mph with a static crush of only 33.5 inches with peak crash pulse g-levels of 55-60 g.

However, in spite of the extreme crash severity, the only injury measures that exceeded the criteria limits were the right femur of the driver in the airbag car and left femur of the FLB restrained passenger in the belt car.

For the driver of the airbag vehicle, the only anomaly was that the firewall intrusion near the centerline of the vehicle was so great that there was not sufficient room for the femur to stroke which resulted in a 2336 lb load on the right femur. Otherwise, as shown below, the results were extremely good.

Figure 7-5. Pre Test, Test No. 3, Belt Car

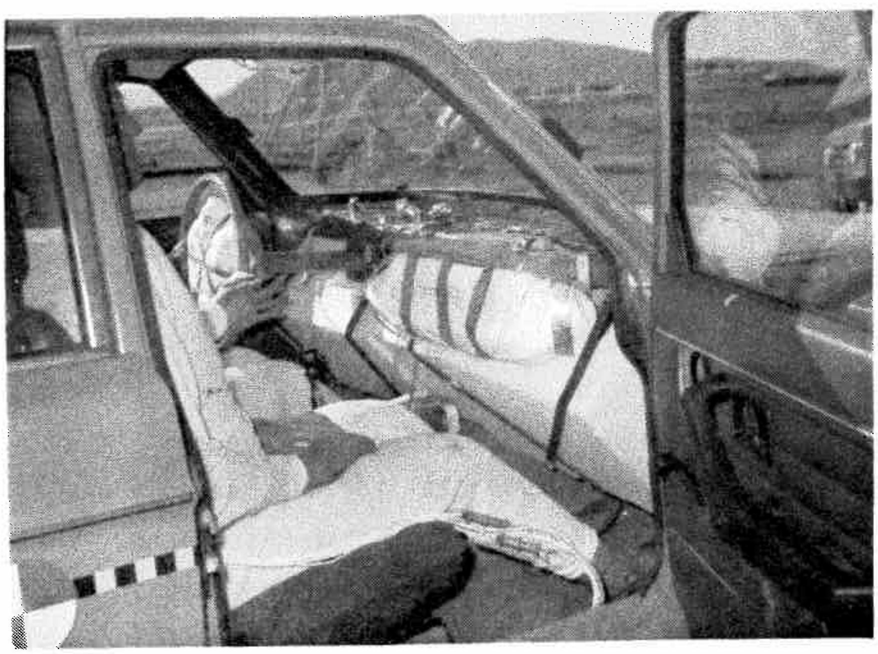


Figure 7-6. Pre Test, Test No. 3, Bag Car

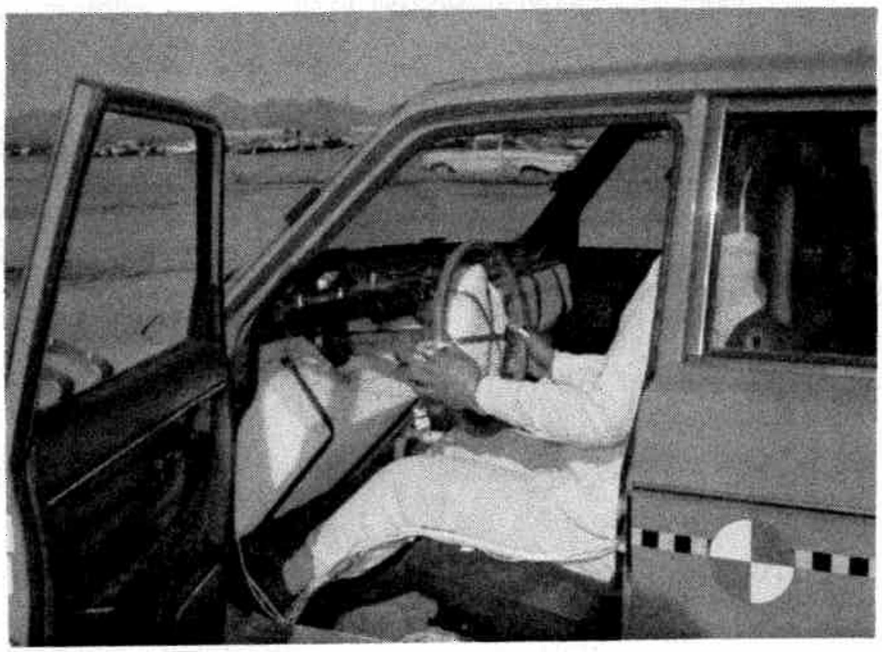


Figure 7-7. Pre Test, Test No. 3, Bag Car

Driver Airbag System (DS)

HIC = 471

Peak Resultant Chest g's (-3 msec) = 46.4 g

Femur Loads: Left 1327 lb, Right 2336 lb

The results were also extremely good for the passenger, in fact, it was a perfect test as far as his results are concerned.

Passenger Airbag System (PS)

HIC = 366

Peak Resultant Chest g's (- 3msec) = 50.3

Femur Loads: Left 1441 lb, Right 1227 lb

Things also went very well in the belt car, although the results for these systems were not quite as extraordinary as for the airbag systems.

For the airbelt restrained passenger all of the injury criteria were met with the results as shown below.

Airbelt System (AB)

HIC = 681

Peak Resultant Chest g's (-3 msec) = 51.2

Femur Loads: Left = 538 lb, Right = 1882 lb

For the passenger restrained with the force-limited seat belt, the HIC was close to the criteria limit of 1000 but nevertheless, "passed". As previously mentioned, the severe intrusion of the mid-firewall area pinned the knee to the seat resulting in a left femur load that exceeded the criteria limit. These results are summarized below.

Force-Limited Belt System (FLB)

HIC = 991

Peak Resultant Chest g's (-3 msec) = 56.9

Femur Loads: Left = 2556 lb, Right = 356 lb

Figures 7-8 through 7-10 show the vehicle and systems following the test.

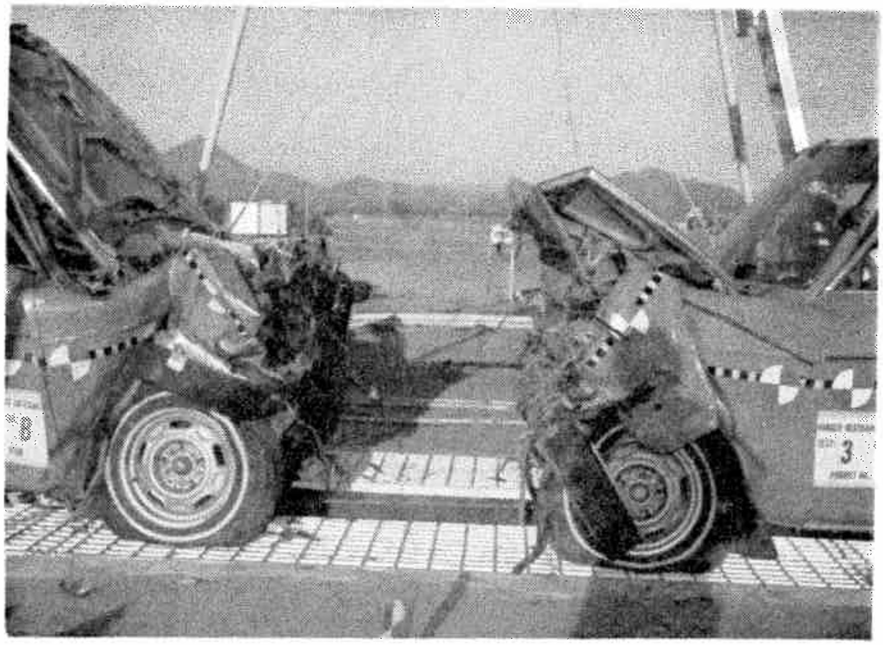


Figure 7-8. Vehicle Damage - Test No. 3

Figure 7-9. Post Test, Test No. 3, Belt Car

Figure 7-10. Post Test, Test No. 3 , Bag Car

7.3.3 Test Conclusions

1. The inflatable restraint systems showed they have the ability to protect vehicle occupants in a production compact size vehicle up to and beyond a 50 mph velocity change. As far as we know, these results are unprecedented in airbag research and development for a production compact car.
2. The force-limited belt system also demonstrated performance within (although barely within) the head and chest criteria limits at a 48 mph velocity change.

7.4 VEHICLE TEST NO. 4

Upon completion of Test No. 3 we had completed three full frontal car-to-car tests with the Volvo 244's with the four advanced restraint systems installed. Since we felt that a further increase in speed would not be warranted due to the extreme amount of lower, mid-firewall intrusion experienced in Test No. 3 and due to the fact that delta V's of greater than 50 mph do not account for a significant amount of total societal cost of accidents, we decided to proceed to another test mode. The test mode selected for Tests 4 and 5 was the offset mode where the two vehicles impact in the frontal direction with 60 percent of each vehicle bearing on the other. This type of test typically results in a softer initial crash pulse and a correspondingly greater amount of total crush than a full frontal crash. For this reason, this test mode is usually "intrusion critical" at the higher velocities.

7.4.1 Test Objective and Set Up

Our objective in conducting this first test in the offset mode was to ascertain whether the four advanced restraint systems would protect the Volvo occupants in this mode at a closing velocity of 80 mph.

The vehicle structure on both vehicles was modified for restraint installation in the same manner described in the previous test.

The restraint system configuration for Test No. 4 was:

Occupant	Vehicle A	Vehicle B
Left Front	RSV Driver Airbag	Force-Limited Airbelt
Right Front	RSV Passenger Airbag	Force-Limited 2-Inch Belt

The test was run with the drivers of the two vehicles lined up (left offset). Figures 7-11 through 7-13 show the pre-test set up.

7.4.2 Test Results

The impact conditions for Test No. 4 were:

Configuration	Closing Speed	Velocity Change (mph) Vehicle A	Vehicle B
Volvo-to-Volvo Offset Left (25")	80.6 mph	43	41

As expected the crash pulse was relatively mild but with significantly more intrusion than in the full frontal tests. Where we saw 33-34 inches static crush for the 89 mph full frontal car-to-car test (Test No. 3), we have 53 inches static crush at the left side of the belt car (Vehicle B) and 42 inches static crush on the left side of the bag car (Vehicle A) for this test. Needless to say, intrusion on the left firewall of the two vehicles was severe (Figure 7-14).

The reason the belt car crushed more than the bag car was due to the fact that the bag car had more extensive structural modification in the cowl area to support the Minicars RSV steering column. This stiffened the bag car in the cowl area somewhat as compared to the belt car.

In spite of the severe intrusion, only one anomaly occurred and this had nothing to do with the instrusion. In the airbag car, the passenger airbag ripped completely open along one side. Subsequent inspection shows that the seam had been improperly stitched resulting in the rip developing when the bag pressure began to increase as the occupant loaded it.

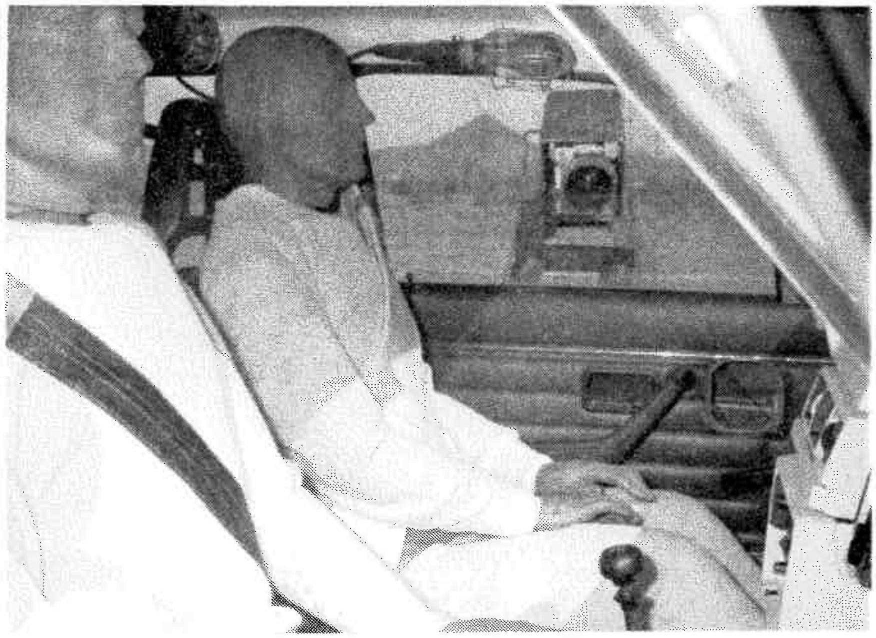


Figure 7-11. Pre Test, Test No. 4, Belt Car

Figure 7-12. Pre Test, Test No. 4, Bag Car

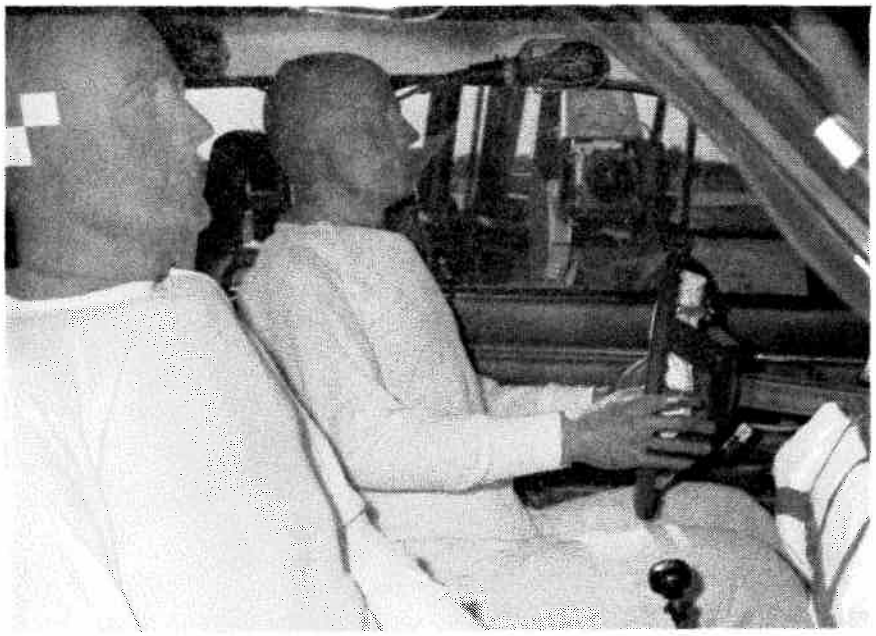


Figure 7-13. Pre Test, Test No. 4, Bag Car

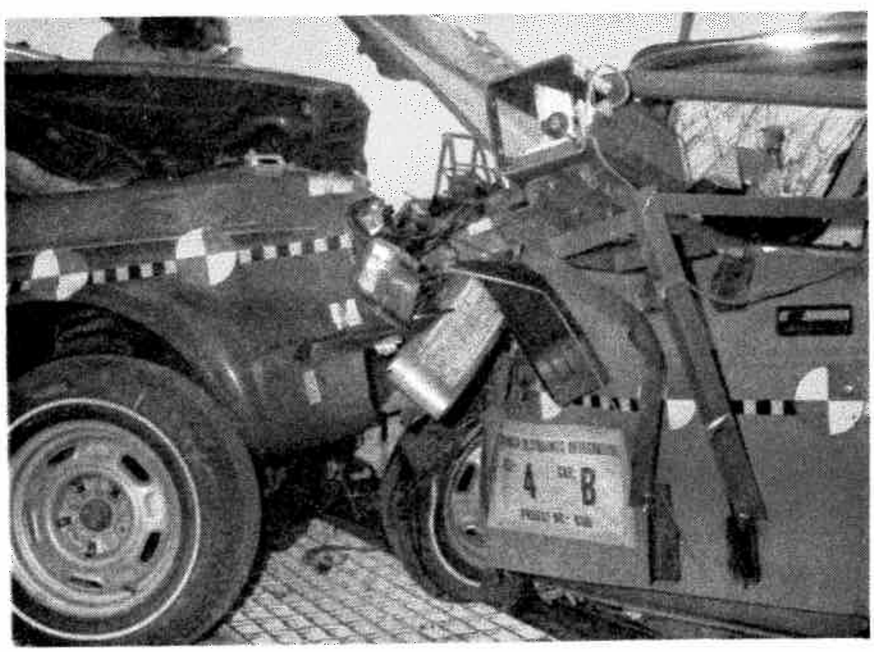


Figure 7-14. Vehicle Damage, Test No. 4

Injury measures for the test are summarized below:

	DS	PS	AB	FLB
HIC	330	1284	255	311
Peak Resultant Chest g's (-3 msec)	35.7	64.5	30.1	27.2
Femur Loads: Left (lb), Right (lb)	1407-2002	1583-1693	1516-1021	520-152

Due to the relatively mild crash pulse g-level, the column stroke was only one-quarter inch rather than its normal 3-1/2 to 4 inches in a full frontal crash. The peak shoulder belt load on the force-limited 2-inch belt system was 1245 lb.

7.4.3 Test Conclusions

1. All the restraint systems, with the exception of the passenger airbag system, showed they had the ability to protect vehicle occupants in a small, compact size vehicle in driver side off-set crashes to a delta V of at least 40-43 mph.

*2. The results for the performance of the passenger bag are inclusive in this test mode as an improperly sewn bag seam resulted in a large rip developing in the airbag which allowed the passenger to "bottom out" on the dash and windshield.

7.5 VEHICLE TEST NO. 5

With the completion of the 80 mph frontal offset test on the left side (Test No. 4) we planned the equivalent test on the right (passenger) side for Test No. 5.

7.5.1 Test Objective and Set Up

Our objective in conducting Test No. 5 was to ascertain whether the four advanced restraint systems would protect Volvo occupants in the right frontal offset mode at a closing velocity of 80 mph.

*Later in the test series, Test No. 18 was conducted which was an exact repeat of the crash mode of Test No. 4. As will be described in that discussion, this time the bag remained intact and the passenger easily met the injury criteria.

The restraint system configuration for Test No. 5 was:

Occupant	Vehicle A	Vehicle B
Left Front	RSV Driver Airbag	Force-Limited Airbelt
Right Front	RSV Passenger Airbag	Force-Limited 2-Inch Belt

Vehicle modifications for restraint installation were as described previously. Figure 7-15 shows the position of the vehicles prior to test.

For this test the passenger airbags were carefully inspected and one was chosen that had the correct stitching pattern.

7.5.2 Test Results

The impact conditions for Test No. 5 were:

Configuration	Closing Speed	Velocity Change (mph) Vehicle A	Velocity Change (mph) Vehicle B
Volvo-to-Volvo Offset Right (25")	81.4 mph	44.4	42.6

Here again, as in Test No. 4, the crash pulse was not at all severe, however, the degree of firewall intrusion was great. Vehicle A had 46 inches of static crush on the right side and Vehicle B had a phenomenal 60 inches static crush. In fact the degree of intrusion on the right side was so severe (Figure 7-16) that the knees of the right front dummy were pressed back into the bottom seat cushion by the firewall. One could actually see the bumper of Vehicle A approximately 3 inches from the knee of the dummy in Vehicle B. After the test the passenger door opening on Vehicle B was only approximately 16 inches wide since the A-pillar had deformed so much.

In spite of the, to be expected, severe intrusion, the head and chest injury measures for all occupants were well within the criteria limits. The only femur load that was not within specification was the right, driver femur in Vehicle A. Figures 7-17 through 7-19 show the post test positions of the occupants.

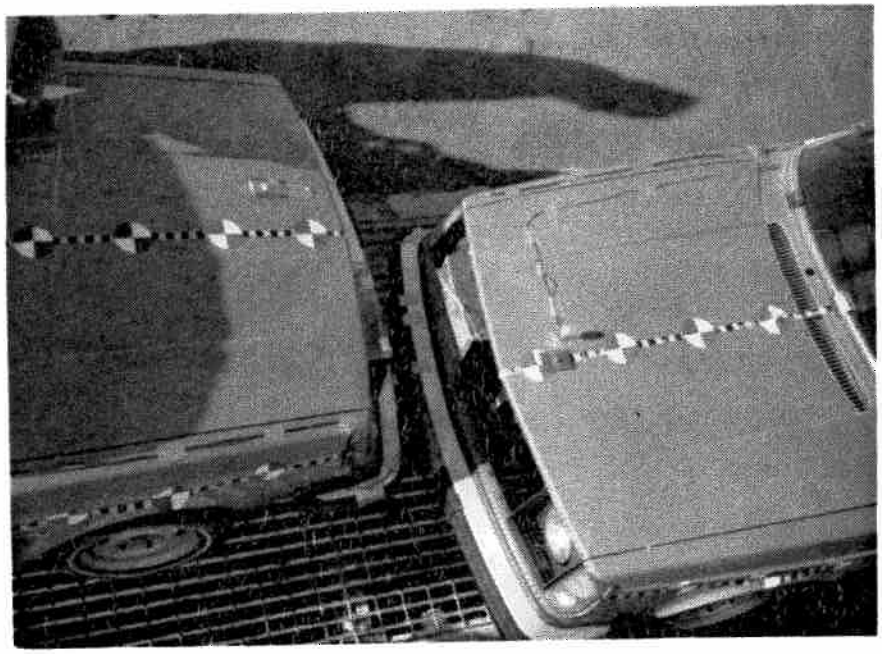


Figure 7-15. Test No. 5, Right Offset

Figure 7-16. Vehicle Damage, Test No. 5

Figure 7-17. Post Test, Test No. 5, Airbag Car

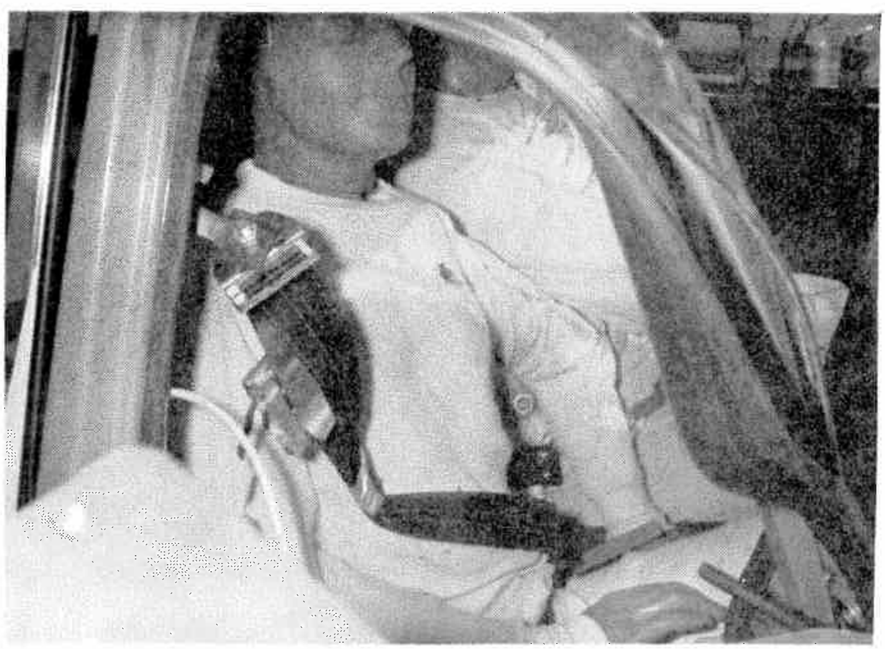


Figure 7-18. Post Test, Test No. 5, Belt Car

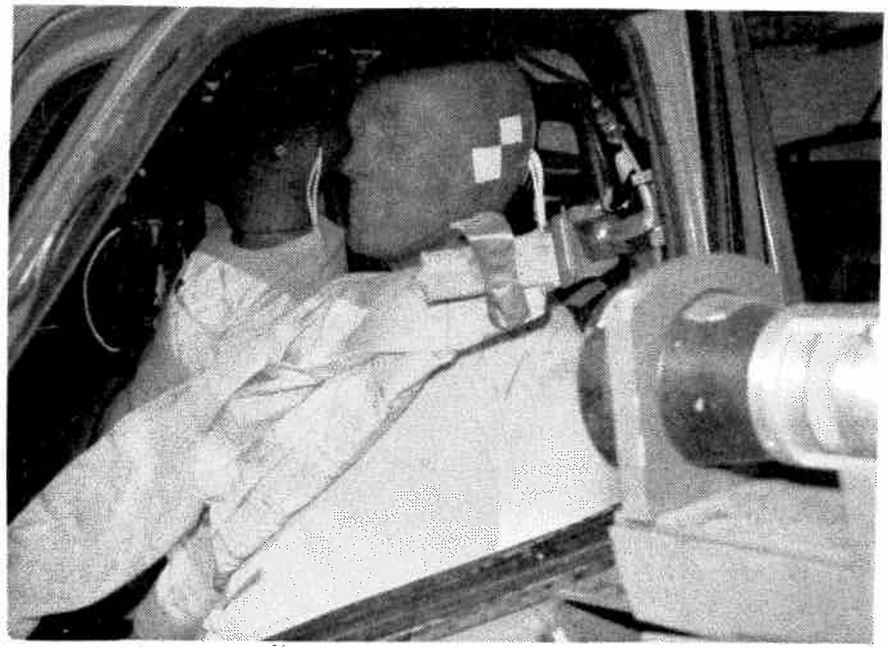


Figure 7-19. Post Test, Test No. 5, Belt Car

Summarized below are the injury measures for all occupants.

	DS	PS	AB	FLB
HIC	119	170	205	596
Peak Resultant Chest g's (-3 msec)	30.4	33.6	36.4	40.0
Femur Loads: Left (lb), Right (lb)	1570-2308	973-1419	91-92	2027-893

The peak shoulder belt load on the FLB system was 1284 lb. As can be seen from the above, the injury measures received were generally very much below the criteria limits. In this right offset test which was concentrated on the passenger side and, therefore, more severe for the passenger, the passenger bag held together and did not rip.

7.6 VEHICLE TEST NO. 6

Up until this point in the program, all of the tests had been vehicle-to-vehicle tests. Since a significant percentage of the total societal cost of accidents is due to fixed object collisions, we scheduled a series of full frontal barrier tests. Although the number of fixed object collisions that involve the full car width are but a small percentage of total fixed object collision, we concentrated on the full frontal mode due to the fact that for the speeds we were interested in (45-50 mph) intrusion would be prohibitive in, say, a simulated pole impact. Since we knew this and wanted to ascertain restraint performance in high velocity impacts, the CTM and Dynamic Science mutually agreed to conduct the full frontal barrier test.

Test No. 6 was divided into two separate tests. Test 6-A would test Vehicle A in a barrier impact while Test 6-B would test Vehicle B in an equivalent impact.

7.6.1 Test Objective and Set Up

The objective of Test No. 6 was to ascertain whether the four advanced restraint systems would protect vehicle occupants in full frontal fixed object impacts at 45-50 mph impact velocity.

The restraint system configuration for Test 6-A and 6-B was:

Occupant	Vehicle A	Vehicle B
Left Front	RSV Driver Airbag	Force-Limited Airbelt
Right Front	RSV Passenger Airbag	Force-Limited 2-Inch Belt

The vehicle structure was again virtually unchanged from what it was in Test No. 2.

7.6.2 Test Results

The impact conditions for Test No. 6 were:

Configuration	Closing Speed	Velocity Change
6-A Volvo-to-Barrier	46.1 mph	48.7 mph
6-B Volvo-to-Barrier	46.1 mph	49.0 mph

In these two tests the crash pulse g-levels were very high with peak g's of 75 g's in the airbag car and 74 g's in the belt car. These values were much higher than expected and resulted from the fact that the flat faced barrier forced a crash mode on the car that included the stiffened upper firewall and cowl area. In the previously conducted vehicle-to-vehicle tests the lower firewall could deform more and absorb their energy so that the intrusion was highest, low in the vehicle and lowest, high in the vehicle. However, the flat faced barrier forced the crush to occur uniformly with the result that the "hard" structure was involved. (Figures 7-20 and 7-21).

In these two tests both vehicles deformed in a practically identical fashion with a static crush of 37 inches in each vehicle. However, there was one important difference - a difference that had also been there in previous tests but not important until now. The difference was this. The airbag car as previously described required two transverse beams from A-post to A-post to support the Minicars RSV steering column. In the belt car, only one beam

Figure 7-20. Vehicle Damage, Test 6-B

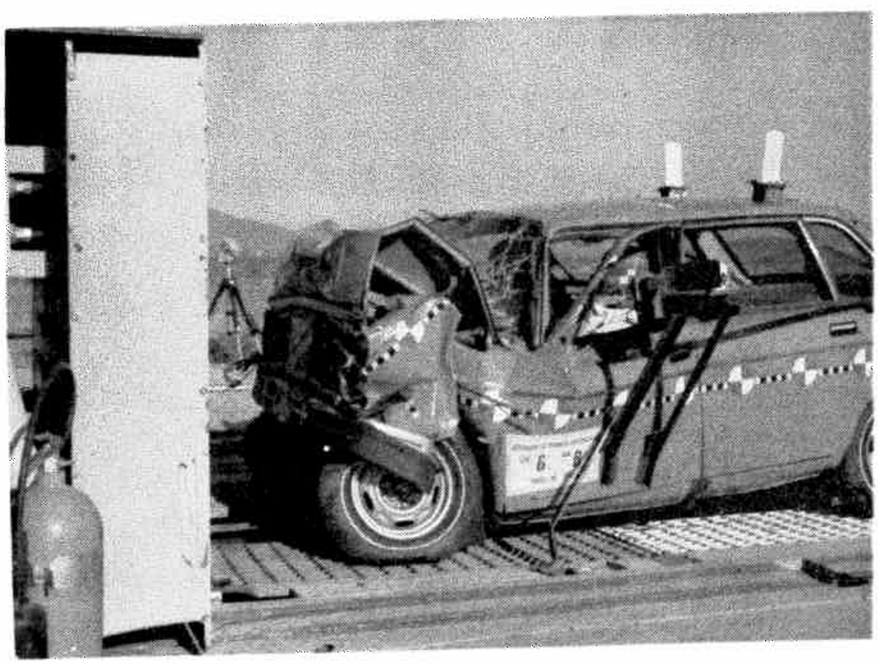


Figure 7-21. Close Up View of Vehicle Damage, Test 6-B

was installed and was installed in a position six and one-quarter inches forward of the position of the aft most beam in the bag car. In addition, the passenger airbag inflator holder extends approximately another four inches aft of this beam. The net result is that the passengers in the belt car have approximately ten and one-quarter inches more stroking space available than the passengers of the bag car.

While this has been true on all the tests, it wasn't until a test was conducted with a very severe crash pulse that this difference became important. On tests such as this one with very high crash pulse g-levels occurring late in the crash event, it can be shown that the required interior stroking space is drastically increased. This requirement was manifested in the airbag car by the driver steering column end impacting the firewall after five and one-half inches of stroke. This bottoming effect resulted in excessive chest g-levels for the airbag restrained driver.

On the passenger side, the driver bottomed against the dash. It wasn't until after Test No. 7-A that the real reason was pinpointed. At first there was evidence that the inflator malfunctioned and not enough gas was produced to prevent bottoming, but when in Test No. 7-A, with a carefully prepared inflator, the same thing happened, the crash pulse severity was then thought to be the prime factor.

We would like to point out that full frontal, fixed object collisions account for only a small percentage of the total societal cost of accidents. Therefore, this full frontal barrier test mode is probably used in testing to a much greater degree than it should be. Over the years the full frontal barrier test has become sort of a standard by which the performance of various restraint systems can be evaluated in a relative fashion. The danger, we feel, lies in the fact that undue emphasis may be placed upon this accident mode to the point that the designer may design a restraint system that functions optimally in a test mode that is not representative of real world accidents. If this happens, the vehicle occupants in more prevalent accident modes may receive injuries that are higher than they would have been had the restraint been designed to function optimally in the more prevalent mode.

Summarized below are the injury measures for each occupant.

	Vehicle A System	
	DS	PS
HIC	572	1671
Peak Resultant Chest g's (-3 msec)	86.7	73.9
Femur Loads: Left (lb), Right (lb)	1947-2772	3306-3794

	Vehicle B System	
	AB	FLB
HIC	408	841
Peak Resultant Chest g's (-3 msec)	57.5	45.0
Femur Loads: Left (lb), Right (lb)	682-2615	2960-693
Peak Torso Belt Load (lb)	N/A*	1549

One further comment; upon study of the high speed films, is is apparent that the right front passenger's head (in the Belt Car) impacted the transverse beam located between the A-posts. Since the airbag car has ten and one-quarter inches less horizontal distance from the passenger head to the hard dash structure, the impact would almost certainly have been more severe if the belt car had the dash equivalent of the bag car. Thus, it is somewhat misleading in this test to compare "bags versus belts". We feel the best answer to both cars would be to restructure the dash area to provide some additional padding should this bottoming occur in severe crashes. In all fairness to the Volvo, had the upper dash been reinstalled over the exposed transverse beams, the results may not have been quite as severe for the airbag restrained occupants.

7.6.3 Test Conclusions

1. There is some question as to why the airbag restrained passenger in Vehicle A received excessive injury measures. The inflator performance was suspect due to the "different" appearance of the

*Not applicable - no transducer on airbelt.

portion of the airbag exposed to the inflator heat. Normally, the bag turns brown over a large area that is exposed to the inflator. In this test the bag was practically unattacked. This made us suspect the inflator. However, the test was severe so that possibly the crash pulse was the controlling factor.
Doubt over which was the reason caused us to schedule another test to investigate this further.

2. It appears that the stiffening of the upper cowl done to support the driver steering column in the bag car results in excessive crash pulse g-levels when crashed into a barrier in the full frontal mode. However, without this stiffening effect, it is questionable whether the intrusion would remain within acceptable limits for impacts in the 50 mph class.

7.7 VEHICLE TEST NO. 7

Since there was some question following tests 6-A and 6-B whether the passenger airbag restraint system inflator malfunctioned and since we had a concept for improving the steering column on the driver side, we decided to repeat the test as 7-A. In order to decide whether the addition of one more transverse beam between the A-post on Vehicle B (making it identical to Vehicle A) would influence injury measures for the belted occupants, we also decided to conduct Test 7-B.

It was decided to increase the velocity still further to obtain further data with which to later construct the crash survivability index.

Thus, Tests 7-A and 7-B were again scheduled as full frontal barrier impacts but at a slightly higher target velocity of 48 mph.

7.7.1 Test Objective and Set Up

The objective of Test No. 7 was to ascertain whether the four advanced restraint systems would adequately protect vehicle occupants in full frontal fixed object impacts at 45-50 mph impact velocity. Further, we wished to determine whether the inflator or the crash pulse was responsible for the high chest g's received by the passenger in Test No. 6-A. Additionally, an improvement to the column was made and we wished to evaluate the effect of this "improvement".

The restraint system configuration for Tests 7-A and 7-B were:

Occupant	Vehicle A	Vehicle B
Left Front	RSV Driver Airbag	Force-Limited Airbelt
Right Front	RSV Passenger Airbag	Force-Limited 2-Inch Belt

Again, the vehicles used for this test were both 1976 Volvo 244's. To reiterate, Vehicle A was structurally modified in the dash, A-pillar, and B-pillar areas to preserve occupant compartment integrity and to accept the restraint systems that were installed in it. These modifications consisted of:

- Reinforced A-pillars
- Two steel tubes across the upper dash
- Continuous sheet metal pan across the front attached to the firewall and rear steel tube for knee restraint support.
- Steel tube under floor pan between B-pillars.

Vehicle B was also modified although not as extensively. The modifications to Vehicle B were:

- Two steel tubes across upper dash (an increase of one tube from the previous test.
- Steel tube under floor pan between B-pillars

- Continuous sheet metal pan across the front attached to firewall and rear steel tube (to duplicate Vehicle A as nearly as possible).
- Reinforced A-pillars.

For this test and all subsequent tests, the driver steering column was modified to prevent the column from impacting the firewall. Let us briefly discuss this modification. As the column was stroking, the column after approximately four and one-half inches stroke, would come out from the protection of its outer shroud and be exposed to impact by intruding structure such as the firewall in Test No. 6. For Test No. 7 we decided to lengthen the protective shroud so that the column, even when fully stroked, would not extend outside of the shroud and be exposed to hostile intruding surfaces. Figures 7-22 through 7-24 show the systems prior to test.

7.7.2 Test Results

The impact conditions for Test No. 7 were:

Configuration	Closing Speed	Velocity Change
7-A Volvo-to-Barrier	48.0 mph	52.5 mph
7-B Volvo-to-Barrier	48.3 mph	54.6 mph

Again, the crash pulse g-levels were very high at approximately 68 g's peak value for each vehicle. The total vehicle static crush was approximately 39.5 inches in Vehicle A and 40.5 inches in Vehicle B.

Again, the injury measures were, in general, in excess of the criteria limits. By this time the reason was obvious. In both this test and in Test No. 6, the crash pulse was so much different than the design crash pulse obtained from NHTSA and used in the sled test phase to tune the restraints, that one could not really expect the restraints to meet the criteria. Figure 7-25 shows a comparison between the design pulse and the pulse obtained in this test.

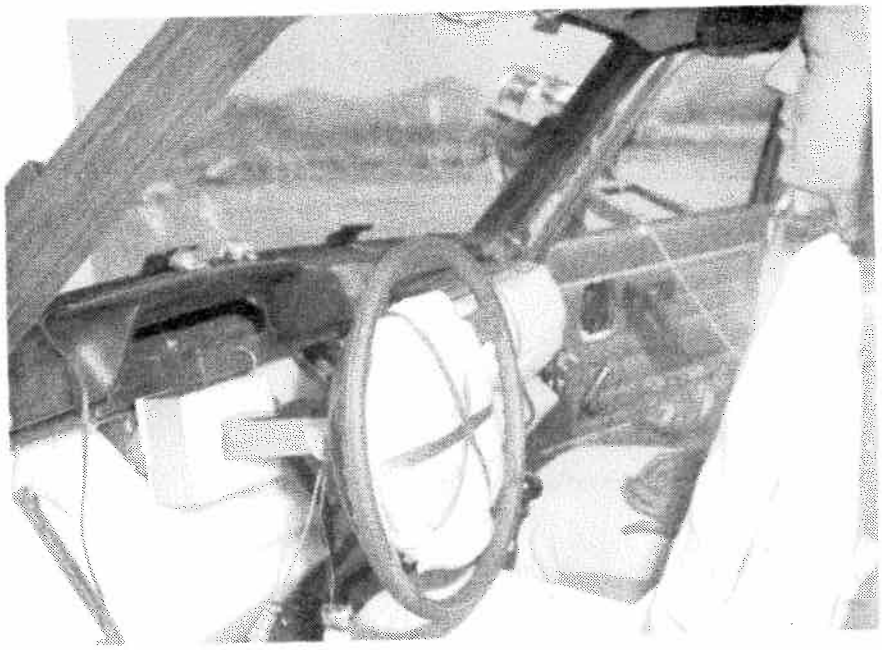


Figure 7-22. Pre Test, Test No. 7-A, Airbag Car

Figure 7-23. Pre Test, Test No. 7-A, Airbag Car

Figure 7-24. Pre Test, Test No. 7-B, Belt Car

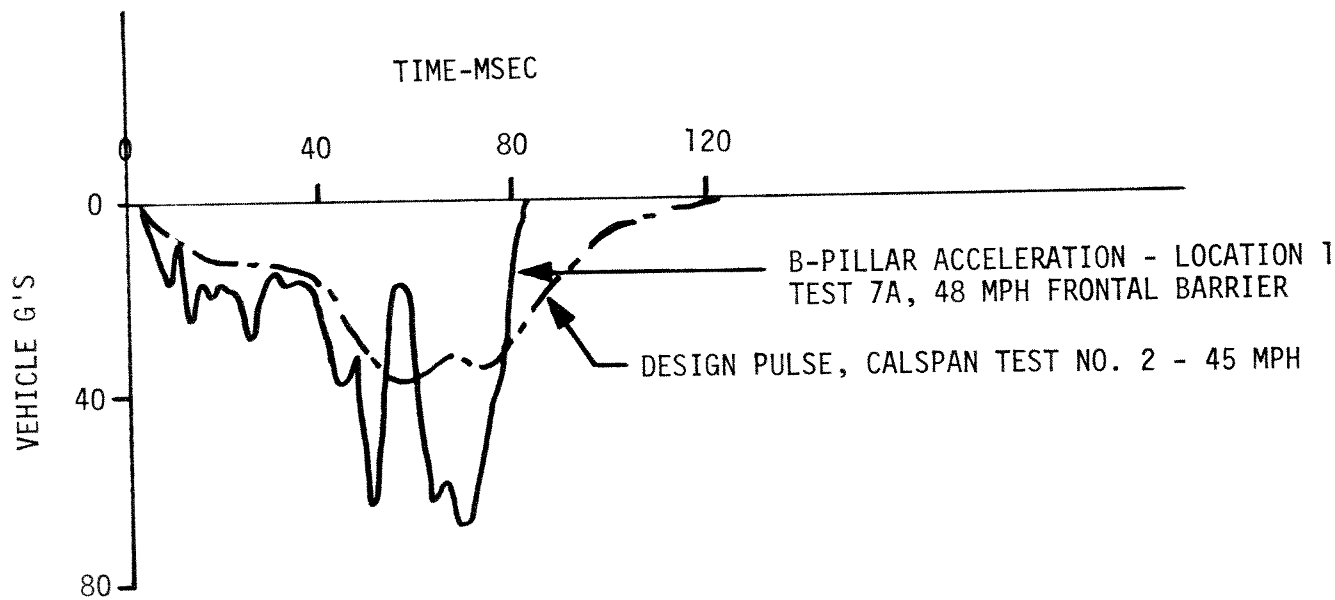


Figure 7-25. Comparison of Design Crash Pulse with Crash Pulse from Test 7A.

As can be seen, the two pulses are very dissimilar. In fact, the crash pulse for Tests 6 and 7 are so severe that it is doubtful that a restraint system could be designed to meet the criteria if these pulses were the design pulses.

On the other hand, the car-to-car crash pulses are fairly representative of the design pulse (Figure 7-26). The reason for this is, as previously mentioned, the stiff upper structure was not brought in to play in the car-to-car impact; therefore, the crash pulse was more like the design pulse and the restraints performed well and as expected.

For the barrier crashes, we therefore find ourselves in the position of having modified the vehicle to an extent during restraint installation that the crash pulse was adversely affected in 45-50 mph impacts.

Listed below are the injury measures for each of the four systems.

	Vehicle A System	
	DS	PS
HIC	674	1313
Peak Resultant Chest g's (-3 msec)	82	70
Femur Loads: Left (lb), Right (lb)	1856-2344	1809-1457

	Vehicle B System	
	AB	FLB
HIC	1378	3046
Peak Resultant Chest g's (-3 msec)	77.2	78.0
Femur Loads: Left (lb), Right (lb)	2726-792	2953-1230
Peak Shoulder Belt Load (lb)	N/A	1517

The effect of the column modification was masked due to another problem; let us explain why. As previously described, we modified the column by extending the protective shroud surrounding the column so that no deforming vehicle structure could again impact and, therefore, hinder the stroking of

7.9.3 Test Conclusions

1. The injury measures received for the FLB restrained dummy were, for both head and chest, very close to the criteria limits which indicates that **this test** delta V is an upper bound for restraint performance for the FLB in this test mode.
2. Since the inflatable torso belt was incorrectly positioned on the dummy in this test, we can make no statement concerning the upper velocity bound for head injury. However, the chest peak g's of 52 g indicate that the airbelt restraint system probably has the potential to go to an even higher delta V before exceeding the criteria limit of chest injury.

7.10 VEHICLE TEST NO. 10

Upon completion of Test No. 9, we had completed the first part of the test matrix and were ready for evaluate the system in a series of oblique tests. For these tests the Ford Torino was the bullet car and the Volvo 244 was the stationary struck vehicle. In these tests both left and right oblique impacts were conducted. In Test 10, the angle between longitudinal axis of the Volvo and the longitudinal axis of the Torino was 30 degrees in Test 10, 25 degrees in Tests 11, 12, 13 and 14, and 45 degrees in Test 16.

7.10.1 Test Objective and Test Set Up

The objective of this test was to ascertain whether the advanced airbag restraints installed in the Volvo would adequately protect the Volvo occupants in a 30 degree right oblique test (Volvo impacted on right front corner, Figure 7-40) when impacted by a larger vehicle (the Torino) at a closing velocity of 60 mph.

The restraint system configuration for Test No. 10 was:

Occupant	Vehicle A	Vehicle B
Left Front	Standard 3-Point Belt	RSV Driver Airbag
Right Front	Standard 3-Point Belt	RSV Passenger Airbag

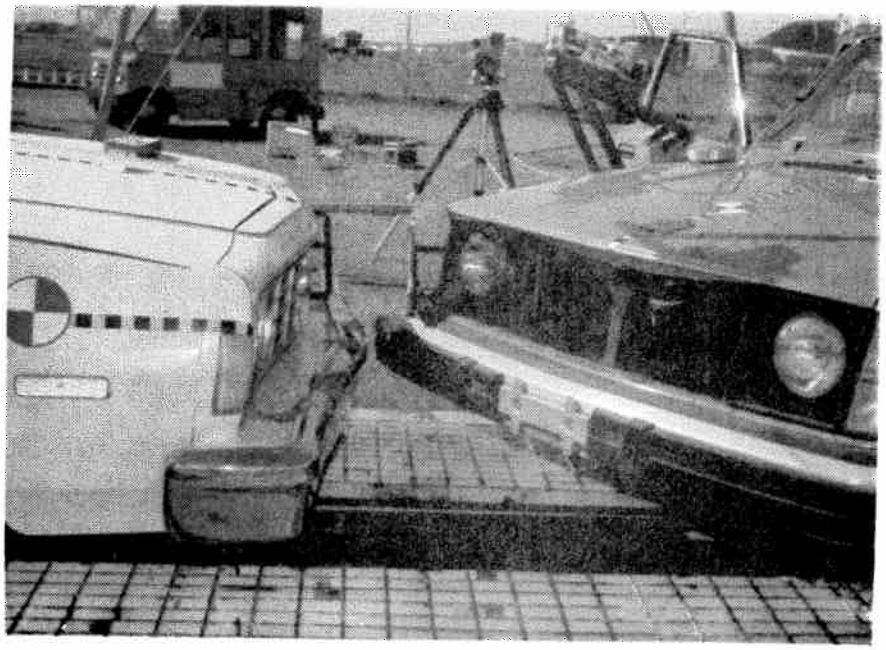


Figure 7-40. Test No. 10, 30 Degree Right Oblique

For this test, Vehicle A was a 1975 Ford Torino and Vehicle B was a 1976 Volvo 244. No structural modifications were made to Vehicle A, while Vehicle B was structurally modified in the dash, A-pillar, and B-pillar areas as previously described, to preserve occupant compartment integrity and to accept the restraint systems that were installed in it. Figure 7-41 shows the airbag systems prior to the test.

7.10.2 Test Results

The impact conditions for Test No. 10 were:

Configuration	Closing Speed	Velocity Change
Torino-to-Volvo Right Oblique (30°)	60.5 mph	34.9 mph

In this first test in the oblique mode, the injury criteria was met for each of the two dummies. However, one thing did occur which detracted from an otherwise perfect test. The passenger airbag, for the second time in the test series, opened up along the seam that runs between the upper and lower bag chambers. Again, the cause was weakly sewn seams in the airbag. After this test the old remaining airbags were discarded and a new batch of airbags were fabricated - all with seams of improved design and increased strength.

Summarized below are the injury measures for this test.

	Vehicle B Systems	
	DS	PS
HIC	333	365
Peak Resultant Chest g's (-3 msec)	38.0	57.6
Femur Loads: Left (lb), Right (lb)	1795-1250	1092-601

Figures 7-42 through 7-44 show Vehicle B and the restraint systems following the test.

7.10.3 Test Conclusions

1. It was demonstrated in this test that the Minicars RSV restraint systems can provide protection in 35 mph delta V right oblique impacts so that the injury measures received are below the criteria

Figure 7-41. Pre Test, Test No. 10, Airbag Car

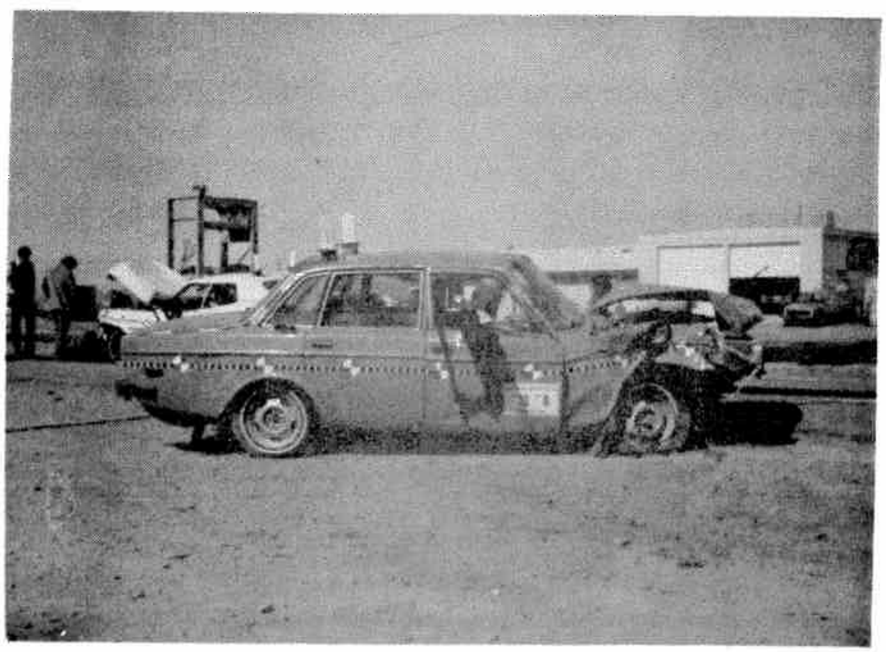


Figure 7-42. Volvo Damage, Test No. 10

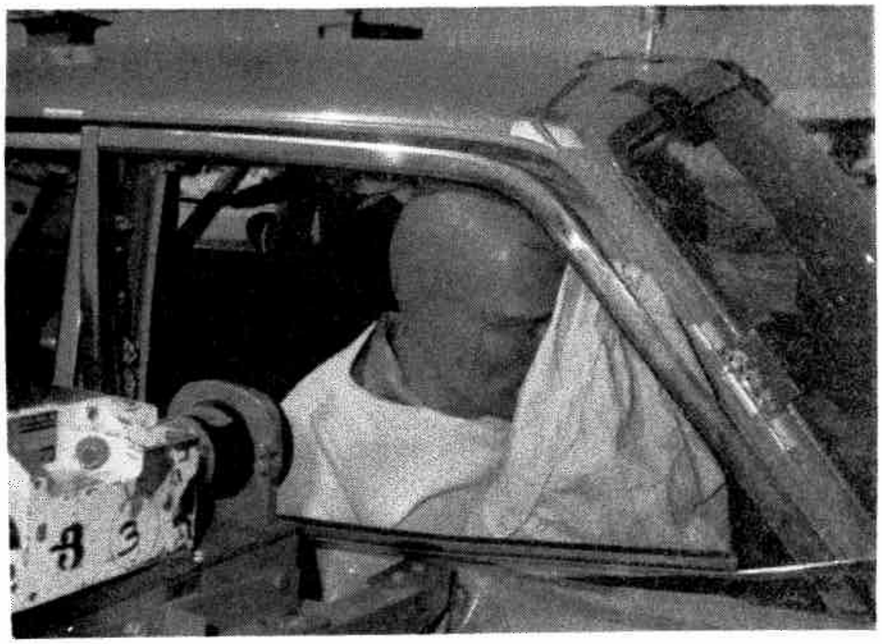


Figure 7-43. Final Position of Passenger, Test 10

Figure 7-44. Driver System, Test No. 10

limits. For the right front passenger, the result in not as clear cut as for the driver due to a seam failure on the air-bag. However, even with this failure, the injury criteria was met.

7.11 VEHICLE TEST NO. 11

In Test No. 10 there was a good deal of rotation by the Volvo when impacted at the 30 degree angle. In addition, the Volvo showed a propensity toward overturning. For these reasons the 30 degree impact angle was reduced to 25 degrees for Tests 11, 12, 13 and 14.

The restraint systems in the Volvo for this test were the advanced belt systems.

7.11.1 Test Objective and Set Up

The objective of this test was to ascertain whether the advanced belt systems installed in the Volvo would adequately protect the Volvo occupants in a 25 degree left oblique test when impacted by a larger vehicle (the Torino) at a closing velocity of 60 mph. Figures 7-45 and 7-46 show the pre-test set up.

The restraint system configuration for Test No. 11 was:

Occupant	Vehicle A	Vehicle B
Left Front	Standard 3-Point Belt with Web Lockers	Force-Limited Airbelt
Right Front	Standard 3-Point Belt with Web Lockers	Force-Limited 2-Inch Belt

7.11.2 Test Results

The impact conditions for Test No. 11 were:

Configuration	Closing Speed	Velocity Change
Torino-to-Volvo Left Oblique (25°)	59.5 mph	35.1 mph

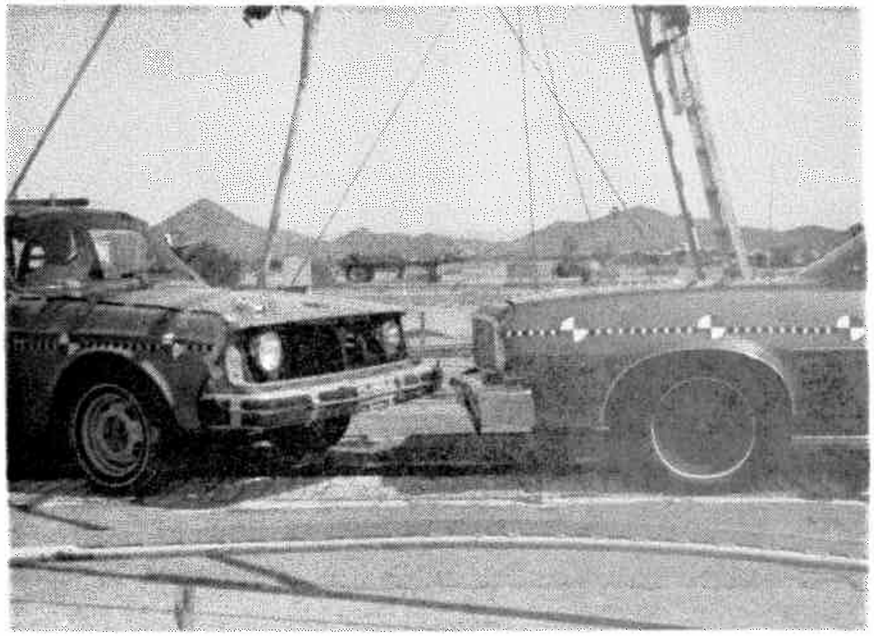


Figure 7-45. Test No. 11, 25 Degree Left Oblique

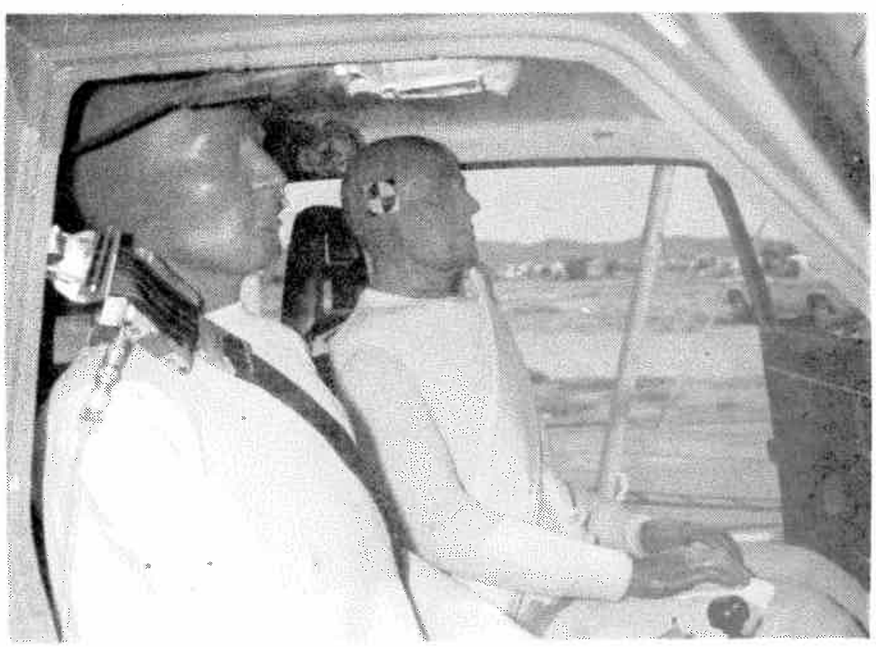


Figure 7-46. Pre Test, Test No. 11, Belt Car

Again, as was the case in Test No. 10 with the bag restrained dummies, the belt restrained dummies received injury measures that were below the criteria limits. Figures 7-47 and 7-48 show Vehicle B and the final dummy positions.

The table below summarizes the injury measures received by the two dummies restrained by the advanced belt systems.

	Vehicle B Systems	
	AB	FLB
HIC	247	236
Peak Resultant Chest g's (-3 msec)	33.5	29.6
Femur Loads: Left (lb), Right (lb)	325-138	656-972
Peak Shoulder Belt Load (lb)	N/A	1556 lb

Figure 7-49 shows a typical final position for the lap belt force-limiter when stroked.

7.11.3 Test Conclusions

1. The advanced belt systems chosen for this program provide protection with injury measures substantially below the criteria limits for vehicle occupants undergoing a crash in the left oblique impact mode for delta V's of at least 35 mph.

7.12 VEHICLE TEST NO. 12

Test No. 12 was scheduled as a repeat of Test No. 10 only at the slightly higher impact velocity of 63 mph closing velocity. Again, the Ford Torino was the bullet car and the 1976 Volvo 244 was the stationary struck vehicle.

7.12.1 Test Objective and Set Up

The objective of this test was to determine whether the advanced airbag restraints installed in the Volvo would adequately protect the Volvo occupants in a 25 degree right oblique test when struck by a larger vehicle such as the Ford Torino at a closing velocity of 63 mph. Figure 7-50 shows the vehicles prior to the test and Figure 7-51 shows the restraint systems.

Figure 7-47. Volvo Damage, Test 11

Figure 7-48. Final Dummy Positions
Test No. 11

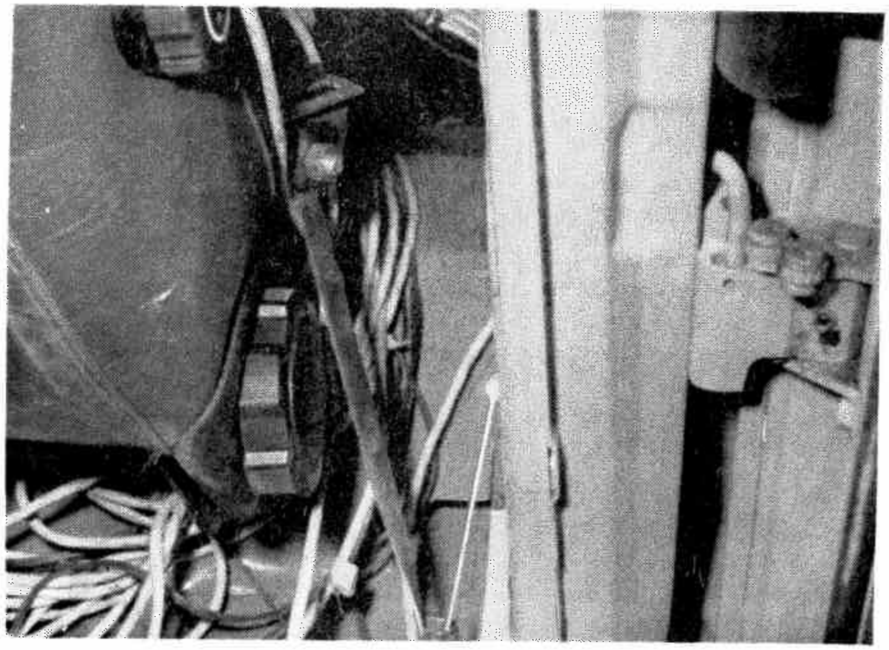


Figure 7-49. Lap Belt Force-Limiter Stroke

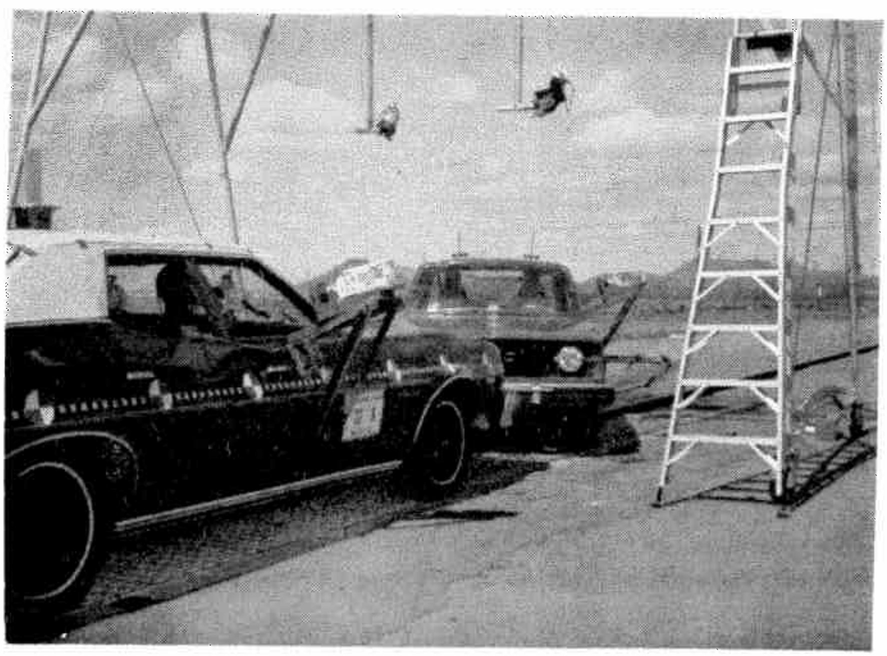


Figure 7-50. Test No. 12, 25 Degree Right Oblique

Figure 7-51. Airbag Systems Prior to Test No. 12

The restraint system configuration for Test No. 12 was:

Occupant	Vehicle A	Vehicle B
Left Front	Standard 3-Point Belt with Web Lockers	RSV Driver Airbag
Right Front	Standard 3-Point Belt with Web Lockers	RSV Passenger Airbag

The Volvo modifications made for installing the airbag restraints were identical to that previously described and is shown by Figure 7-52.

Two changes were made for this test in order to insure that no further bag rips would occur in the passenger bag. One change was mentioned previously, the old airbags with improperly constructed seams were discarded and new airbags of an improved design with stronger seams were fabricated. This in itself was probably enough to provide certainty that no further bag rips would take place. However, as added insurance, the airbag gas generator was downloaded from 460 grams to 440 grams propellant charge. We were confident this slight reduction in generator charge would not adversely affect performance since in another NHTSA program with similar goals also conducted by Minicars, the same gas generator was used successfully with 420 grams of identical propellant formulation (Contract No. DOT-HS-6-01384).

7.12.2 Test Results

The impact conditions for Test No. 12 were:

Configuration	Closing Speed	Velocity Change
Torino-to-Volvo Right Oblique (25°)	63.3 mph	40.2 mph

In this test both systems performed well with the result that both dummies easily met the injury criteria. In the table on the next page, the injury measures are summarized. Figures 7-53 and 7-54 show the post test vehicle and dummy positions.

Item	Req'd	Description	Material and Overall Size	Weight
1	2	Pillar Plates	16 GA. x 28 x 26-3/4 CRS	13.0
2	1	Angel Mount	16 GA. x 2 x 52-1/2 CRS	1.8
3	1	Knee Restraint Plate	16 GA. x 20-1/4 x 52-1/2 CRS	19.0
4	14	Stiffeners	16 GA. x 1-1/4 x 81-1/2 CRS	1.8
5	2	Angel Mounts	16 GA. x 2 x 64 CRS	1.1
6	2	Dash Support Tubes	.083 x 2 x 2 x 106 CR Tubing	19.1
7	1	Dash Top	16 GA. x 9 x 52-3/8 CRS	8.2
8	-	Mounting Hardware	-	1.0
9	-	Welding Material	-	1.0
Dash Structure Total Weight (lb) Items 1 Through 9				66.0
10	1	Floor Bear	.095 x 2 x 2 x 54-1/2 CR Tubing	11.2
11	2	Floor Bear Strap	14 GA. x 2 x 26 CRS	1.1
12	2	Floor Beam Plate	1/8 x 2 x 4 CRS	.3
13	-	Mounting Hardware	-	1.0
14	-	Welding Material	-	1.0
Floor Reinforcement Total Weight (lb) Items 10 Through 14				14.6
Total Weight (lb) Items 1 Through 14				80.6

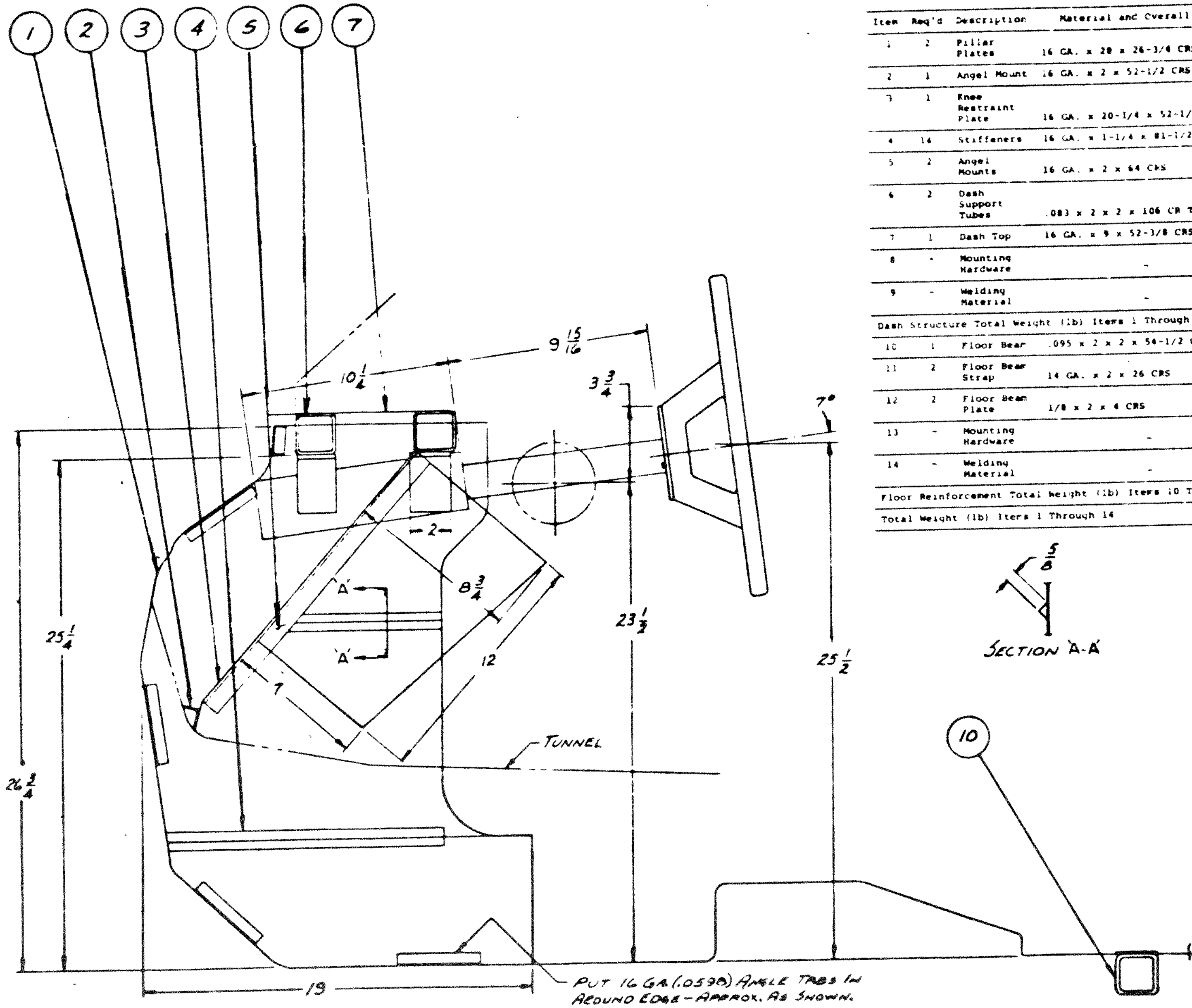


Figure 7-52. Final Structural Modification to Airbag Car.

Figure 7-53. Volvo Damage, Test No. 12

Figure 7-54. Final Dummy Position, Test No. 12

	Vehicle B Systems	
	DS	PS
HIC	233	219
Peak Resultant Chest g's (-3 msec)	37.9	30.5
Femur Loads: Left (lb), Right (lb)	1103-1440	672-744

7.12.3 Test Conclusions

1. The advanced airbag systems result in injury measures substantially below the criteria limits for vehicle occupants undergoing a crash in the left oblique impact mode for delta V's of at least 40 mph.

7.13 VEHICLE TEST NO. 13

Upon completion of Test No. 12 the advanced airbag restraints had proven themselves capable of providing adequate protection to vehicle occupants in right oblique impacts and in the various frontal impact modes previously tested. With Test No. 13 we hoped to show that the injury criteria could also be met in the left oblique impact mode even with a slightly increased test velocity.

7.13.1 Test Objective and Set Up

The objective of this test was to determine whether the advanced airbag restraints installed in the Volvo would adequately protect the Volvo front seat occupants in a 25 degree left oblique test when impacted by a larger vehicle (the Ford Torino) at a closing velocity of 66 mph.

The restraint system configuration for Test No. 13 was:

Occupant	Vehicle A	Vehicle B
Left Front	Standard 3-Point Belt	RSV Driver Airbag
Right Front	Standard 3-Point Belt	RSV Passenger Airbag

Due to the success obtained in Test No. 12 with the passenger airbag gas generator downloaded 20 grams to 440 grams of propellant, it was decided to continue testing with the 440 gram change for the remainder of the program. Figures 7-55 and 7-56 show the pre-test set up.

Figure 7-55. Test No. 13, 25 Degree Left Oblique

Figure 7-56. Airbag Systems Prior to Test No. 13

7.13.2 Test Results

The impact conditions for Test No. 13 were:

Configuration	Closing Speed	Velocity Change
Torino-to-Volvo Left Oblique (25°)	65.7 mph	42.5 mph

Here again, both of the advanced airbags performed extremely well with the result that both dummies easily met the injury criteria. In addition, this was accomplished at the relatively high delta V (for the oblique impact mode) of 42.5 mph. Figures 7-57 and 7-58 show the final positions of Vehicle B and the dummies. In the table below the injury measures are summarized.

	Vehicle B Systems	
	DS	PS
HIC	206	195
Peak Resultant Chest g's (-3 msec)	38.3	42.3
Femur Loads: Left (lb), Right (lb)	1699-1278	No Data - 523

7.13.3 Test Conclusions

1. The driver and passenger advanced airbag systems result in injury measures substantially below the criteria limits for vehicle occupants undergoing a crash in the left oblique impact mode for delta V's of at least 42.5 mph.

7.14 VEHICLE TEST NO. 14

Once Test No. 13 was completed, it had been demonstrated that the advanced airbag restraint systems would provide protection to front seat vehicle occupants in the right and left oblique impact mode with a substantial margin of safety (injury measures were substantially below criteria limits). In Test No. 14, we changed the systems tested back to the advanced belt systems to obtain additional information on belt performance levels in equivalent impacts.

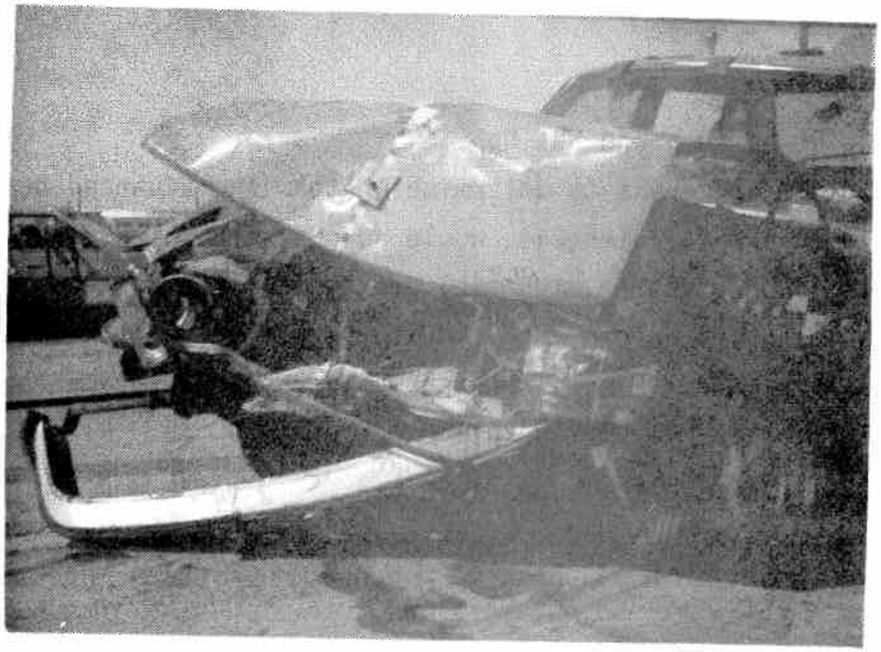


Figure 7-57. Volvo Damage, Test No. 13

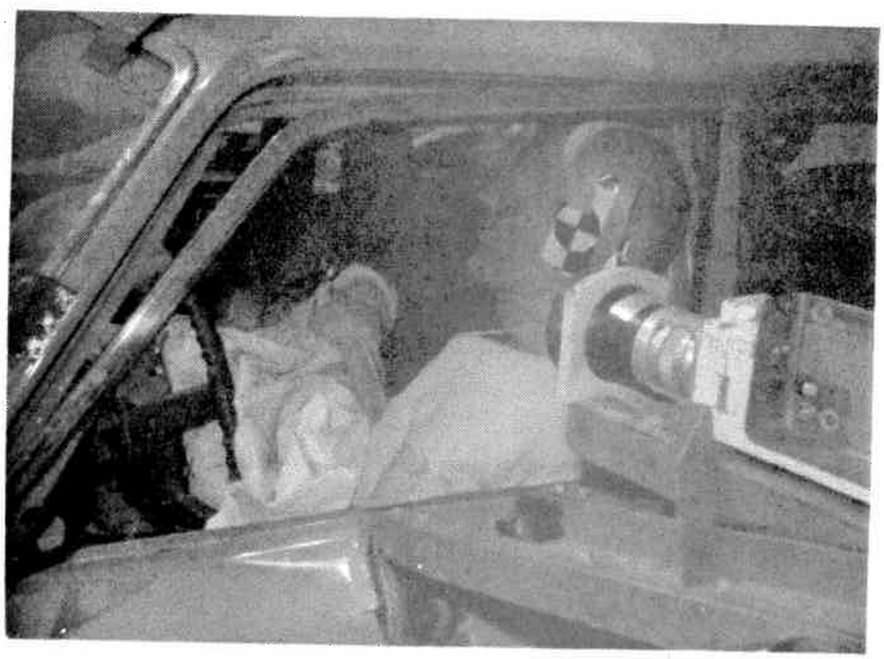


Figure 7-58. Final Dummy Positions, Test No. 13.

7.14.1 Test Objectives and Set Up

The test objective was to determine whether the advanced belt systems, when installed in a 1976 Volvo 244, would adequately protect the Volvo front seat occupants in a 25 degree right oblique test when impacted by a larger vehicle (Ford Torino) at a closing velocity of 67 mph - the highest velocity yet tested in this mode. Figure 7-59 shows the vehicles prior to the test.

The restraint system configuration for Test No. 14 was:

Occupant	Vehicle A	Vehicle B
Left Front	Standard 3-Point Belt with Web Lockers and Force-Limiters	Force-Limited Airbelt
Right Front	Standard 3-Point Belt with Web Lockers and Force-Limiters	Force-Limited 2-Inch Belt

7.14.2 Test Results

The impact conditions for Test No. 14 were:

Configuration	Closing Speed	Velocity Change
Torino-to-Volvo Right Oblique (25°)	66.6 mph	40.5 mph

The results of this test are summarized below. As can be seen from the table, both of the dummies easily met the injury criteria.

	Vehicle B Systems	
	AB	FLB
HIC	313	396
Peak Resultant Chest g's (-3 msec)	45.1	50.9
Femur Loads: Left (lb), Right (lb)	577-681	571-957
Peak Shoulder Belt Load	N/A	1404

Figure 7-60 shows Vehicle B after the test.

Figure 7-59. Test No. 14, 25 Degree Right Oblique

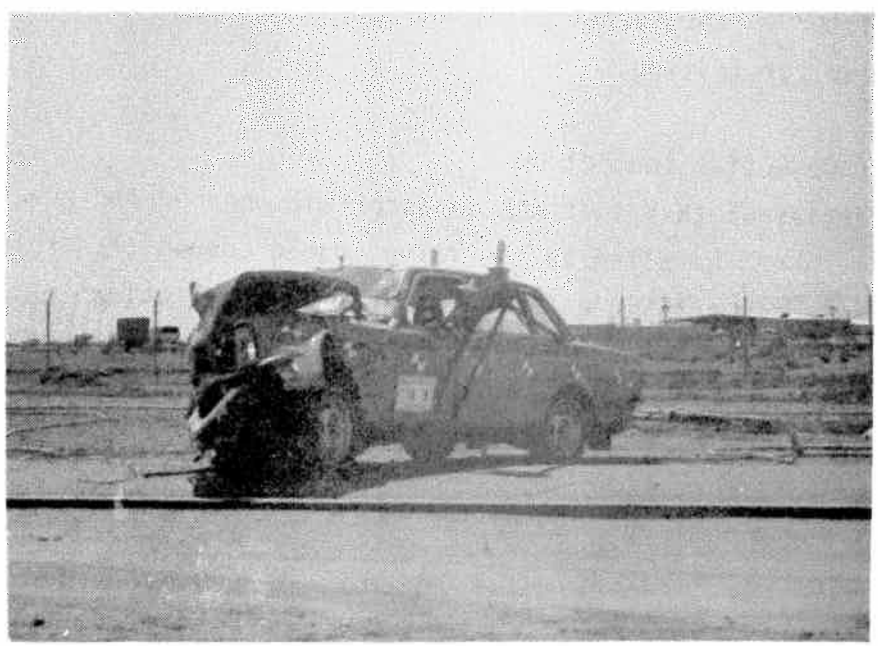


Figure 7-60. Volvo Damage, Test No. 14

7.14.3 Test Conclusions

1. The airbelt and force-limited 2-inch belt restraint systems result in injury measures substantially below the criteria limits for vehicle front seat occupants undergoing a crash in the right oblique impact mode for delta V's of at least 40.5 mph.

7.15 VEHICLE TEST NO. 16

Test No. 14 completed the 25 and 30 degree left and right oblique tests for both the advanced airbag and advanced belt systems. Test No. 15 was a Torino-into-Torino test in which none of the advanced restraints were tested and is, therefore, not included in this report.

With Test No. 16 we decided to run one more oblique test at an even higher impact angle of 45 degrees. The approach velocity for the Torino was selected at 60 mph. As in the previous tests, the Torino was the bullet car and the Volvo was the stationary struck vehicle. The left side of the Volvo was selected as the target point and the advanced airbag systems as the restraint system for testing.

7.15.1 Test Objective and Set Up

The objective of this test was to ascertain whether the advanced air-bag restriants, when installed in the Volvo, would adequately protect the Volvo front seat occupants in a 45 degree left oblique test when impacted by a larger vehicle such as the Ford Torino at a closing velocity of 60 mph.

The restraint system configuration for Test No. 16 was:

Occupant	Vehicle A	Vehicle B
Left Front	Unrestrained	RSV Driver Airbag
Right Front	Unrestrained	RSV Passenger Airbag

Figures 7-61 and 7-62 show the vehicle impact configuration and the restraint system installation in Vehicle B.

Figure 7-61. Test No. 16, 45 Degree Left Oblique

Figure 7-62. Airbag Systems Prior to Test No. 16

7.15.2 Test Results

The impact conditions for Test No. 16 were:

Configuration	Closing Speed	Velocity Change
Torino-to-Volvo Left Oblique (45°)	60.3 mph	31.6 mph

The results of this test are summarized below:

	Vehicle B Systems	
	DS	PS
HIC	207	1246
Peak Resultant Chest g's (-3 msec)	32.1	31.5
Femur Loads: Left (lb), Right (lb)	423-592	365-937

As one can see from the above data, the passenger HIC is above the criteria limit. It is obvious from looking at the head acceleration traces that the passenger head struck either the unpadded transverse beam (installed to mount the steering column in the car) running from A-post to A-post or, possibly, the steering wheel rim. After studying the movies, it is impossible to tell which of those two items the head hit. If it was the unpadded dash structure, it would be a freak occurrence and should be discounted. If impact with the wheel occurred, this could be a real occurrence. However, we might add here that the steering wheel used on the driver system is a heavy-duty wheel fabricated by General Motors especially for the airbag. It is this author's opinion that a lighter-duty, more easily deforming wheel could be used without compromising the performance of the wheel as a reaction plate for the airbag. As can be seen from Figure 7-63, the Volvo overturned in this high angle test.

7.15.3 Test Conclusions

1. The driver airbag system will protect the driver in 45 degree left oblique impacts, however, the passenger translates across the compartment and impacts either the wheel or the hard, unpadded cowl structure. No general statement can therefore be made about the adequacy of the passenger system in this type of impact.
2. As expected, the Volvo overturned. This tendency was evident in the lower angle impacts which was an indication of a more severe tendency as the angle of impact was increased.

Figure 7-63. Volvo Damage, Test No. 16

7.16 VEHICLE TEST NO. 17

With the completion of Test No. 16, the complete series of oblique tests was finished. Only two tests remained to complete the overall matrix. For the first of these two tests a test was scheduled where, for the first time, we would evaluate the performance of the four advanced restraint systems with occupants that were of different size than the ones previously tested. In all previous tests the 50th percentile male surrogate was tested; in Test No. 17 NHTSA requested that a 95th percentile male surrogate be placed in the driver position and a 5th percentile female surrogate in the right front passenger position of the airbag car. The test mode selected was a full frontal Volvo-into-Volvo mode with the dummies in one Volvo (Vehicle A) restrained with the airbag restraint systems and the dummies in the other Volvo (Vehicle B) restrained with the advanced belt systems. A closing velocity of 84-85 mph was selected as the test velocity.

7.16.1 Test Objective and Set Up

The objective of this test was to determine the degree of protection that would be afforded by the advanced airbag restraint systems and the advanced belt system, when installed in a 1976 Volvo 244 and crashed head-on with another Volvo, at a closing velocity of 84-85 mph.

Unlike previous tests with the advanced belt systems in which the belt systems tested were right front passenger systems, for this test it was decided to switch to driver restraint systems for the belted passengers.

The restraint system configuration for Test No. 17 was:

Occupant	Vehicle A	Vehicle B
Left Front	RSV Driver Airbag (95th percentile male)	Force-Limited Airbelt (with steering column installed)
Right Front	RSV Passenger Airbag (5th percentile female)	Force-Limited 2-Inch Belt (with steering column installed)

The vehicles used for this test were both 1976 Volvo 244's. Vehicle A was structurally modified in the dash, A-pillar, and B-pillar areas to preserve occupant compartment integrity and to accept the restraint systems that were installed in it. These modifications consisted of:

- Reinforced A-posts
- Reinforced side rails
- Two steel tubes across the upper dash
- Continuous sheet metal pan across the front attached to firewall and rear steel tube to support foam knee bolster
- Steel tube under floor pan between B-pillars

Vehicle B was also modified and its modifications were:

- Reinforced A-posts
- A double hat section across the middle firewall
- Two steel tubes across the upper dash
- Steel tube under floor pan between B-pillars
- Advanced steering columns at both front seat positions

The 95th percentile male dummy was installed in the driver position of Vehicle A and a 5th percentile female dummy in the passenger position. For this test with Vehicle A, the driver seat was fixed in the aft most position while the passenger was placed in the mid-adjustment position. The mid-adjustment seat location was used for the passenger since we thought that this position would probably be the most common position. Again, as in the last test where the passenger airbag was used, the inflator was loaded to 440 grams of propellant.

In Vehicle B two Minicars "RSV type" steering columns were installed on the left and right sides of the vehicle and placed so that each of the front seat positions would, for all practical purposes, be a driver position. The energy-absorbing units installed in the columns were of a much lower force than was used in any previous tests since the column assembly itself was not required as an energy-absorber. Rather, all the dummies kinetic energy as in previous tests with the belted systems, would be absorbed by the belt systems themselves. The energy-absorbing units selected, then, were selected to "stroke" under the mass of the column acting alone. It was hoped that this "inertia stroking" would move the column out of the way of the head and allow the dummy head to rotate forward without hitting the steering wheel.

In most of the tests we are familiar with and virtually all such tests at delta V's greater than, say, 35-40 mph, the belted dummies head would impact the steering wheel. Since this was a virtual certainty in this test, at least for the FLB system, it was decided to do as much as possible to mitigate this impact.

The energy-absorber force level for the columns used in the belt car were set at approximately 125 lb each. For a stroking mass of column of 15 lb (approximate weight of stroking portion of column) the column would begin to stroke when the vehicle crash pulse reached the 8-9 g-level. No femur load cells were installed in the surrogates in the airbag car (Vehicle A) Figures 7-64 through 7-67 show the pre-test restraint installations.

7.16.2 Test Results

The impact conditions for Test No. 17 were:

Configuration	Closing Speed	Velocity Change (mph) Vehicle A	Velocity Change (mph) Vehicle B
Volvo-to-Volvo Head-on	84.2 mph	45.8	44.7

First, let us describe the test results for Vehicle A. As previously discussed, Vehicle A had the airbag restraints installed to protect the 95th percentile male driver and the 5th percentile female passenger surrogates. The table below summarizes the injury measures for the occupants of Vehicle A.

	Vehicle A Systems DS	Vehicle A Systems PS
HIC	319	712
Peak Resultant Chest g's (-3 msec)	64.3	44.3

Figure 7-68 shows the vehicles following the crash.

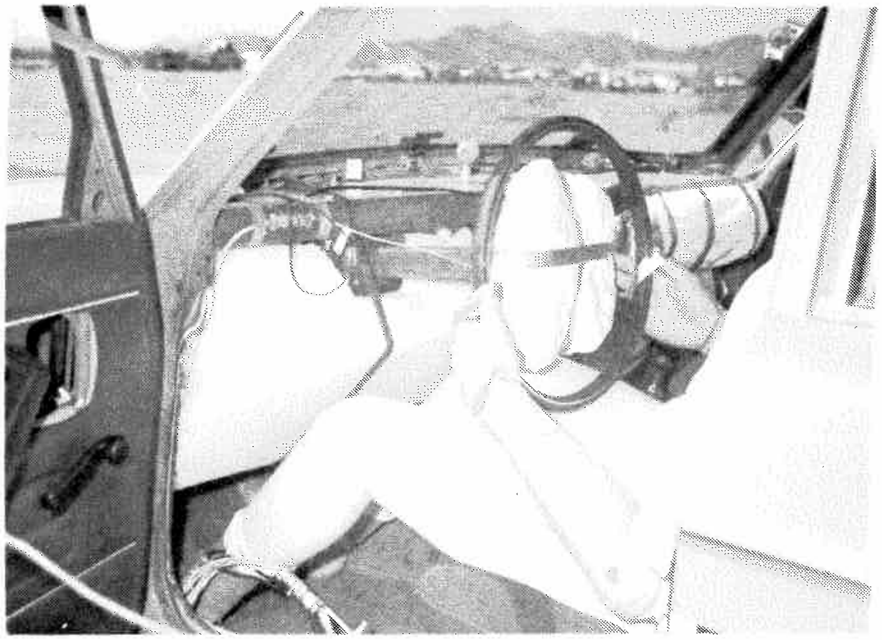


Figure 7-64. Driver Airbag System Prior to Test No. 17

Figure 7-65. Passenger Airbag System Prior to Test No. 17

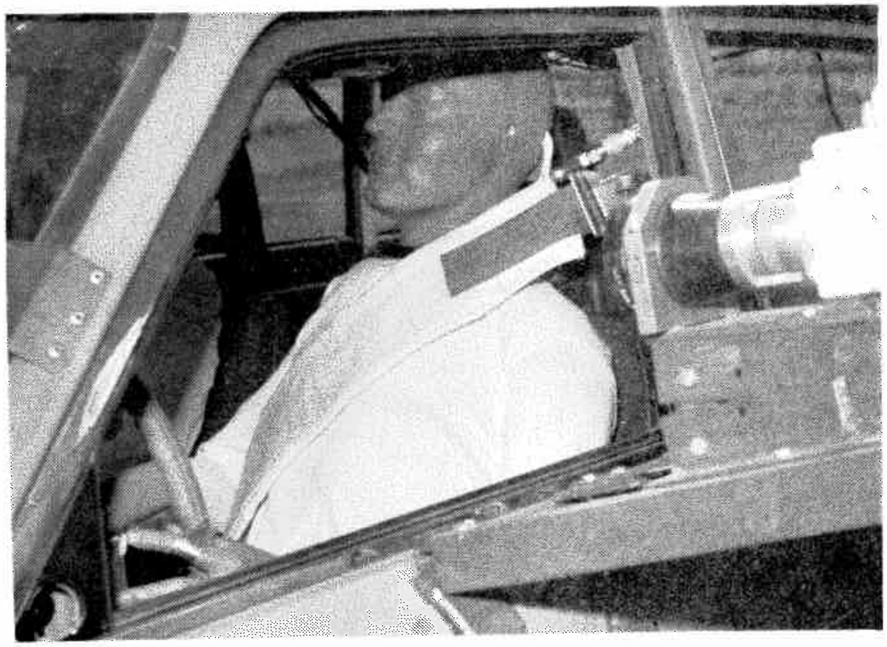


Figure 7-66. Airbelt System Prior to Test No. 17

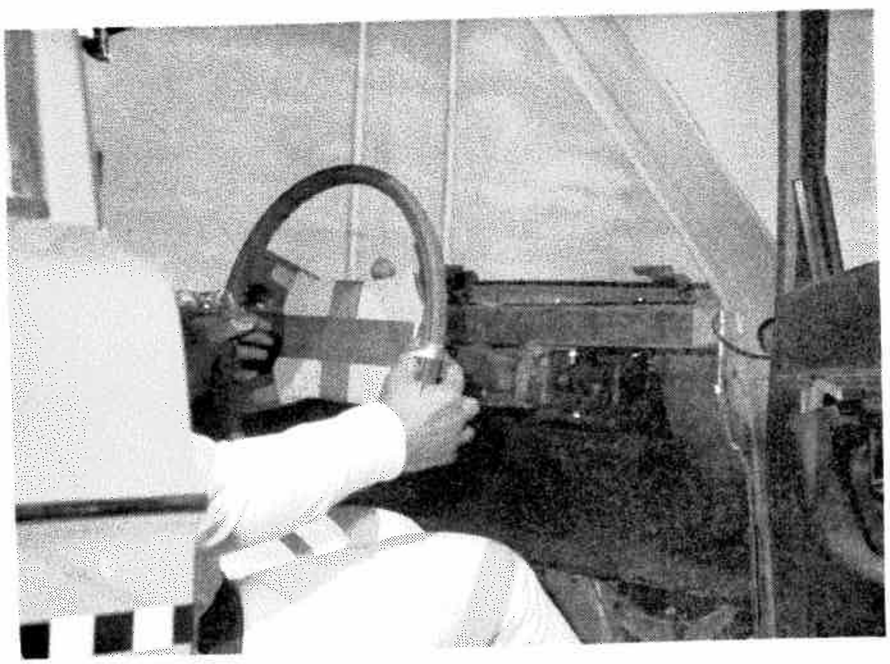


Figure 7-67. Force-Limited 2-Inch Belt, Test No. 17

Figure 7-68. Volvo Damage, Test No. 17

The only drawback to an otherwise successful test was the fact that the 95th percentile male driver chest g's were slightly in excess of the 60 g criteria limit. The chest trace shows a spike occurring at 90 msec into the crash event. Up until this point, the chest pulse was "flatening out" at the 30 g level. Since there was approximately 3 inches of unused column stroke remaining, this "bottoming" effect could not have been due to column bottoming out.

What we feel happened is this. Frequently we see that with the 95th percentile male there is a tendency for the knees to rise as the legs pivot about the foot at the toeboard. Since the 95th percentile's legs are long, relative to his distance from the toeboard, and since he strokes further in the car than the 50th percentile dummy, there is an increased tendency for the knee to rise during his forward translation and it is this phenomenon that often times causes the knee(s) to become pinched between the steering wheel and the knee bolster. Whenever this happens the column immediately stops its forward stroke.

After the test, the driver dummy's final position was noted and it indeed did appear that this was the case. Further evidence was forthcoming when the column was removed from the car and checked for obstruction or any tendency to bind up. There was no such obstruction. Further, a force crush test done on the remaining three inches of stroke showed that the column stroked smoothly at the normal crush load. Fig. 7-69 shows the dummy final positions.

For Vehicle B the results were also mixed. The installation of the driver column and steering wheel makes a world of difference to the performance of the force-limited 2-inch belt system. Even with both columns stroking the full limit of available stroke (7 inches) before the head rotated forward, the FLB restrained dummy's head impacted the top of the steering wheel rim across the full width of his forehead (Figure 7-70). Thus, the inertial stroking column did no good as far as this dummy was concerned.

Figure 7-69. Final Positions of Dummies, Test No. 17, Airbag Car

Figure 7-70. Wheel Rim After Impact with FLB Restrained Dummy's Head

For the airbelted dummy the column also stroked the full limit; however, in this case, it was not required. The airbelt restrained dummy's head missed the steering wheel by at least a foot since there was no forward head rotation due to the chin support given by the airbelt. It was also obvious from the high speed movies that even with no column stroke, his head would still have easily missed the steering wheel.

Therefore, it appears that whether the column strokes or not makes no difference since the FLB restrained dummy impacts the wheel anyway and the airbelt restrained dummy would not strike the wheel in either case.

The injury measures for the belt restrained 50th percentile dummies are summarized below.

	Vehicle B Systems	
	AB	FLB
HIC	954	1179
Peak Resultant chest g's (-3 msec)	38.6	52.2
Femur Loads: Left (lb), Right (lb)	1397-1600	509-1315
Peak Shoulder Belt Load (lb)	N/A	1499

As can be seen from the table above, the FLB restrained dummy received a HIC value in excess of the criteria limit of 1000 due to his head impacting the wheel rim.

7.16.3 Test Conclusions

1. The 95th percentile restrained driver does not have sufficient leg to toeboard distance available to prevent knee interference with column stroking. One solution might be to increase the column stroking force level after, say, 4 inches of stroke to allow the chest to come to rest with respect to the vehicle before this pinching effect occurs. Another possible solution would be to raise the column somewhat.

2. The 5th percentile female performance in head-on impacts with a vehicle delta V of 45 mph is very satisfactory and approximately equal to the 50th percentile performance with the same restraint system.
3. The force limited 2-inch belt system has a definite drawback when used as a driver system. Head impact with the steering wheel is virtually assurred and the resulting HIC value in high speed impacts can be expected to be excessive.
4. The airbelt restraint system continues to be a very reliable system. In fact, there was not one case in any of the impacts where the belt was properly installed that the system failed to meet the head and chest injury criteria. Even with the steering column installed the system will perform satisfactorily.

7.17 VEHICLE TEST NO. 18

This test was the last test of the series. Actually Test No. 17 completed the tests we had originally planned to do; however, since in Test No. 4, the passenger airbag had ripped, NHTSA requested that we run this last test to repeat Test No. 4. In this way we could determine whether the passenger system could perform satisfactorily in this mode.

7.17.1 Test Objective and Set Up

The objective of this left offset test at 82 mph was to determine whether the advanced airbag restraint systems would protect the Volvo front seat passengers within the criteria limits. It had already been demonstrated in an equivalent test (Test No. 4) that the driver system could perform within criteria limits, however, for the passenger, the results were not so obvious. In Test No. 4 the airbag had ripped due to improperly sewn seams. For this reason we scheduled an exact repeat of Test No. 4 as far as Vehicle A was concerned. We hoped to show that the test anomaly that occurred in Test No. 4 was just that, an anomaly that would not repeat itself.

The restraint system configuration for Test No. 18 was:

Occupant	Vehicle A	Vehicle B
Left Front	RSV Driver Airbag	None
Right Front	RSV Passenger Airbag	None

The vehicles used for this test were both 1976 Volvo 244's. Vehicle A was structurally modified in the dash, A-pillar, and B-pillar areas to preserve occupant compartment integrity and to accept the restraint systems that were installed in it. These modifications consisted of:

- Reinforced A-pillars
- Reinforced side rails
- Two steel tubes across the upper dash
- Continuous sheet metal pan across the front attached to firewall and rear steel tube to support the foam knee bolster.

The dash padding was reinstalled over the two steel tubes in its original position. Vehicle B had no structural modifications.

In Vehicle A, therefore, the advanced airbag restraints were installed. In Vehicle B, in order to obtain some unrestrained dummy data to provide some baseline injury measures, no restraints were installed.

50th percentile male dummies were installed in both cars. Figures 7-71 through 7-73 show the test set up.

7.17.2 Test Results

The impact conditions for Test No. 18 were:

Configuration	Closing Speed	Velocity Change (mph) Vehicle A	Velocity Change (mph) Vehicle B
Volvo-to-Volvo Head-on	81.9 mph	44.1	46.4

Figure 7-71. Test No. 18, Left Offset

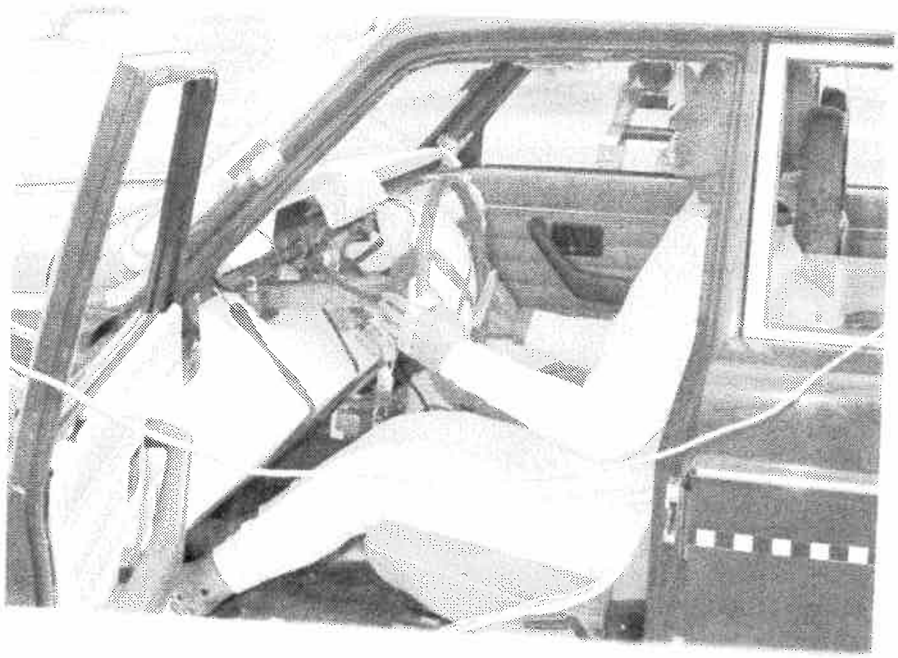


Figure 7-72. Driver System Prior to Test No. 18

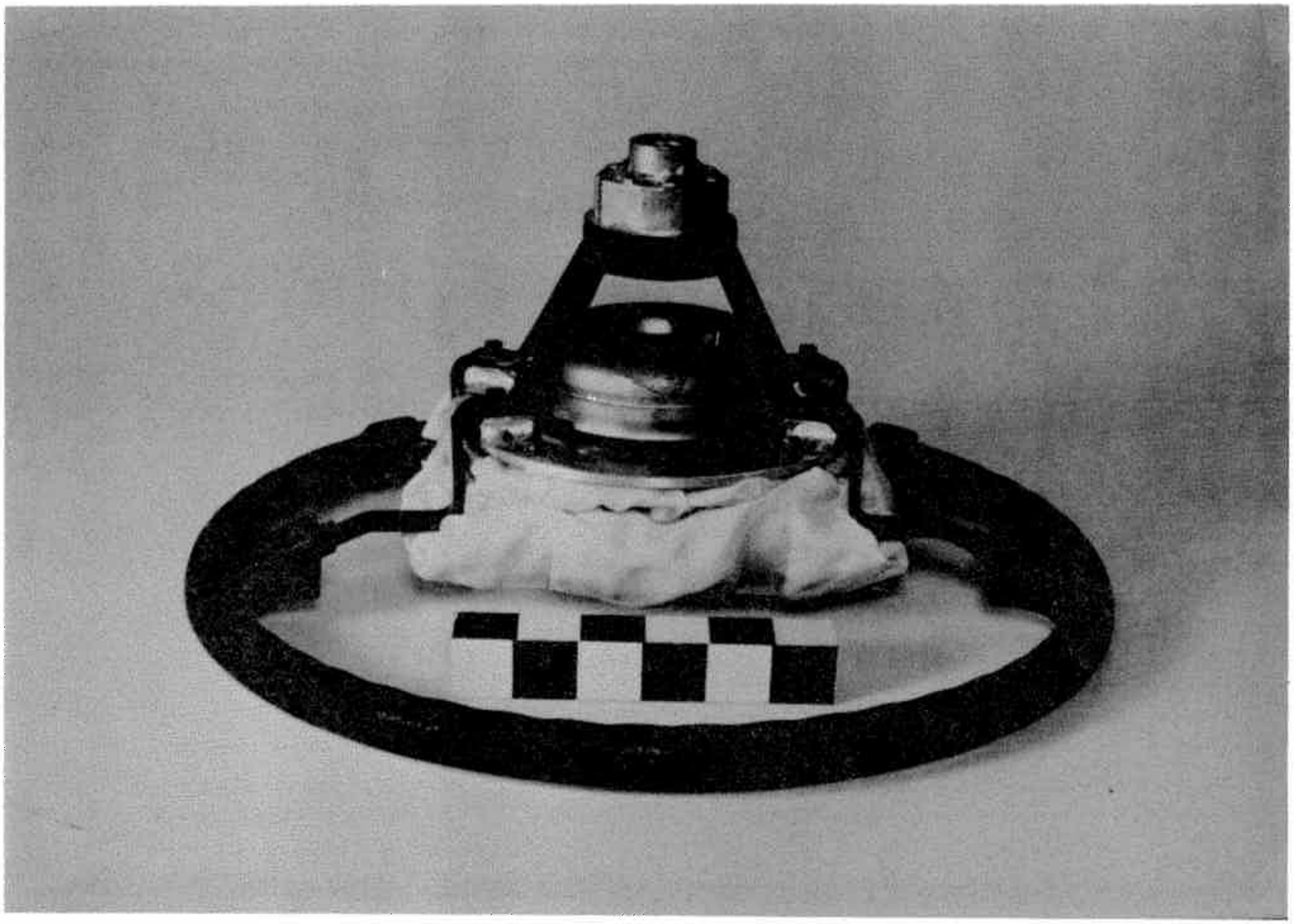


Figure 8-2. Airbag Mounted on Wheel - Side View

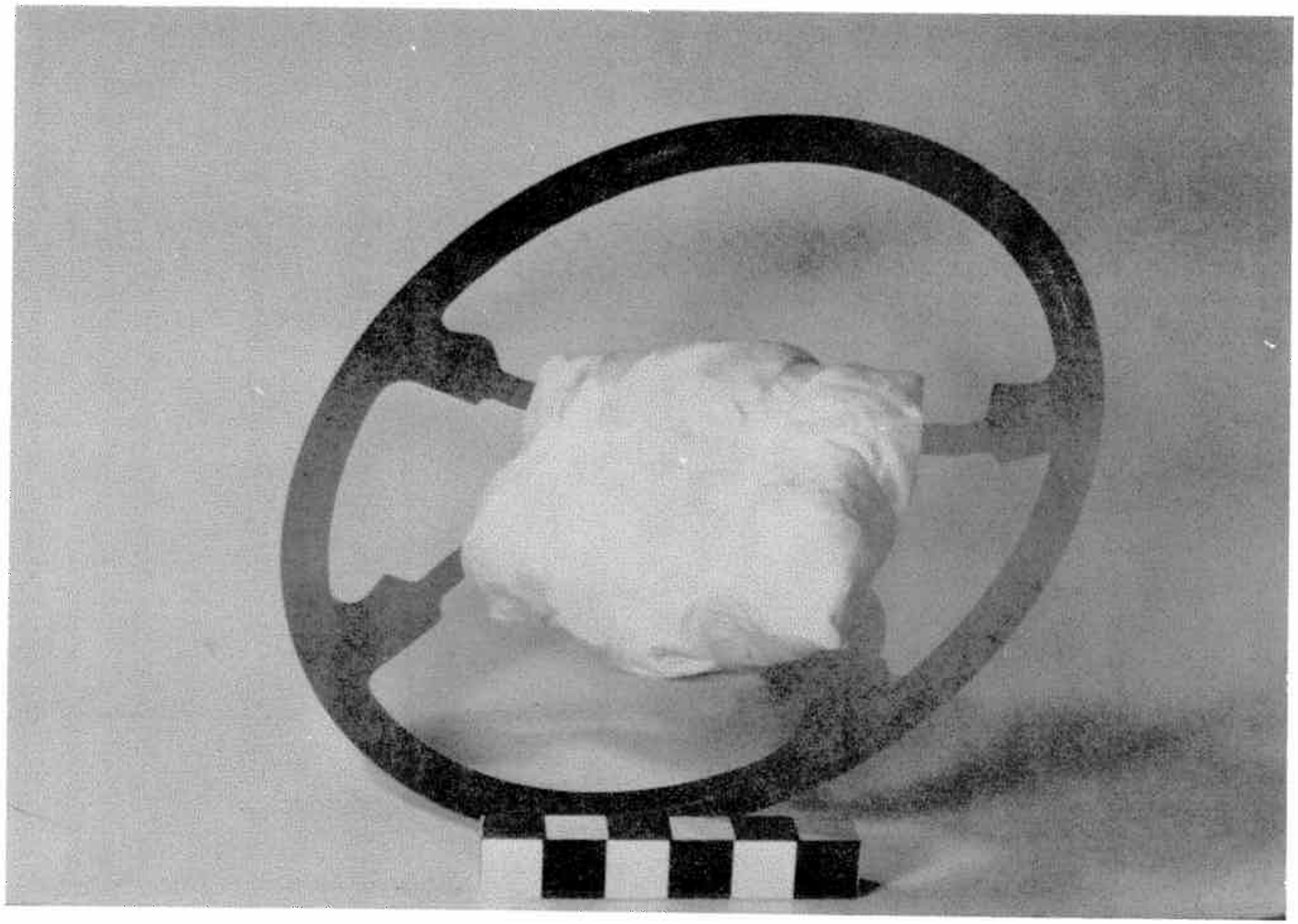


Figure 8-3. Airbag Mounted on Wheel - Front View

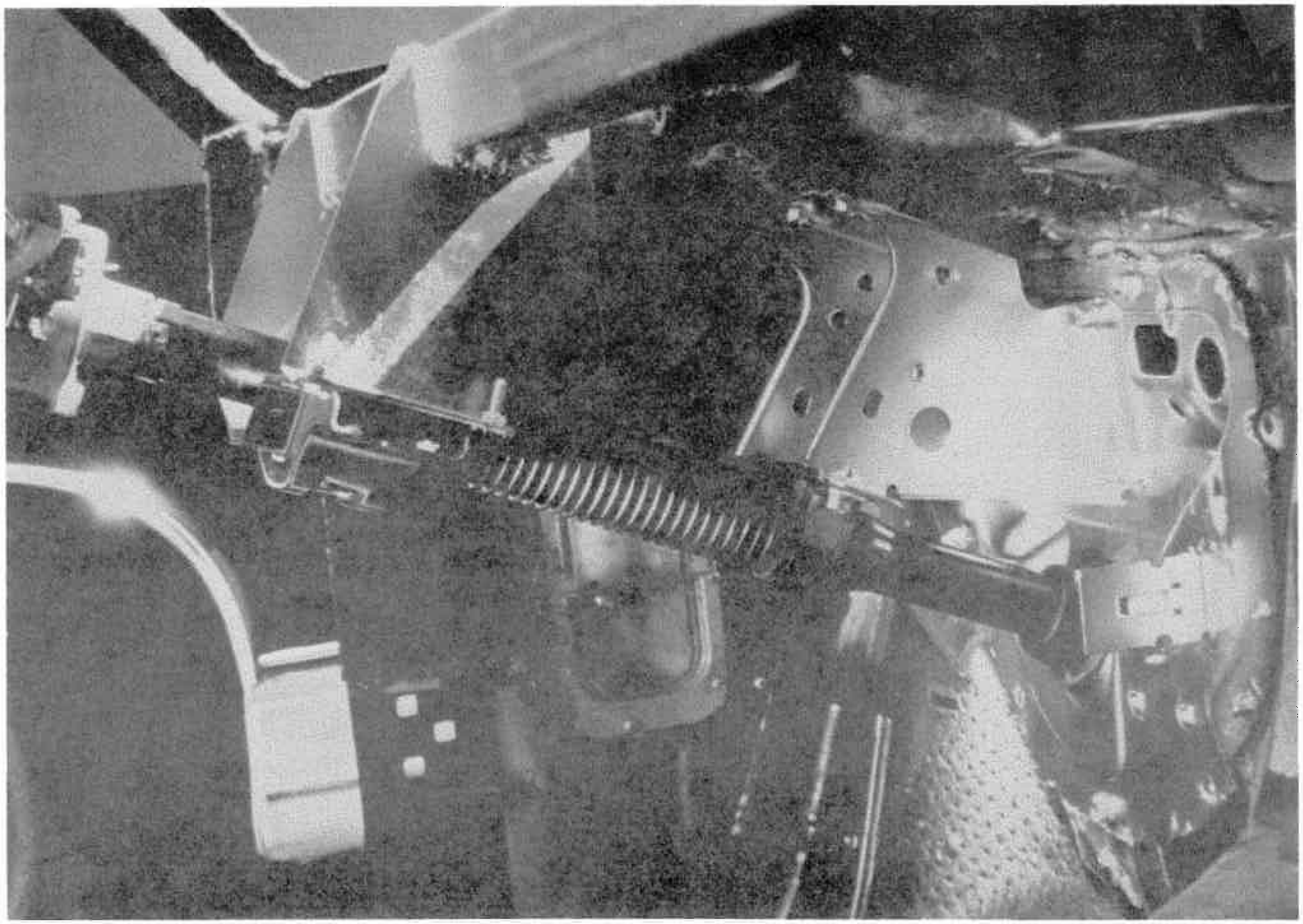


Figure 8-4. Column Mounting Structure

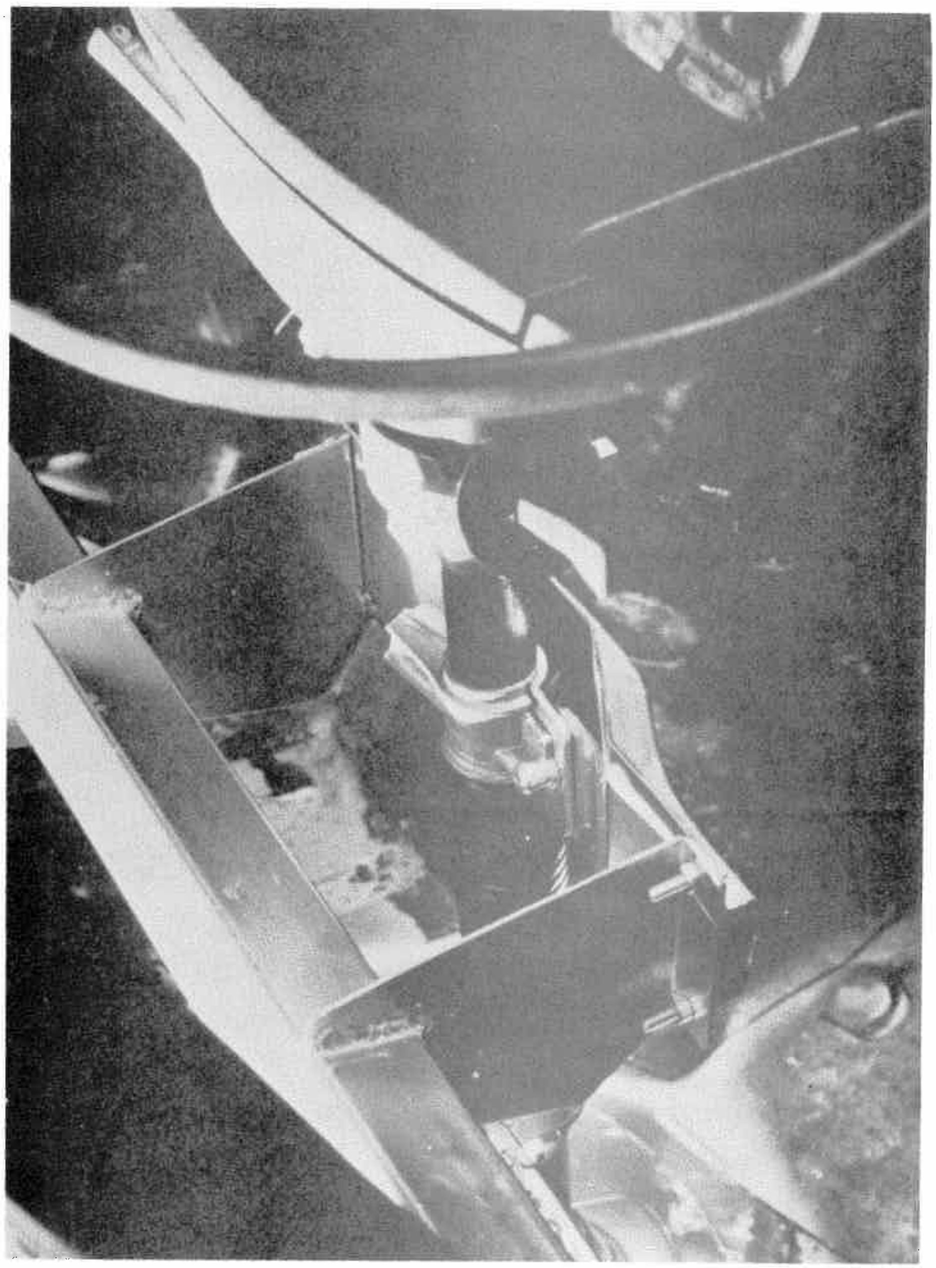


Figure 8-5. Aft Column Mount - Side View

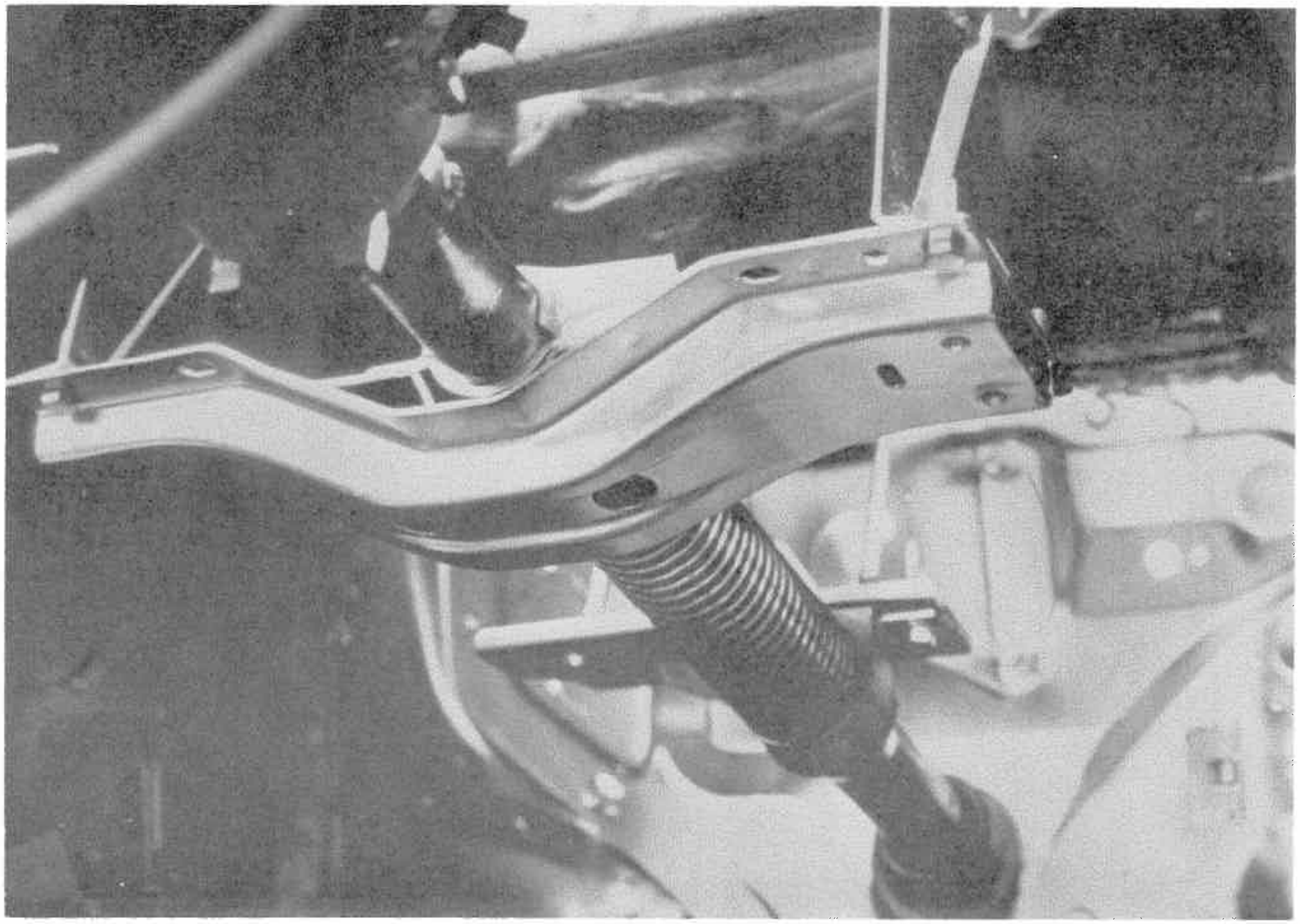


Figure 8-6. Aft Column Mount - Front View

Figure 8-7. Driver Restraint System Immediately Prior to Test

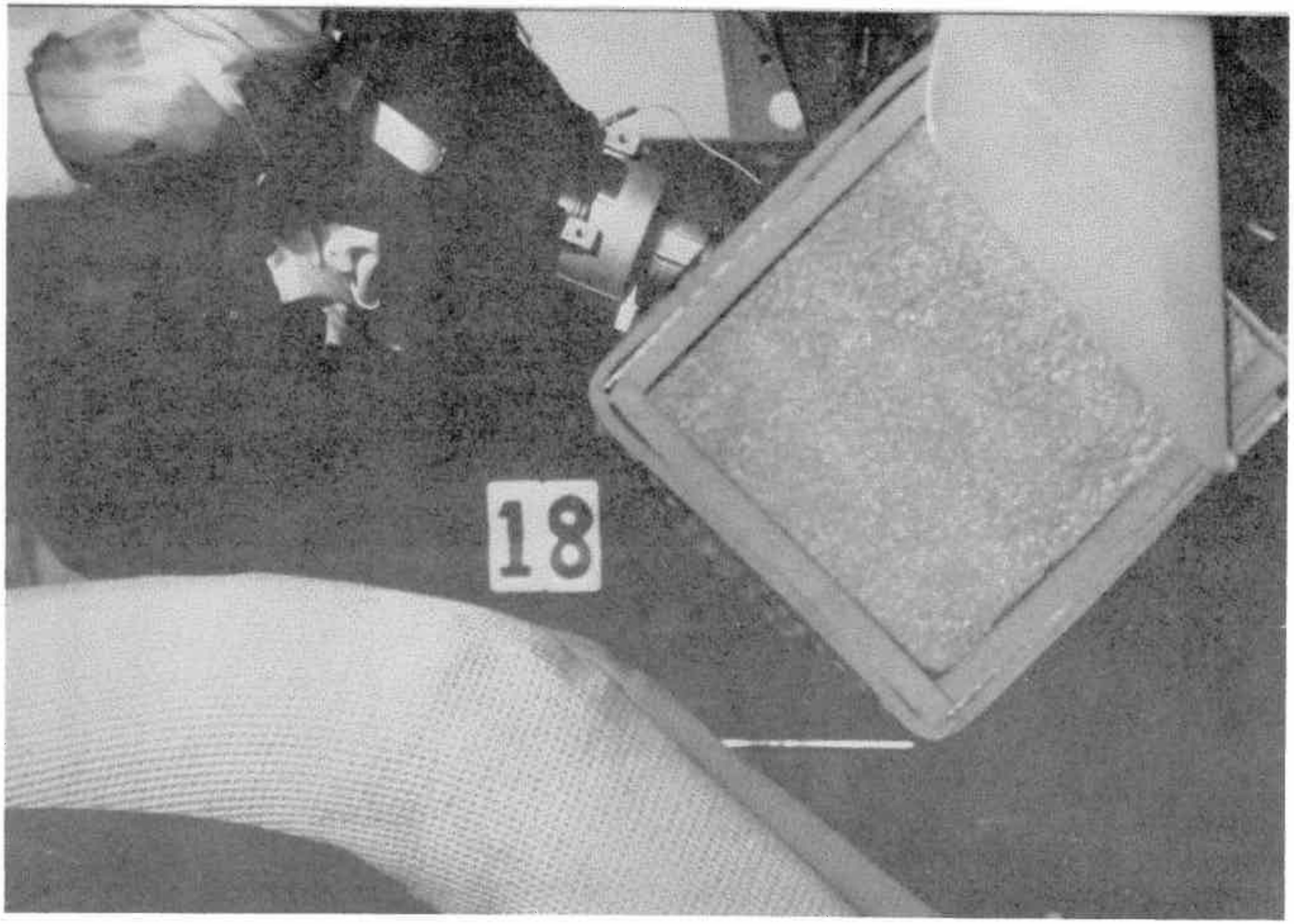


Figure 8-8. Knee Bolster

Two basic airbag assemblies were selected for use:

1. A single cell driver airbag (no inner bag) with Thiokol inflator.
2. A dual cell driver airbag with Thiokol inflator (Figure 5-3).

The complete test set up is shown in Figures 8-9 and Figure 8-10. Figure 8-11 shows a few pertinent installation dimensions. The steering column used was an unmodified Volvo column installed at the same angle as in the Volvo. We selected the Thiokol inflator loaded to 115 grams of propellant and an airbag of Minicars design to be installed on the wheel. All eleven tests were conducted with the 50th percentile male dummy. The crash pulse chosen was the Volvo pulse as used in the first seventeen runs conducted earlier in this contract (Section 5.0). Table 8-1 summarizes the results of the sled tests.

8.2 TEST RESULTS AND CONCLUSIONS

A statement must be made here as regards the column force-crush relationship. In the actual Volvo installation, there is a hard, plastic crushable element between the wheel and dash that was impossible to simulate exactly on the sled as the device would not fit in the space provided with the knee bolster installed. To maintain as much realism as possible, we sculpted a styrofoam block that was placed between the wheel and dash in the same area. Figure 8-12 shows a comparison of the column force-crush relationship for the two cases. As can be seen from the figure, the element, as simulated, even with the 200 pound additional crush strength (Tests 26, 27 and 28), is still slightly below the actual column force as installed in the Volvo (at least in the initial deformation stages). Overall though, for the sled, the simulated column force-crush relationship was close enough to the actual (as determined in an "in-car" crush test) force-crush properties to be a valid representation of a real world crash insofar as the function of the main restraint element is concerned.

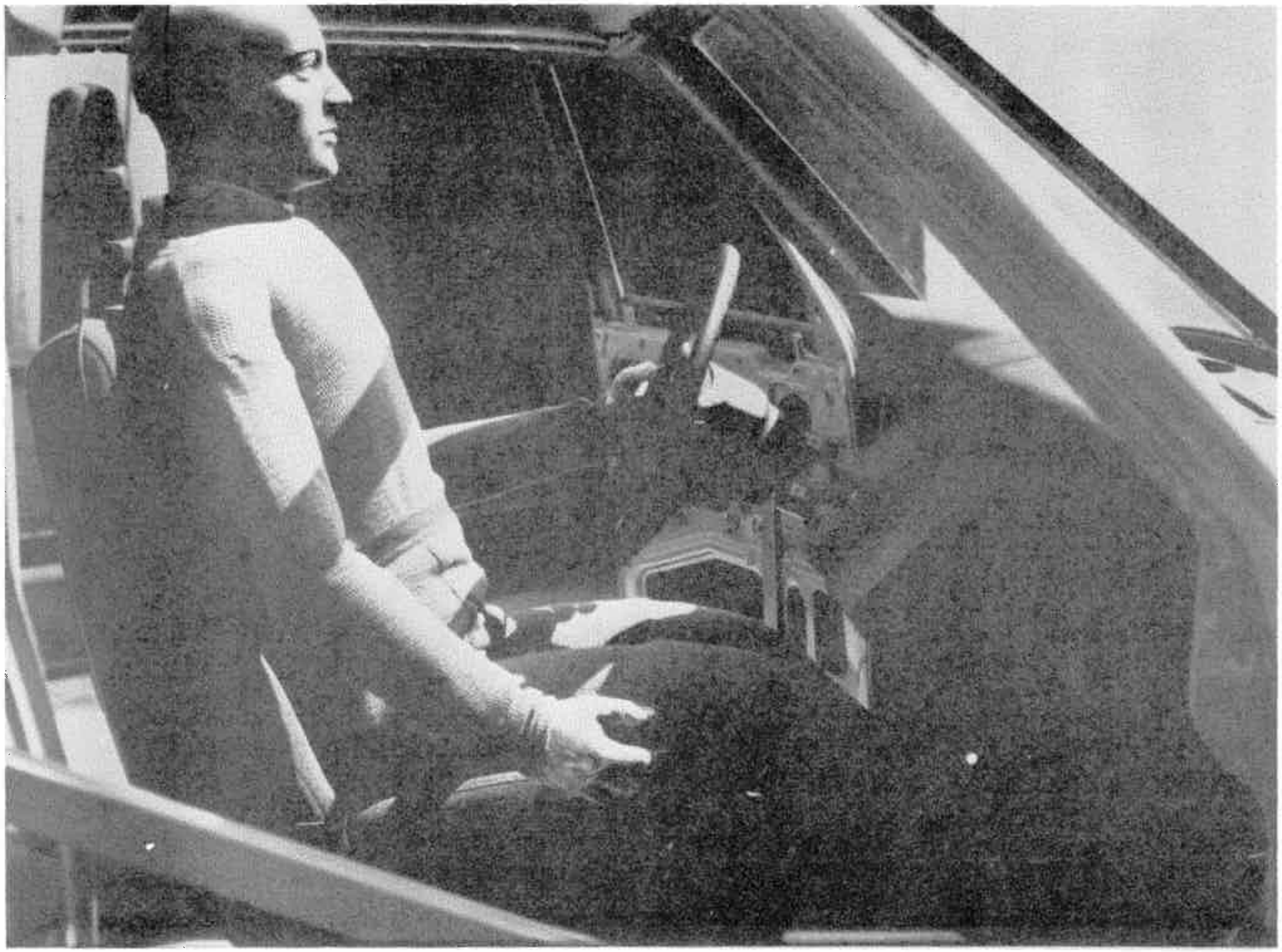


Figure 8-9. Driver Restraint System Installed in Buck

Figure 8-10. Volvo Sled Test Compartment with Driver Restraint System Installed

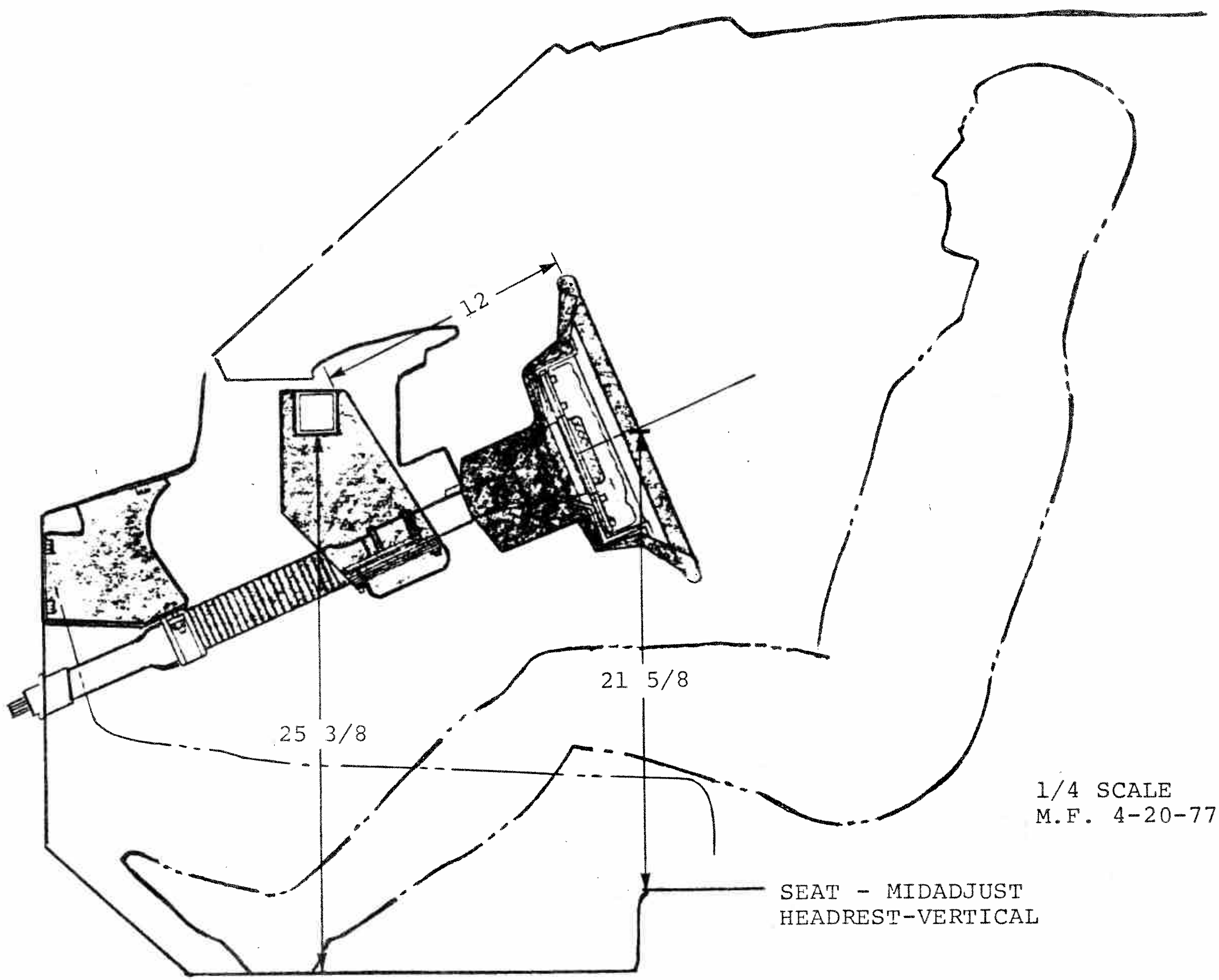


Figure 8-11. 50th Percentile Male in 1976 Volvo Compartment

Table 8-1. Sled Test Results with "Productionized" Driver System

SLED RUN	DATE	VELOCITY (MPH)	AIRBAG DESIGN	HIC	HSI	PEAK RESULTANT CHEST G's (-3 MSEC)	CSI	FEMUR LOADS (LB) LEFT	FEMUR LOADS (LB) RIGHT	REMARKS
18	5-07-77	37.4	Single Cell	410	502	60	625	1920	1120	Dummy moved rearward during sled acceleration
19	5-10-77	40.2	Single Cell	338	642	53	477	1580	1530	Moved dummy forward 2-5/8 in. to allow for rearward movement during sled acceleration; added foam simulated lower dash, reduced venting; airbag tore badly and this helped lower chest g's.
20	5-12-77	40.5	Single Cell	910	1164	88	1081	1880	1920	Repeat of #19 except for reinforced airbag. Airbag too hard, column bottomed.
21	5-13-77	39.8	Dual Cell	261	315	77	814	1300	1680	Went to dual cell bag. Column hit transverse bar running between A-post.
22	5-17-77	38.3	Single Cell	415	599	75	744	1270	1600	Went back to single cell bag; reduced force provided by foam simulated dash.
23	2-23-77	37.8	Large Single Cell	276	343	59	481	1450	1380	Stiffened wheel rim, used larger volumn airbag. Results improved.
24	5-26-77	38.5	Single Cell	425	635	48	469	1250	1210	Stiffened wheel rim still more, went back to smaller airbag. Pulse a little soft; good test.
25	5-27-77	38.1	Dual Cell	360	548	69	565	1550	1250	Went to dual cell bag, used stiff 1975 Volvo wheel. Inner bag ripped open. Column bottomed.
26	6-1-77	39.1	Dual Cell	206	287	55	-	1700	1420	Went back to stiffened 1976 Volvo wheel. Increased column force 200 lb to make it closer to column as installed in Volvo. (see Figure 8-12)
27	6-6-77	45.2	Dual Cell	588	688	85	1007	1700	1500	Increased velocity. Column bottomed internally.
28	6-7-77	41.9	Dual Cell	412	479	55	567	1480	1250	Changed inner bag design; cored knee restraint. Good test. Column stroke 3-5/8".

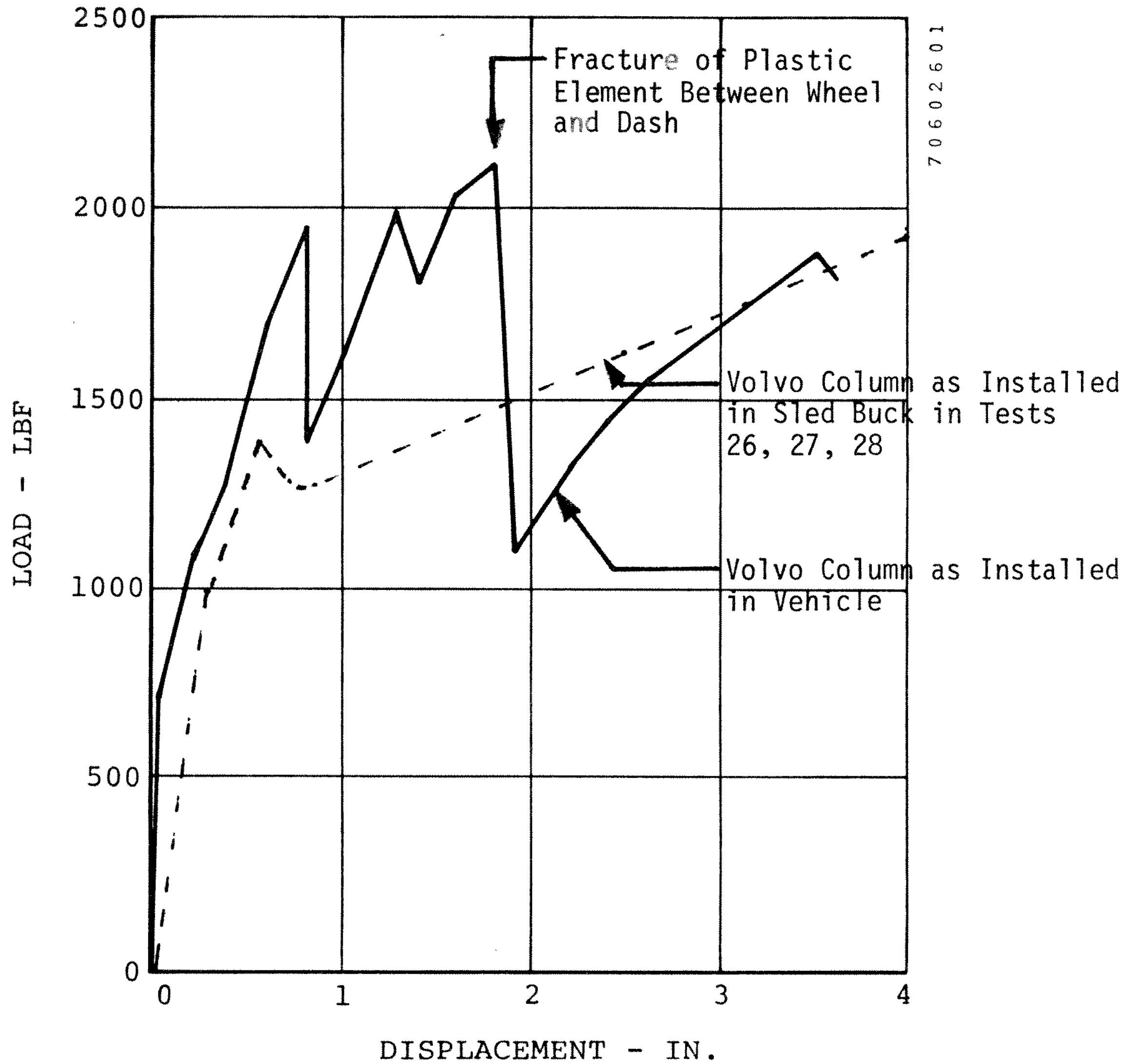


Figure 8-12. Force-Deflection, 1976 Volvo 244 Steering Column

Based upon the results of these eleven tests we can draw some conclusions:

1. The 1976 Volvo steering wheel and column can be integrated with the Minicars airbag and the Thiokol inflator with the column installed at its normal 23° angle.

2. The production 1976 Volvo steering wheel collapse force is too low. A stiffened version of this wheel performs much better with each spoke made 0.074-inch thicker.

3. The single cell airbag integrated with the Volvo column and the stiffened wheel, in combination with the Thiokol 115 gram inflator will meet the FMVSS 208 injury criteria at velocities up to about 40 mph. The 40 mph upper limit is based upon test results and visual determination that there is not available room for head stroke at velocities in excess of 40 mph.

4. The dual cell airbag, when used in conjunction with the stiffened 1976 Volvo steering wheel, a Volvo column, and the Thiokol 115 gram inflator will meet the FMVSS injury criteria for the 50th percentile male to at least 42 mph. At 42 mph there was additional room left in the compartment for added stroke indicating that, with more tuning, the system potential might be approximately 45 mph. For detailed data traces in this test series, refer to the appropriate progress report.

All things considered, the integration of the Minicars airbag, the Thiokol inflator and the Volvo column was very successful. Injury measures were met in a compact size compartment at velocities substantially above those required by FMVSS 208 with a system that is easily producible by today's techniques.

9.0 DETERMINATION OF CRASH SURVIVABILITY ENVELOPE

Upon conclusion of the nineteen Volvo crash tests sufficient data existed for us to attempt construction of a "crash survivability envelope. Perhaps we had better define this term. What we mean by determination of a "crash survivability envelope" is to make a determination of the occupant survivability limits in terms of the allowable velocity change where the injury measures "nudge" the criteria limits for each of the variety of accident modes simulated in this program with the Volvo automobile. In three cases where even at the highest velocity tested no injury measures were above or close to the criteria limits, we defined a new term, "Survivability margin", which indicates the difference between the percent of the criteria limit realized for that mode and 100% (the criteria limit). With this in mind, let us now describe the process used to reduce the data to obtain the necessary information.

The first thing to be done was to eliminate those data points that were obviously inconclusive or "bad" data points. For example, in the cases where a bag rip occurred, the force-limiters were incorrectly installed, the column broke loose from its mount (Test No. 1), and the column was impacted by the firewall before the shroud was extended, (Test No. 6-A), the data was eliminated from consideration. We did this, of course, to prevent test anomalies that invariably are present to some degree in any research program from clouding the meaning of the crash survivability envelope.

A second decision to be made was how to best present the results so that as much meaningful information as possible would be forthcoming from the envelope. Velocity change was our first choice as an indicator of survivability limit. In other words, we hoped to be able to state that restraint so-and-so would provide acceptable protection (within the criteria limits) up to such-and-such a velocity change in a particular accident mode. The only trouble with this rationale is that it presupposes that we have exercised the restraints to their limit for each crash mode. This was not the case.

In the oblique and offset impacts, the results for all four advanced restraints were generally well within the allowable criteria so that the velocity change at which the system would be marginal simply could not be determined.

One possibility we considered to obtain this velocity was to plot the different injury measures as a function of velocity and extrapolate the results to see at what velocity we would exceed the criteria limits. This, however, was not feasible due to the fact that the test velocities for each accident mode were generally "clustered" together so that no general curve shape could be estimated.

What we finally decided to do was this. In those accident modes where the restraint system was taxed to its limits so that injury measures were close to or in excess of criteria limits we would present the "survivability limit". In those cases where the restraint was not exercised near to its limits, we would present a "survivability margin". By choosing a method at presentation where both could be viewed simultaneously, one could immediately get a "feel" for the survivability potential for each crash mode for each system.

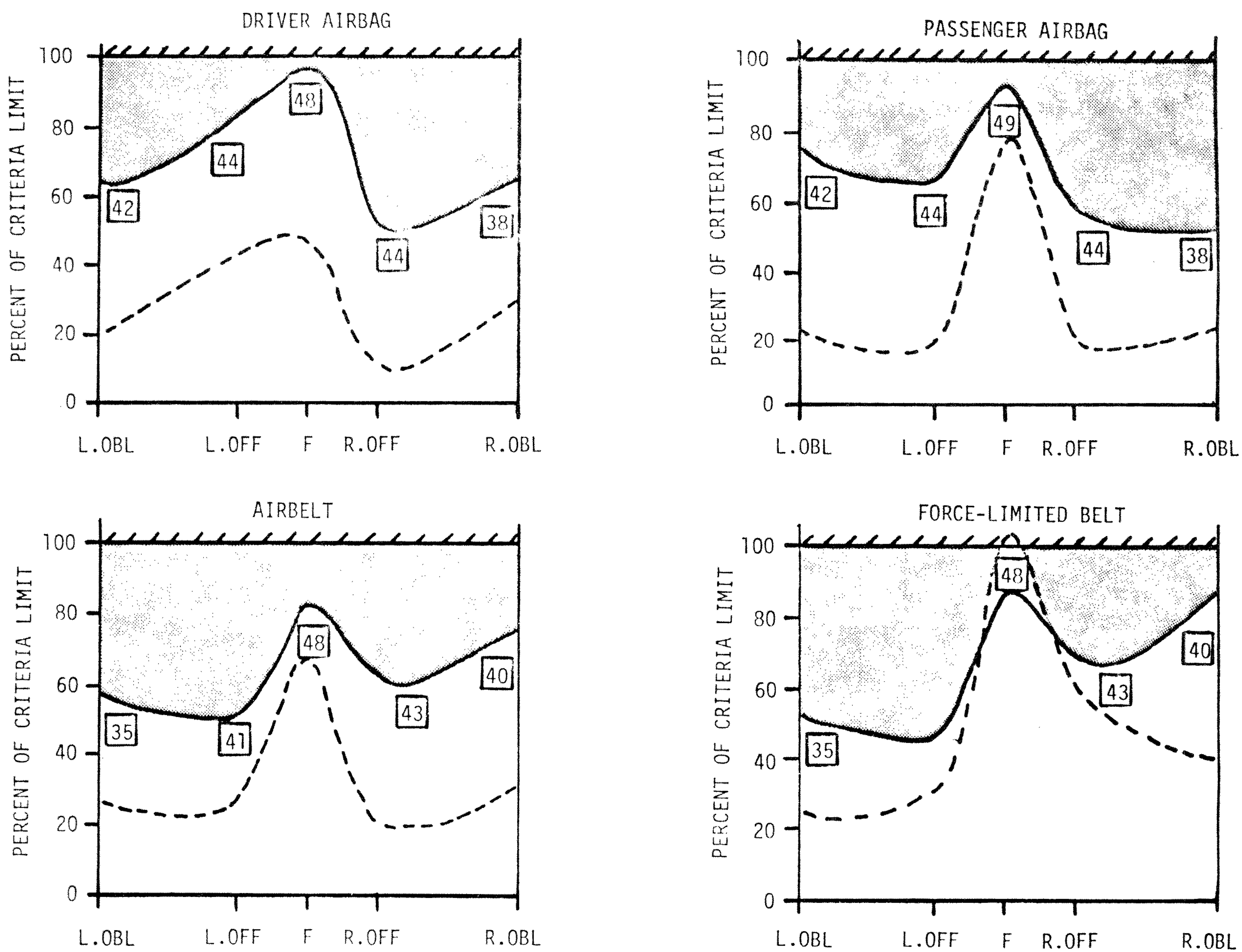
One further word is in order. Where several data points were gathered for the same test mode for almost the same velocity, both the injury measure and the velocity were averaged so that one average injury measure and an average velocity were obtained for each crash mode. We felt this would be more representative of the total picture obtained and would eliminate the confusion that several points for the same accident mode would generate when plotted on the same diagram. One other approach considered and rejected was to only plot the highest injury measure for each accident mode, thereby presenting a survivability envelope that would indicate a lower allowable delta V than the restraint would on the average perform to. We felt this approach would create the wrong impression - namely that the system could only be expected to perform <u>up to</u> this limit, whereas in actuality it had performed <u>beyond</u> this limit in all cases but one - the one presented.

Since delta V could not be used as a universal indicator of the expected survivability limit, since in some accident modes it could not be determined, we chose another parameter that, although, perhaps, not as meaningful, could be used throughout. The parameter we chose was "percent of survivability limit". This parameter could be calculated in every case and when the velocity at which a particular percent value is obtained was presented along with the percent value, a complete picture is obtained. With the foregoing in mind, let us now present the results of this analysis.

Figure 9-1 presents the crash survivability envelope. We feel it is both convenient and informative to present the results on one page. In this way, both the head and chest survivability limits and survivability margins can be readily seen for each restraint system and readily compared.

There is one other way in which we would like to present the Crash Survivability Envelope. In Figure 9-1 the survivability envelope is presented in terms of percent of criteria limit versus crash mode so that one may readily visualize the survivability margin in terms of restraint system performance for each crash mode. What is lacking in this presentation is a clear picture of what the vehicle structural limitations might be that might be the limiting factor on restraint performance. For example, just because a high survivability margin exists for, say, the left oblique mode, this does not necessarily mean one could increase the test velocity substantially and still meet the criteria limits since intrusion may be the limiting factor instead of restraint performance.

Or, to put it another way, just because the percent of criteria limit for the FLB, say, is 50 percent for the left oblique mode at 35 mph delta V (Figure 9-1), this does not mean one could increase the test speed drastically to say, 50 mph and still meet the criteria limit since the vehicle intrusion would be too severe.



The percent of FMVSS 208 criteria limit and Delta V represent average values of the data for each test mode in which more than one test was conducted.

HEAD
CHEST
TEST DELTA V'S

Figure 9-1. Survivability Envelope

(Shaded Areas Represent Survivability Margin)

For this reason we have chosen a second way of presenting the information in which we have attempted, based upon observation of the vehicle damage and an educated guess on how much more intrusion could be withstood prior to drastically changing the compartment geometry, to estimate these structural limits. Figures 9-2 through 9-5 is such an attempt. Here the upper solid line is based upon either the restraint performance being critical, as it generally was in the frontal mode, or the vehicle structural performance being critical, as it generally was in the offset and oblique modes. As such this upper bound to performance is somewhat subjective but does, nevertheless complement Figure 9-1 in that the Volvo structural performance is included in our evaluation and critical delta V can be easily estimated. By studying both sets of figures one may obtain a good "feel" for the performance capabilities of both the restraint systems and vehicle structure.

There is one additional set of data we would like to present. Although peak shoulder belt loads were not part of the criteria that was contractually specified as criteria that would determine whether a system "passed or failed", it is, nevertheless, of interest since recent NHTSA sponsored research has recommended an upper limit on the shoulder belt load of 1500 lb. Figure 9-6 therefore, presents the equivlaent of Figure 9-1 for 1500 lb shoulder belt load as being 100 percent of the criteria limit.

As can be seen from the figure, if 1500 lb were specified as the upper limit on allowable shoulder belt load the "survivability margin" would be much less than was the case when HIC and peak chest g's were compared with the criteria limit.

From these diagrams several conclusions may be drawn.

1. After studying Figures 9-2 through 9-5 we see that using the present FMVSS 208 injury criteria, the restraint systems may be ranked in order of overall performance as:

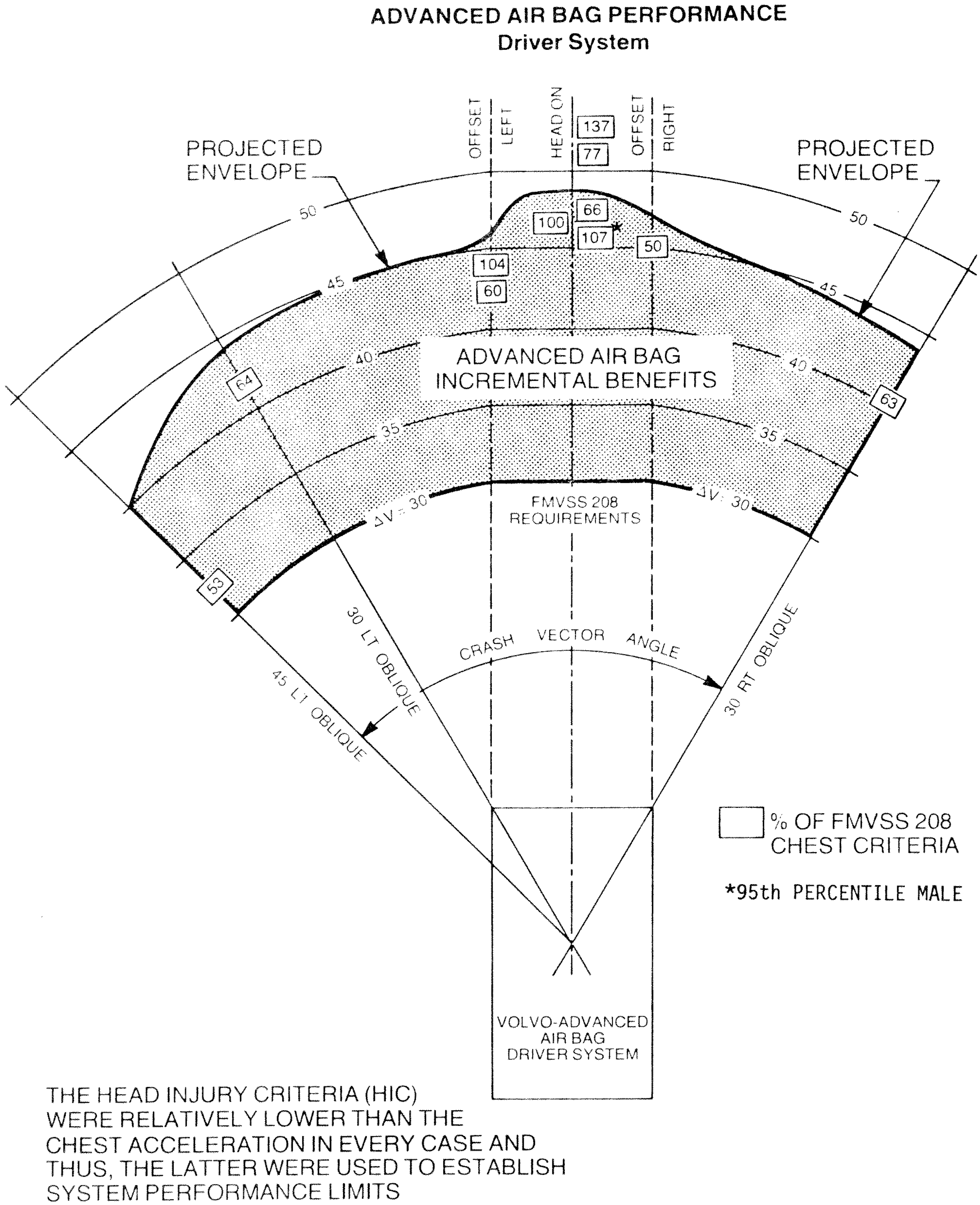
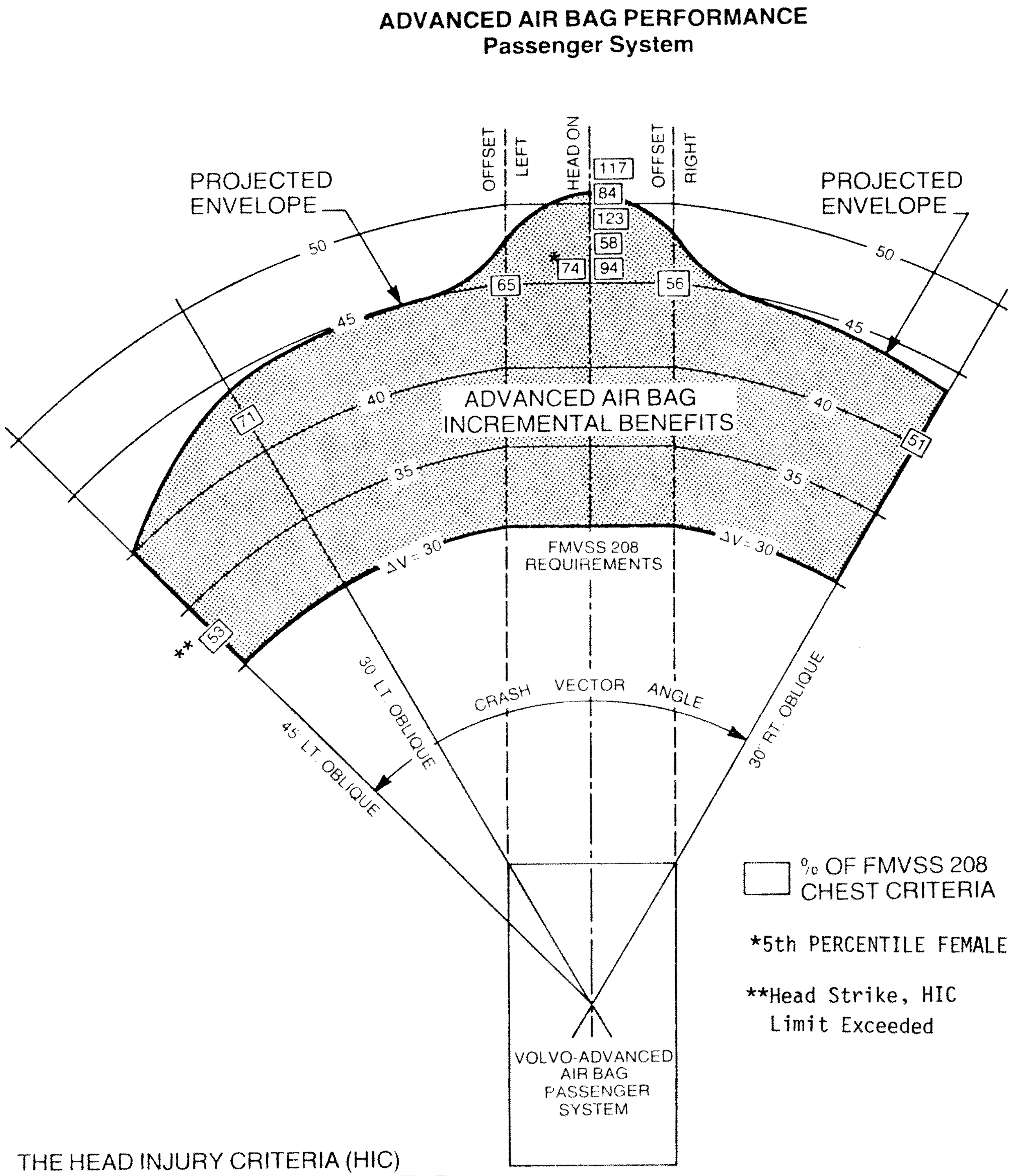


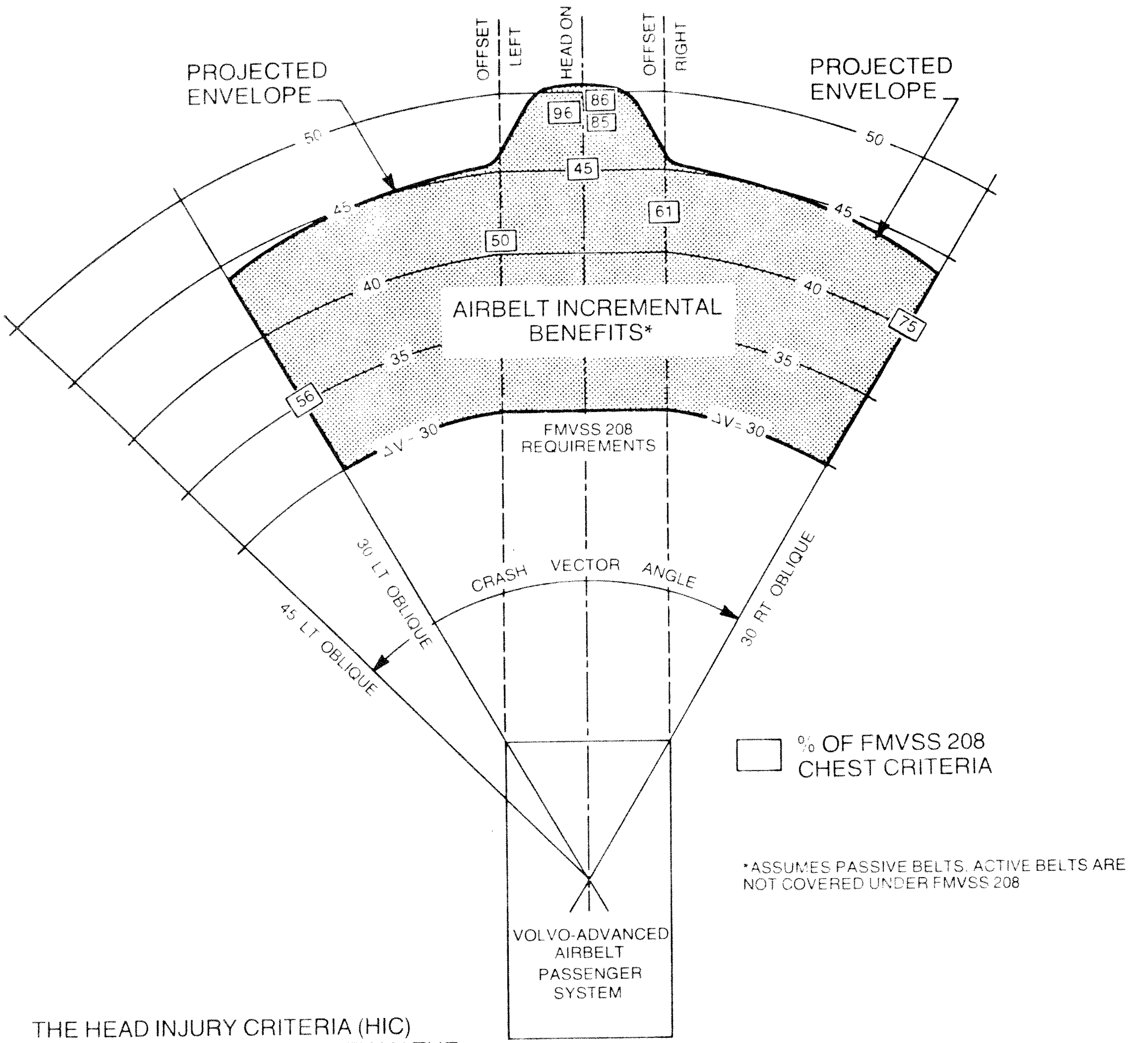
Figure 9-2. Crash Survivability Envelope - Driver Airbag System



THE HEAD INJURY CRITERIA (HIC) WERE RELATIVELY LOWER THAN THE CHEST ACCELERATION IN EVERY CASE AND THUS, THE LATTER WERE USED TO ESTABLISH SYSTEM PERFORMANCE LIMITS

Figure 9-3. Crash Survivability Envelope - Passenger Airbag System

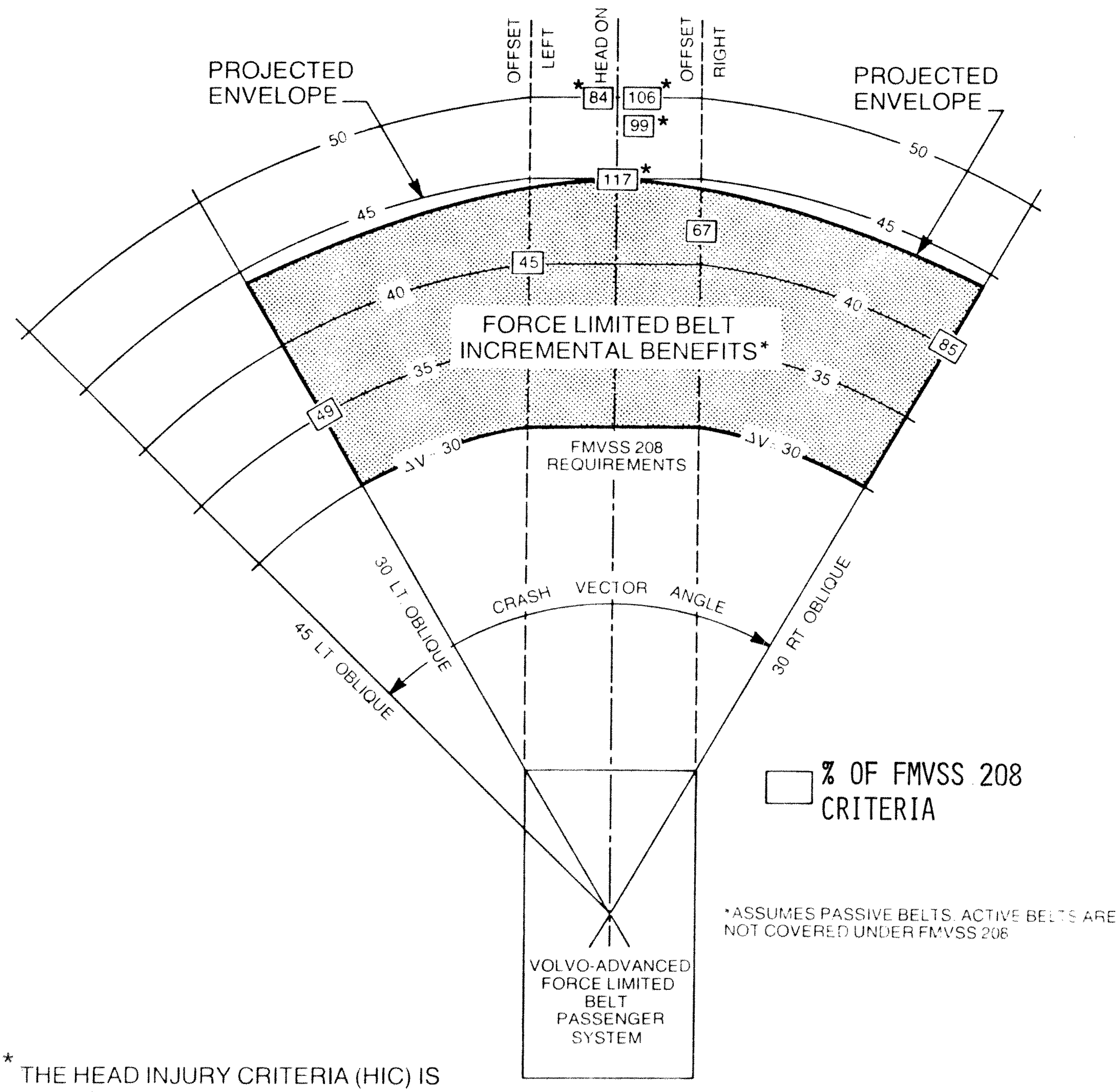
ADVANCED AIRBELT PERFORMANCE



THE HEAD INJURY CRITERIA (HIC) WERE RELATIVELY LOWER THAN THE CHEST ACCELERATION IN EVERY CASE AND THUS, THE LATTER WERE USED TO ESTABLISH SYSTEM PERFORMANCE LIMITS

Figure 9-4. Crash Survivability Envelope - Airbelt System

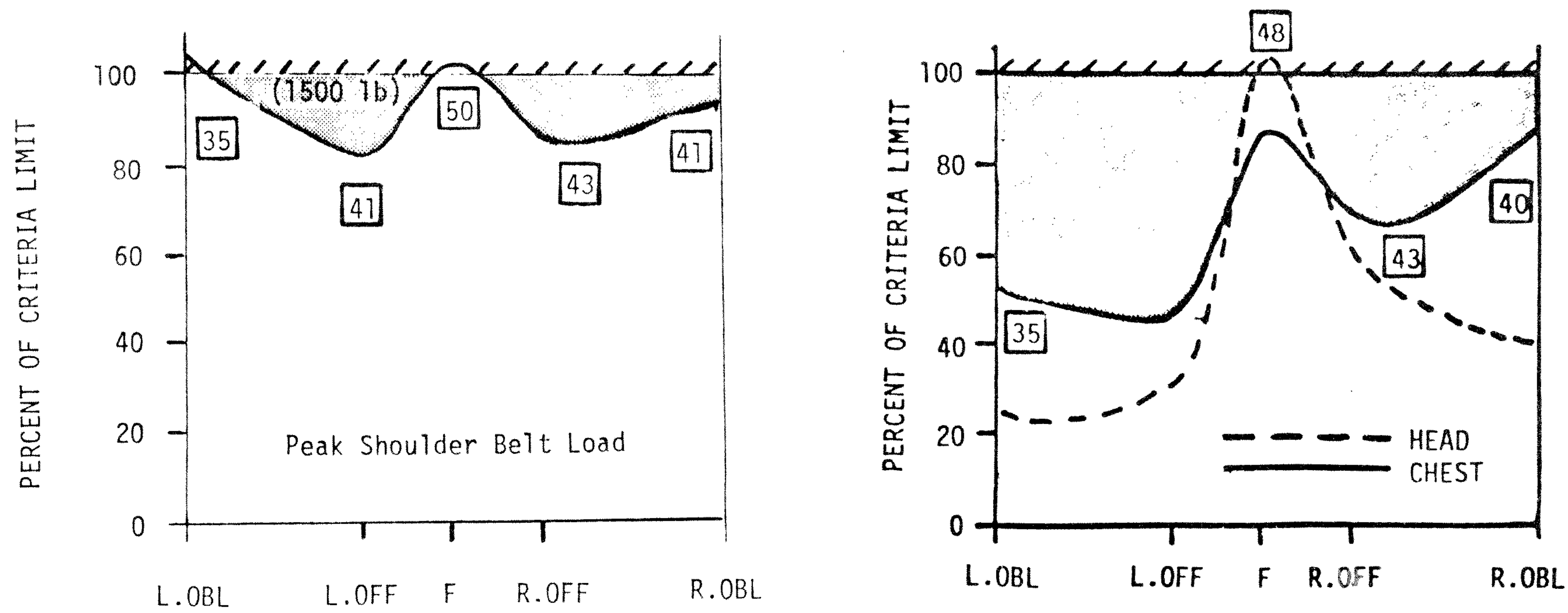
ADVANCED FORCE LIMITED BELT PERFORMANCE



*ASSUMES PASSIVE BELTS. ACTIVE BELTS ARE NOT COVERED UNDER FMVSS 208

* THE HEAD INJURY CRITERIA (HIC) IS CRITICAL FOR THE HEAD-ON MODE, WHILE THE CHEST G'S ARE CRITICAL FOR ALL OTHER MODES.

Figure 9-5. Crash Survivability Envelope - Force-Limited Belt System



The percent of FMVSS 208 criteria limit and Delta V represent average values of the data for each test mode in which more than one test was conducted.

(Shaded Areas Represent Survivability Margin)

Figure 9-6. Force-Limited 2-Inch Belt - Survivability Margin

a) Airbelt or right front passenger system (a virtual tie)

b) Driver airbag system

c) Force-limited 2-inch belt system.

If however, the 1500 lb torso belt load were used as limiting criteria, we see from Figure 9-6 that there would be an even greater spread between the number two system (the Driver Airbag System) and the number three system (the Force-Limited 2-Inch Belt System) since, as shown in the figure, the survivability margin for the LFB system would decrease drastically.

2. On the average, three of the four restraint systems can be expected to "meet" the head and chest injury criteria for all accident modes as the speeds listed on the diagram. Only the force-limited 2-inch belt fails, on the average, to meet the HIC requirement for the full frontal impact mode. For all other modes this restraint can be expected to meet the injury criteria at the velocities shown on the diagram.

3. The chest can be expected to be the critical anatomical area for the occupants restrained by the inflatable restraint systems while the head is the critical area for the occupants restrained by the force-limited 2-inch belt system.

4. Frontal impact is the critical test mode for all four restraint systems. Only accidents in this mode really exercised the systems near or above the criteria limits.

5. The critical delta V for each restraint system in the frontal mode is approximately:

System	Critical Delta V (Survivability Limit)
Airbelt System	> 50 mph
Right Front Passenger Airbag System	> 50 mph
Driver Airbag System	48-50 mph
Force-Limited 2-Inch Belt	< 48 mph

*6. The force-limited 2-inch belt system is "chest critical" for the offset and oblique modes and "head critical" for the frontal mode. All other systems are "chest critical" for all modes.

7. In general, it may be said that all four of the advanced restraints tested showed a performance level far above that required by FMVSS 208. When one considers this was accomplished in a production, compact size automobile the results are truly extraordinary.

8. Since all four of these basic systems show a great deal of potential for increased protection levels over that which is currently being experienced in production automobiles, the author feels there is a moral obligation to continue their development. These basic systems should now be "productionized" and then retested to become viable candidates for eventual installation in production vehicles. One such exercise done with the driver airbag system as part of this program was successful (Section 8.0) and there is no reason to believe further productionizing of the other three systems would not be successful.

*Note: The above conclusion is based upon the same injury criteria being applied to each restraint. In this author's opinion the force-limited 2-inch belt should be judged with different chest criteria than the inflatable devices since the load is more concentrated with the 2-inch belt.