SECTION 11
LARGE RESEARCH SAFETY VEHICLE

11.1 INTRODUCTION

The Large Research Safety Vehicle (LRSV) Program was devised to show that RSV technology could be applied to other vehicle sizes - in this case, full-size automobiles. The central goal of the program was to develop a six passenger sedan having a curb weight less than 3000 pounds (1360 kg), yet still demonstrating superior crashworthiness, excellent fuel economy and low emissions.

Because the LRSV Program was limited in scope (compared to the RSV Program), we based our design on a modified production vehicle (rather than developing a vehicle from the ground up). Three candidates were considered for the base vehicle: Ford LTD, Plymouth Fury and Chevrolet Impala. We chose the Impala because it (and other GM B-bodies) had recently been subjected to a comprehensive weight reduction treatment and because its construction (weld fences and panel formations) would be the simplest to integrate with RSV-style structural components. Since the Impala's interior and exterior configurations were left essentially intact, the LRSV has almost identical dimensions to the Impala. It is 213 inches (541 cm) long, 76 inches (193 cm) wide and 59 inches (150 cm) high, and has an EPA Interior Volume Index of 111 cubic feet (3.14 cubic meters). By incorporating the smaller RSV fuel cell (8.3 gallon capacity), we increased the cargo volume to 20.5 cubic feet (0.58 cubic meters). The curb weight is 3004 pounds (1363 kg), which, because of our weight reduction efforts, is 865 pounds (392 kg) less than that of the stock Impala. Figure 11-1 shows the operational mockup of the LRSV.

The LRSV structure, like that of the RSV, evolved through lumped mass model computer simulations, component crush tests and full-scale vehicle crash tests. Its design also is based on a comparatively stiff passenger compartment, foam-filled sheetmetal boxes, and flexible urethane front and rear bumpers. We reduced vehicle weight by using closed sheetmetal box structures and by substituting plastic for steel in some of the non-stuctural Impala parts

FIGURE 11-1. LARGE RESEARCH SAFETY VEHICLE (LRSV)

(including the hood, front fenders and deck lid). The structural development of the LRSV is discussed in Subsection 11.2.

The LRSV also utilizes much of the RSV's occupant packaging technology. The driver's foam and sheetmetal knee restraint is of similar design, the energy-absorbing steering column is virtually identical, and both steering wheel airbags are cylindrical (although the LRSV has only a single chamber). On the other hand, the LRSV passenger restraint is significantly different, because two front seat passengers must be protected. Three airbags are mounted in the dash: two individually-vented torso bags and a single, downward-deploying knee bag. Subsection 11.3 lists the specific crashworthiness objectives set at the start of the program, describes the development of the occupant packaging systems, and discusses the LRSV's performance in crash tests.

To maximize emissions and fuel economy performance, the LRSV's powertrain is front engine/front wheel drive, and to maximize frontal crush space, the engine is transversely mounted. The modified Volvo B-21 fuel injected, four cylinder in-line engine (with a three-way catalyst and Lambda-Sond* feedback emissions control) is mated to a GM X-body four-speed manual transmission. The propulsion system development is discussed in Subsection 11.4.

The LRSV steering and suspension systems consist mostly of stock and modified components from the Fiat Lancia Beta sedan, which has front wheel drive and a front/rear weight distribution similar to that of the LRSV. The main exceptions are the Chevrolet Citation rear axle and Volvo 244 rear springs. This choice of components gives the LRSV four-wheel disk brakes with rack and pinion steering.

*Registered trademark of A.B. Volvo.

11.2 LRSV STRUCTURAL DEVELOPMENT

11.2.1 Front Structure

Operational Mockup

The operational mockup of the LRSV was constructed on a ladder frame of 2 x 4 x 0.083 inch (51 x 102 x 2.1 mm) rectangular steel tubing, extending the full length of the vehicle. The front rails provided the main support for the front suspension lower control arms and the powertrain. The front suspension selected was a McPherson strut assembly from the Lancia Beta sedan. The upper ends of the struts were attached to foam-filled sheetmetal fender boxes, cantilevered over the front wheels (Figure 11-2). These fender boxes were designed to be one of the major load paths in frontal collisions.

The forward ends of the fender boxes were connected by vertical supports to a foam-filled sheetmetal crossmember. Loads were also to be fed into the main frame by extensions of this vertical support structure. The crossmember was used, in turn, to support the bumper system.

Bogey Crash Test Articles Preliminary Design

The LRSV front structure design was initially based on a lumped mass mathematical model of a transverse engined, front-wheel drive vehicle. This simple model consisted of three masses and six springs, a schematic of which is shown in Figure 11-3. The materials and sizing of the structural members were based on a series of static crush tests; samples of the basic size and shape of each structural element were crushed. The metal gauge of the samples was varied until a wide variety of force-deflection characteristics was obtained. These force-deflection characteristics were then used to define the nonlinear springs in the lumped mass model; and the spring characteristics were varied until an acceptable crash pulse was obtained.

The preliminary design of the first crash test bogey represented a second iteration of the front structure. Figure 11-4 shows a partial section of the

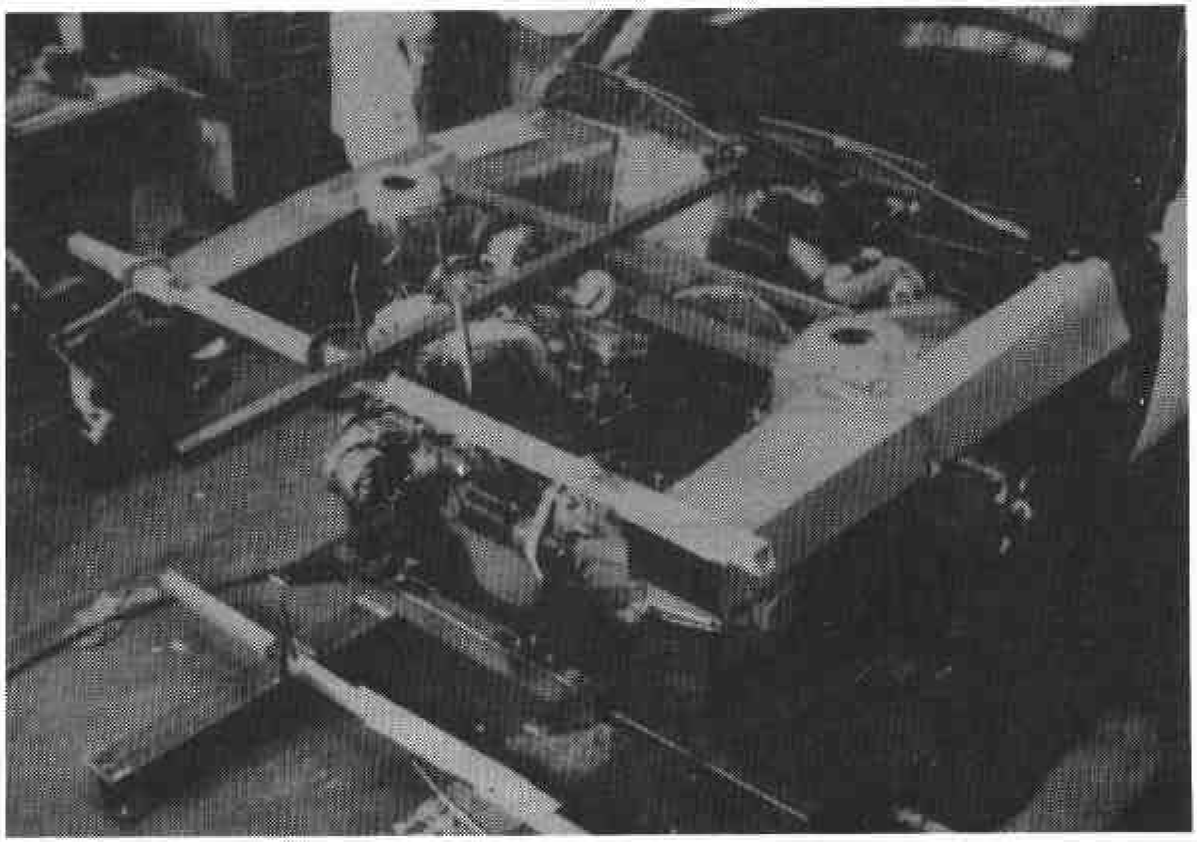
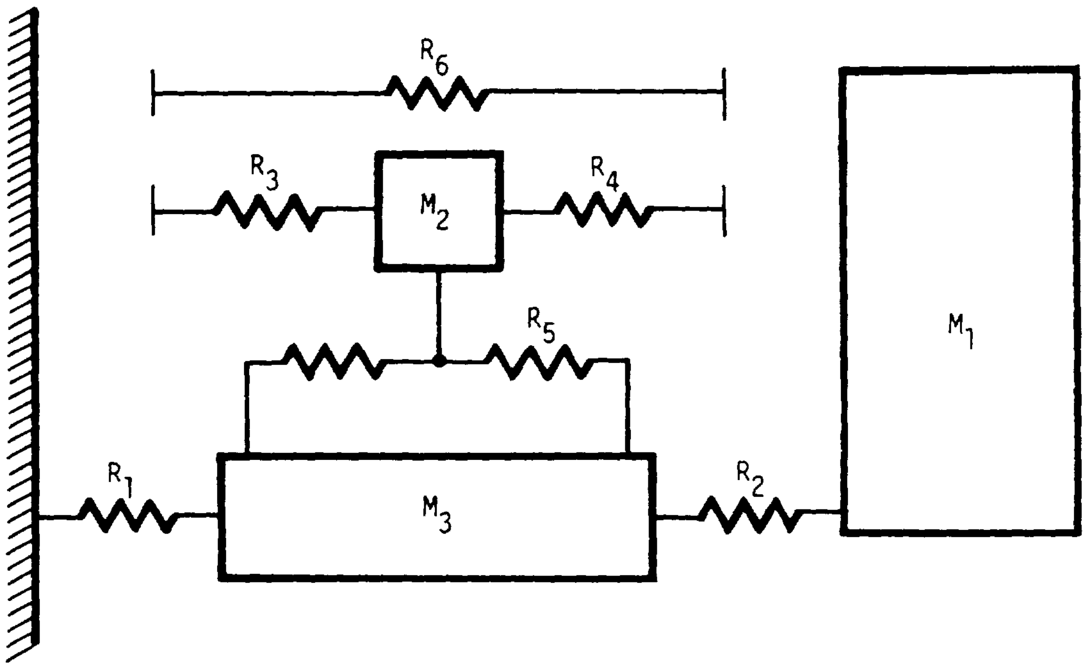


FIGURE 11-2. MOCKUP OF LRSV FRONT STRUCTURE



Mass	Definition
M_1	Body
M_2	Engine, radiator and front sheetmetal
M_3	Front suspension, bumper and front frame

Force	Definition
R_1	Front frame
R_2	Rear frame
R_3	Engine-to-radiator, etc.
R_4	Engine-to-firewall
R_5	Engine mount system
R_6	Upper load path structure

FIGURE 11-3. LUMPED MASS MODEL OF THE LRSV FRONT STRUCTURE

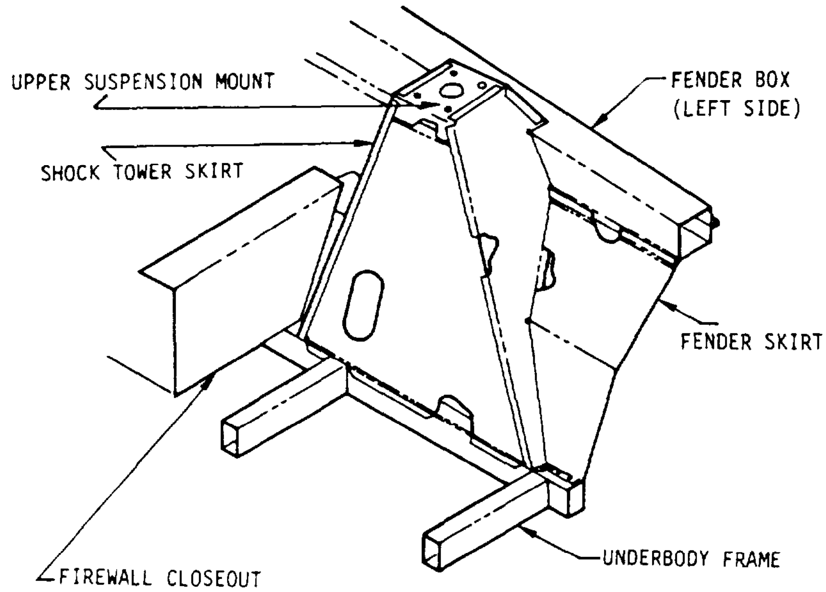


FIGURE 11-4. SUSPENSION MOUNT - FIRST DESIGN ITERATION

front structure in the first iteration; this design combined the upper mount for the suspension and the skirt around the shock absorbers into a structural element integrated with the fender skirt. The second iteration (Figure 11-5) simplified the design. We incorporated a fore/aft beam halfway down the fender skirt to better control frontal crash loads. The upper suspension mount became a smaller, simpler can which was integrated into the upper part of the fender skirt.

The configuration of the underbody frame is shown in Figure 11-6. The basic frame was made up of crossmembers, side rails and corner gussets (Items 1, 2, 3, 4 and 11 in Figure 11-6). Side rail extensions (Items 6 and 7) supported the front bumper channel (Item 5), which incorporated mounting brackets (Item 8) for the energy-absorbing bumper. The side rails also supported the brackets for mounting the front and rear control arms and sway bar (Items 9 and 10).

The configuration of the nose section is shown in Figure 11-7. The fender boxes and the fender closeout cans supported the nose. The nose, fender boxes and closeouts were foam-filled to improve their energy absorption.

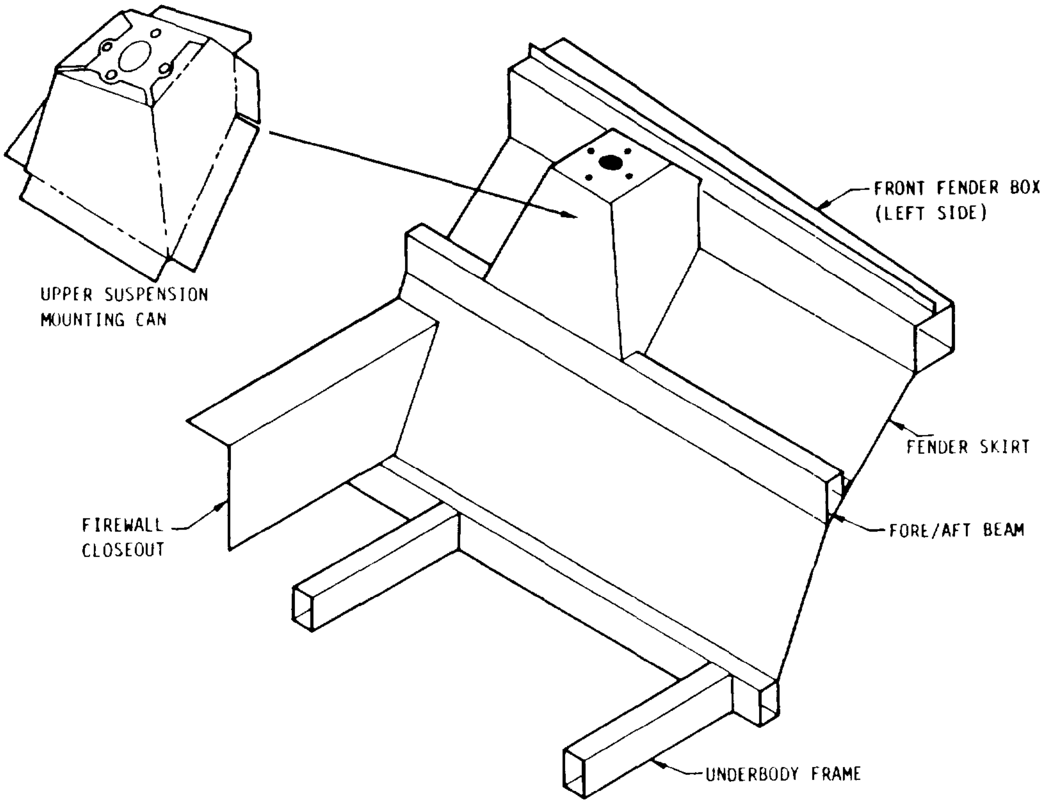


FIGURE 11-5. SUSPENSION MOUNT - SECOND DESIGN ITERATION

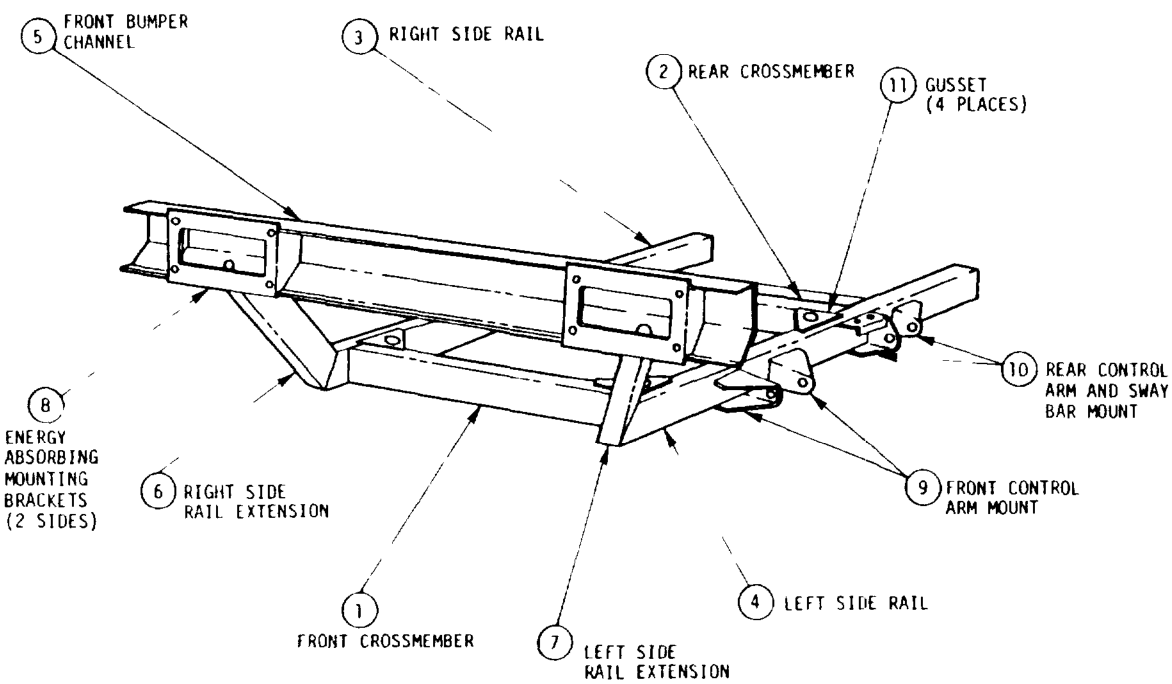


FIGURE 11-6. FRONT UNDERBODY FRAME STRUCTURE

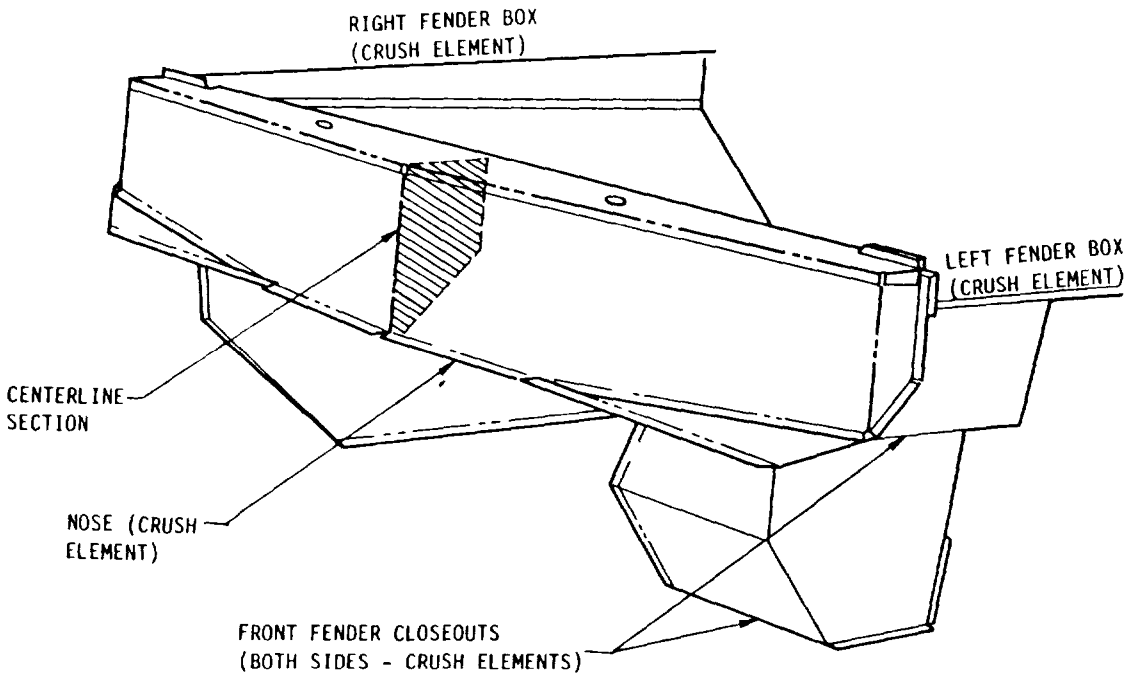


FIGURE 11-7. NOSE SECTION

Bogey Vehicle Development

For the first bogey vehicle, the left and right fender boxes were fabricated from 16 gauge (0.060 inch; 1.5 mm) brake-formed sheet steel. The side rails, side rail extensions and front and rear frame crossmembers were constructed from 2 x 3 x 0.083 inch (51 x 76 x 2.1 mm) mild steel rectangular tubing. Suspension mounting cans were brake-formed from 18 gauge (0.048 inch; 1.2 mm) steel. The front bumper channel and energy-absorber mounting brackets were fabricated from 16 gauge steel. All other components (e.g., the nose crush element, front and rear fender closeouts and inner fender skirts) were formed from 22 gauge (0.030 inch; 0.76 mm) steel.

We conducted a 40 mph (actual speed was 37.2 mph) barrier crash test of this front structure. Unfortunately, an unprecedented instrumentation malfunction caused the loss of all longitudinal acceleration data. An analysis of the test films indicated that the dynamic crush was between 25.3 and 26.2 inches (64.3 and 66.5 cm). The time required for the vehicle to decelerate was approximately 77 msec.

We calculated that the front structure would have crushed between 28.0 and 29.1 inches (71.1 and 73.9 cm) in a 40 mph impact. Since a dynamic crush of 34 inches (86 cm) was optimal, the stiffness should have been only 82 to 85 percent of the actual stiffness of the test structure. Consequently, we undertook a minor redesign of the front structure to soften the crash pulse (and to reduce the vehicle's tendency to pitch nose up). This redesign consisted of a gauge reduction of the structure in the upper load path and a change in the lower load path to increase the frame crush at the rear of the structure.

In the lower load path we replaced the compartment portion of the lower frame with a "torque box" which fed the frame rail loads outward into the sill sections. Figure 11-8 shows a bottom view of the torque box configuration. In the upper load path, the gauge of the fender box crush elements was reduced to 18 gauge (0.048 inch; 1.2 mm). These structural changes were then implemented in a second bogey vehicle, which was crash tested at 39.4 mph (63.4 km/h).

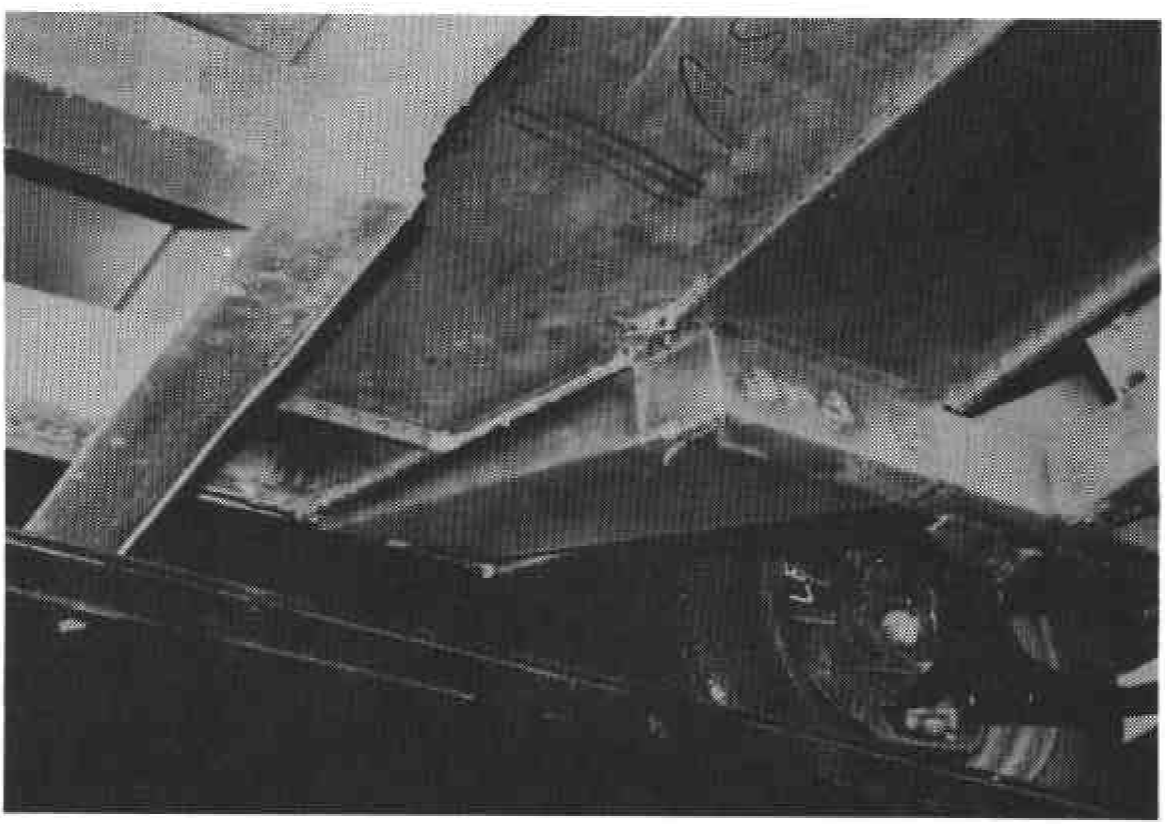


FIGURE 11-8. TORQUE BOX (BOTTOM VIEW)

An excellent crash pulse was obtained; however, the redesigned lower load path reduced the rear frame stiffness excessively, causing excessive lower dash deformation and accentuating the nose-up pitch seen in the previous 40 mph barrier impact. These results indicated a need for several revisions, including a reduction of the gauge of both the lower frame structure and the structure in the upper load path, and a change in the design of the interface between the lower frame and the body structure. The lower frame structure was reduced from 0.083 to 0.060 inch (2.1 to 1.5 mm) wall, 2 x 3 inch (51 x 76 mm) rectangular tubing. The upper load path was further downgauged from 18 to 20 gauge (0.036 inch; 0.91 mm) steel. The torque box structure was reinforced with a longitudinal tapered hat section beam which would feed loads rearward into the front seat crossmember (Figure 11-9). These design revisions were implemented and third barrier test was conducted.

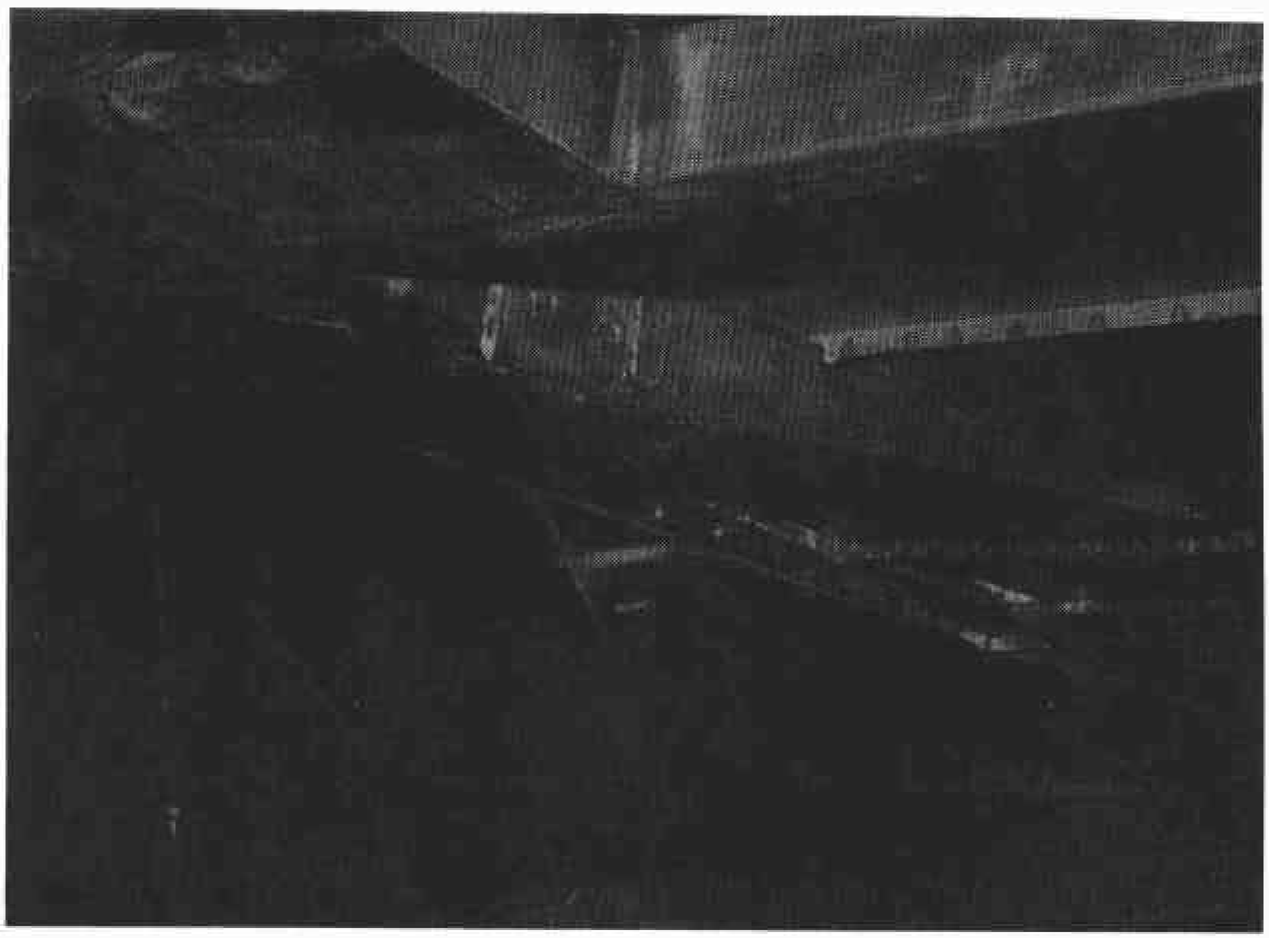


FIGURE 11-9. TORQUE BOX REINFORCEMENT

As expected, the crash pulse measured in the third test had a slightly higher acceleration level than did the previous pulse; however, the nose-up pitch and the rear frame deformation were significantly reduced. Table 11-1 compares the results of Bogey Tests 2 and 3.

TABLE 11-1. COMPARISON OF RESULTS FROM TEST NUMBERS 1341 AND 1386

	Test 1341 Bogey Test 2	Test 1386 Bogey Test 3
Test speed (mph)	39.4	41.5
Dynamic crush (inches)	41.0	39.0
Vehicle deceleration time (msec)	119	102
Toe pan intrusion (inches)	10	3 to 5

The front structure developed in the three bogey tests was then integrated into two crash test vehicles to be barrier-tested at 40 mph (64 km/h). The first test would involve an aligned barrier and the second either an aligned or a 30 degree angle barrier, depending on the results of the first test.

We conducted a nominal 40 mph frontal barrier crash test (Test 1436, shown in Figure 11-10) of the first LRSV crash vehicle. Post-test inspection indicated that the structure deformed similarly to the LRSV bogey test vehicle in the preceding 41.5 mph (66.8 km/h) frontal barrier crash. The toe pan intrusion and door deformation were within acceptable limits, and all four doors were readily opened by hand after the test. The basic test data were:

Test Speed	39.0 mph
Dynamic Crush	45.0 inches
Vehicle deformation time	124 msec
Toe pan intrusion	4 inches

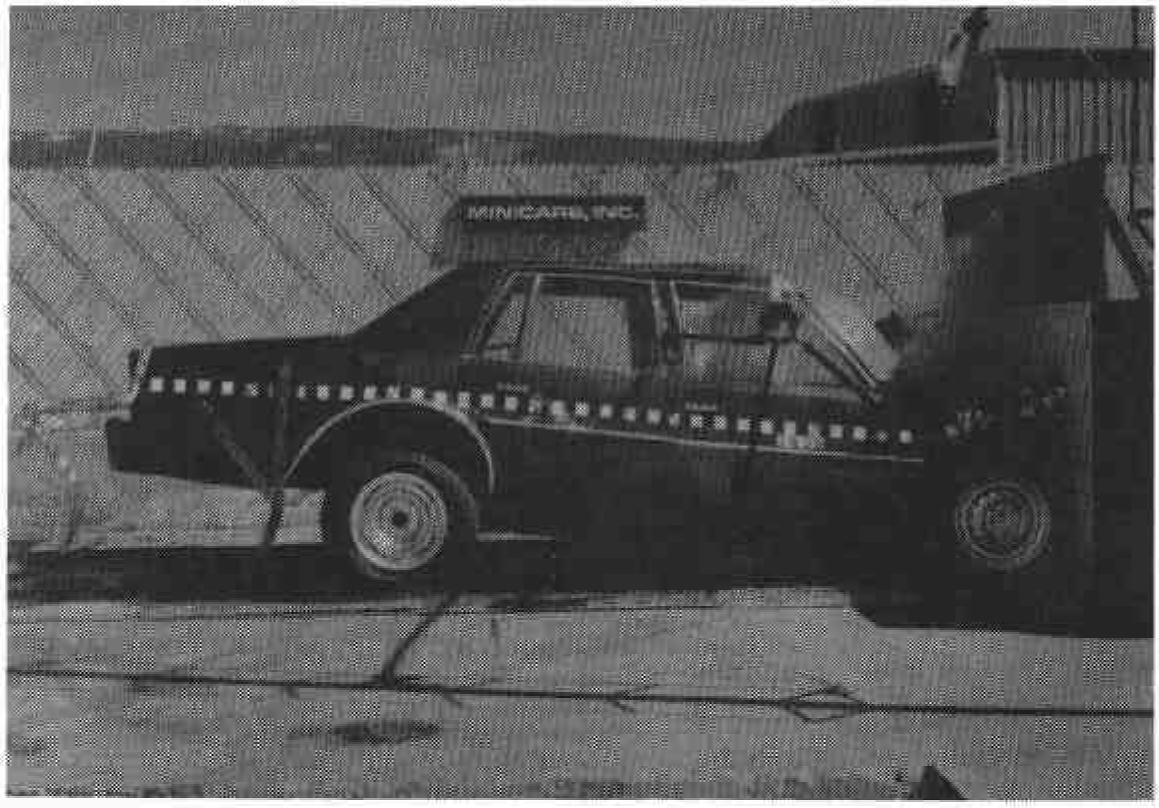


FIGURE 11-10. LRSV 39 MPH ALIGNED BARRIER IMPACT

The low average acceleration level of the crash pulse, the minimal compartment deformation, and the efficient restraint system combined to produce remarkably low injury numbers for the three dummy occupants. These good results led to the decision to proceed to the 30 degree barrier test.

The second crash had a very long duration, low acceleration level crash pulse. The vehicle did not exhibit significant steering column rearward displacement, and the toe pan rearward displacement of 4 inches was also relatively low (for an impact in which the decelerating forces were concentrated on one side of the vehicle).

Show Vehicle Structure

We continued to make minor modifications to the LRSV front structure after the frontal crash testing was completed. Two goals were established (beyond maintaining the successful crashworthiness): to downsize and relocate some of the structural components (as indicated by the crash test data), and to revise the assembly procedures for easier handling and spot welding. This redesign also provided an opportunity to "clean up the design" and to establish a common structural design theme for the rest of the structure.

The front impact beam weldment (Figure 11-11) was modified to accommodate the headlamp mounting panels and the hood latch mounting plate. The front bumper weldment (Figure 11-12) remained unchanged, but the front inner fender assemblies (Figure 11-13 shows the left side unit) underwent the most extensive changes. The upper fender box was revised to incorporate the final interface attachment at the hinge post. The inner fender was changed to accommodate a strut tower reinforcement spanning the distance between the front and rear fender closeouts. Previously, the reinforcement ran the full length of the fender; this caused assembly problems and, under crush, produced severe floor and firewall deformation. The front and rear fender closeouts were changed to conform with the new inner fender configuration.

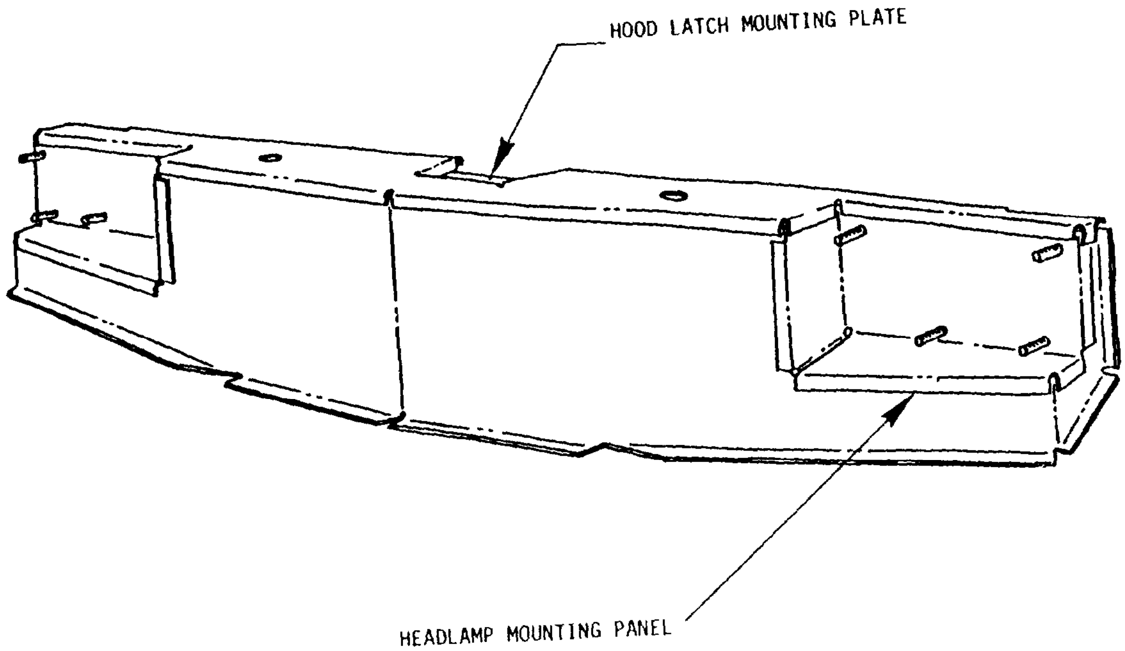


FIGURE 11-11. FRONT IMPACT BEAM WELDMENT

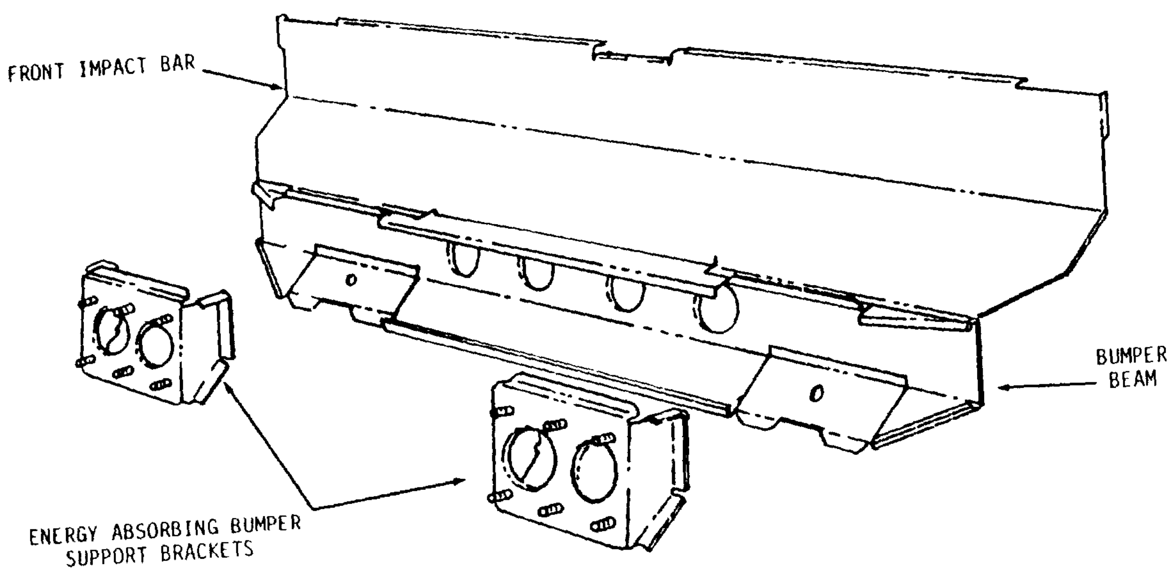


FIGURE 11-12. FRONT BUMPER WELDMENT

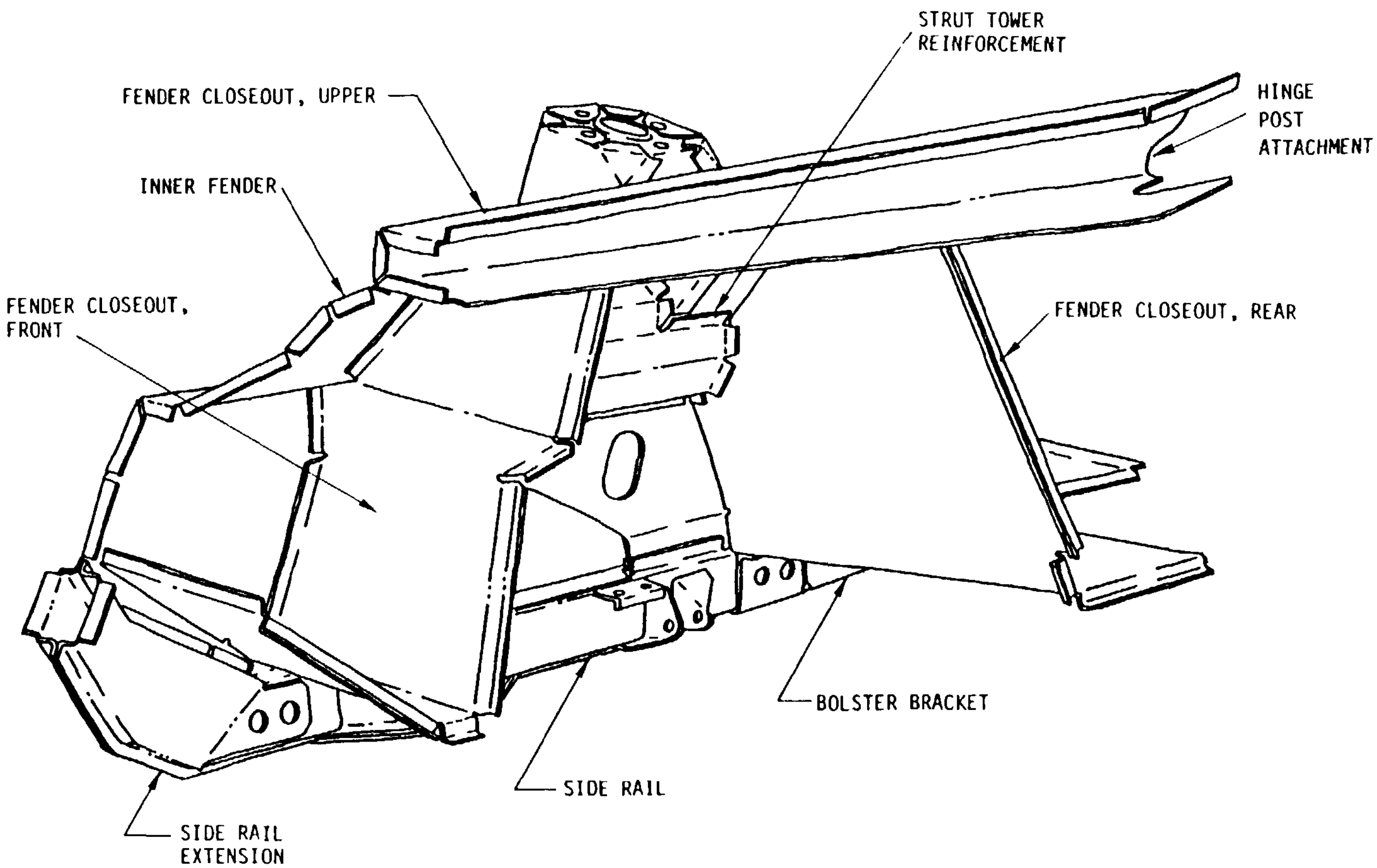


FIGURE 11-13. LEFT FRONT INNER FENDER WELDMENT

11.2.2 Compartment Structure

Operational Mockup

Inside the passenger compartment of the operational mockup the conventional floor was replaced by a thin foam-filled sheetmetal sandwich. Additional longitudinal support was provided by increasing the depth of, and foam-filling, the rocker panels (sills). Lateral crossmembers were fixed underneath the front and rear seats (Figure 11-14).

The four doors (Figure 11-15) of the mockup were modified to meet the augmented side impact performance requirements described in Section 11.3. The standard door beam was replaced with a foam-filled Aramid section between the exterior door skin and the window mechanism; and an additional tubular steel door beam was added above the standard latch assembly. The steel exterior skins of the doors were retained.

Preliminary Design for Frontal Crash Protection

The structure of the mockup vehicle was found to have some minor deficiencies which compromised occupant kinematics in crashes and occupant entry into the vehicle. The occupant kinematics was hampered by an inadequate knee trajectory; the entrance problem was primarily a matter of a high sill.

To produce a more desirable knee trajectory, we lowered the forward portion of the floor (between the front seat box and the firewall). We also lowered the seat box to provide more room for forward H-point translation. These changes reduced the under-floor room available for the vehicle frame structure, thereby eliminating the continuous front-to-rear frame rails of the mockup. Fortunately, we were able to decrease the depths of the mockup's sills, since structural analysis showed they were stiffer than necessary to provide adequate beaming and torsional capability in the compartment. Reducing the sill depth also eliminated the entry/egress problems with step-over height.

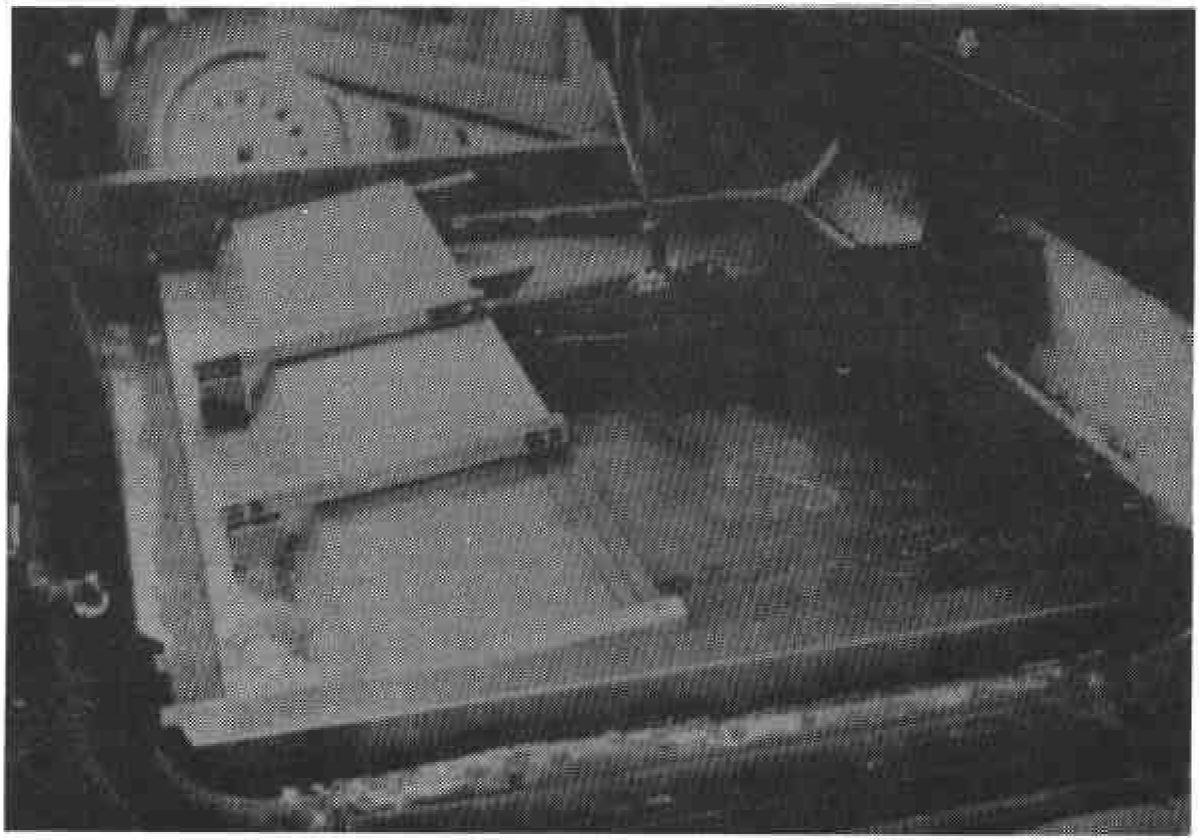


FIGURE 11-14. LRSV MOCKUP COMPARTMENT FLOOR

FIGURE 11-15. LRSV MOCKUP REAR DOOR DURING CONSTRUCTION

During the bogey tests load cells were used to monitor the upper load path forces transmitted to the front hinge pillar by the upper fender boxes. The magnitude of these loads caused concern that the compressive stiffness of the base vehicle's upper door, even with the hat section reinforcements used in the mockup, would be inadequate to handle forces of this magnitude. We, therefore, conducted a static compression test of the base vehicle's upper door and found it to buckle at 10,000 pounds (44,000 N) less than the required force level. A brake-formed upper door reinforcement was designed to replace the upper 3 inches (7.5 cm) of the base vehicle's inner door panel (Figure 11-16).

We also replaced the Aramid reinforced foam-filled doors of the mockup with a lightweight HSLA steel side guard beam. The design used in the mockup was revised because of significant problems in sealing and bonding the Aramid reinforcements to the door skins.

11.2.3 Rear Compartment Structure

In the operational mockup the rear spring towers were attached to the top of the rear inner fenders near the package tray. The towers were connected to the frame by large vertical members along the inner fenders and were separated laterally by a small member behind the rear seat. The luggage compartment floor rested on three longitudinal members running from the rear suspension support to the rear bumper. The no-damage bumper system was mounted on the rear bumper support, a foam-filled sheetmetal section extended across the rear face of the vehicle. Additional longitudinal strength was provided by closing out and foam-filling the rear fender sections (Figure 11-17).

The rear compartment structure of the prototype LRSV was considerably simplified in comparison to the mockup. This simplification was obtained by substituting a Chevrolet Citation beam rear axle for the mockup's Lancia independent rear suspension. Adaptors were used to mount the Lancia rear disc brakes and hubs to the Citation axle, providing the correct track width and a compatible brake system with the Lancia front brakes. The kickup section from a Chevrolet Citation was integrated with the LRSV foam-filled sill structure; this section provided mounting points for the Citation suspension control arms.

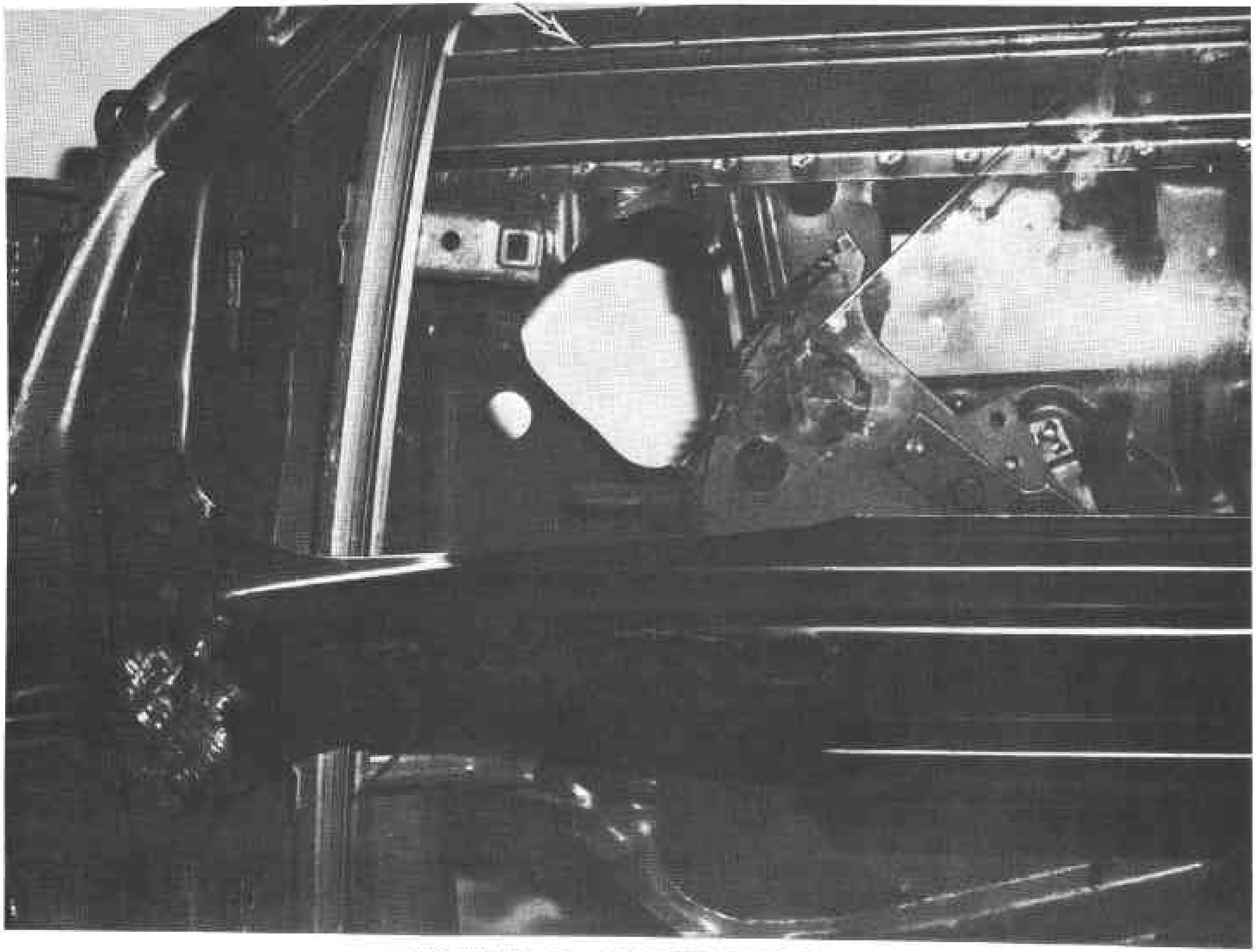


FIGURE 11-16. NEW SIDE GUARD BEAM

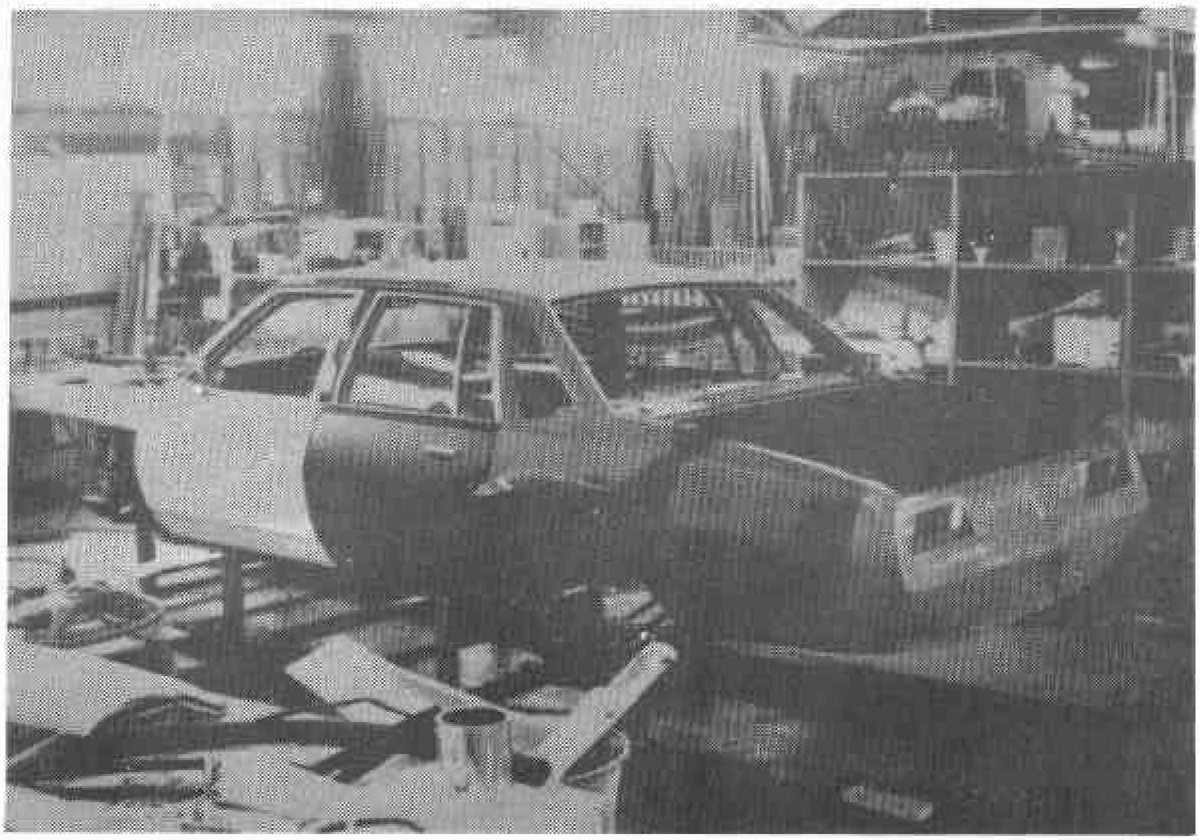


FIGURE 11-17. LRSV COMPARTMENT

As there were no contractual goals for improved rear crashworthiness, our consideration of high speed rear impacts was limited to the placement of the prototype's fuel tank in a protected location over the rear axle. For low speed impacts the prototype retained the mockup's no-damage bumper (with rubrics) and flexible fascia. Two rectangular steel tubes were mounted longitudinally beneath the trunk floor to reinforce the trunk for the low speed impacts.

11.3 LRSV OCCUPANT PACKAGING SYSTEM

The objective of the LRSV occupant packaging system is to function together with the vehicle's structural crashworthiness features to provide the occupant protection levels above those specified in current safety standards in front and side impacts. The packaging system is designed to at least meet the occupant protection requirements of FMVSS 208 at 40 mph (64 km/h) - rather than 30 mph (48 km/h) - and to meet the side impact requirements of FMVSS 208 at a bogey velocity of 25 mph (40 km/h) - rather than 20 mph (32 km/h).

The following section describes the features and performance of the LRSV air cushion and door padding systems.

11.3.1 LRSV Air Cushion System

The layout of the complete LRSV air cushion system is illustrated in Figure 11-18. Essentially, the system is comprised of the sensor and diagnostic circuitry, the driver restraint system, and the passenger restraint system. The system is designed to provide 40 mph barrier impact protection to the driver and two front seat passengers.

11.3.2 LRSV Driver Restraint System

The LRSV driver restraint system is a derivative of the earlier RSV system; in fact, it uses a number of the same components (e.g., the steering shaft assembly and steering wheel). But the LRSV had much less severe performance criteria

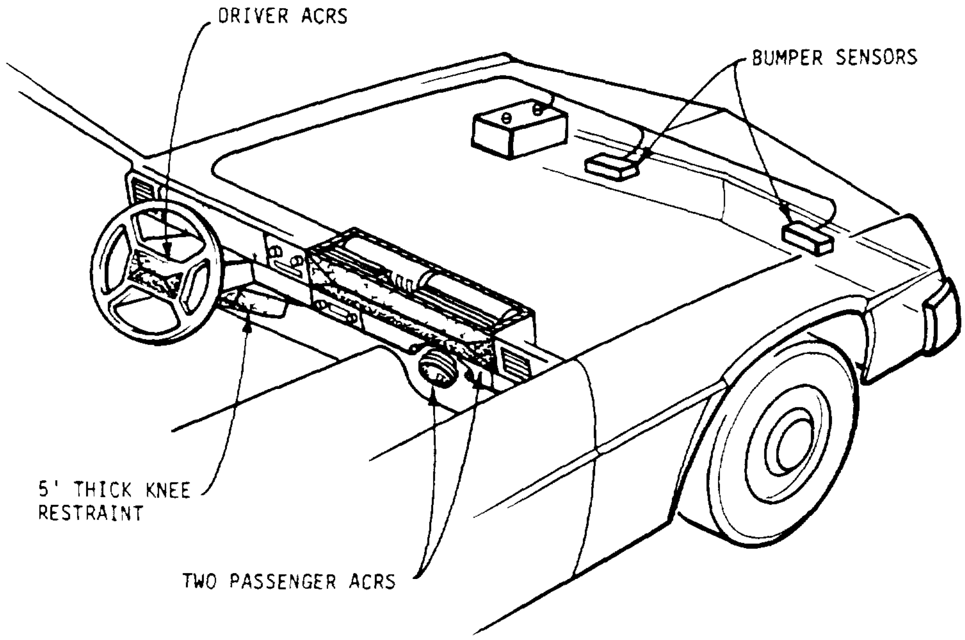
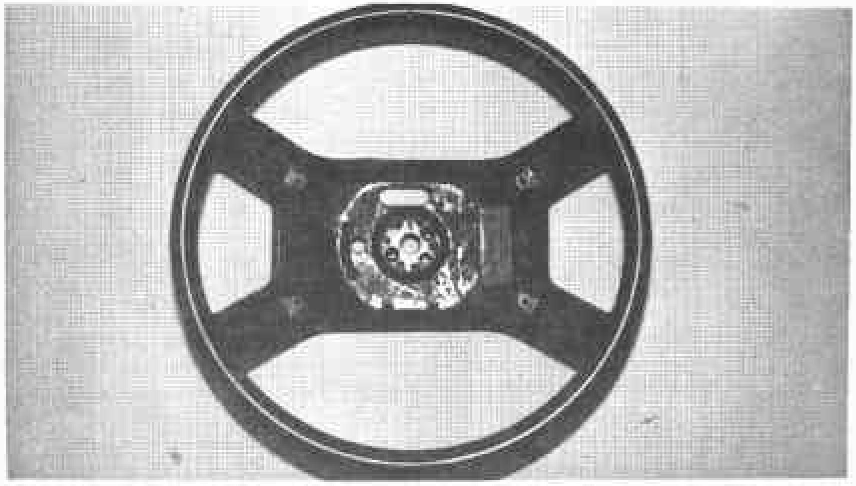


FIGURE 11-18. MAJOR COMPONENTS OF THE RESTRAINT SYSTEMS

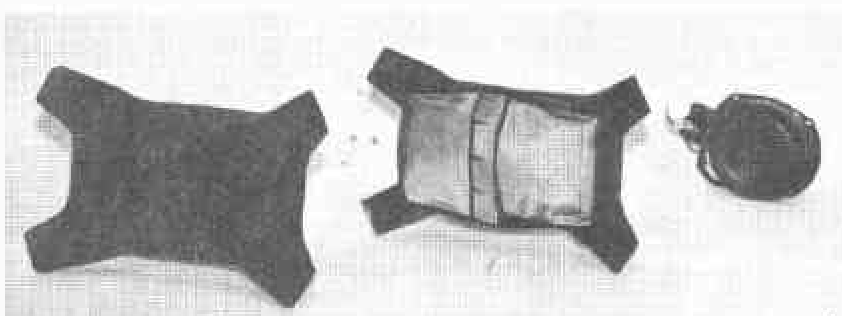
(requiring only about two thirds of the energy absorption capability of the RSV system). It, therefore, was possible to configure the LRSV system in a more conventional manner.

Wheel Module Subsystem

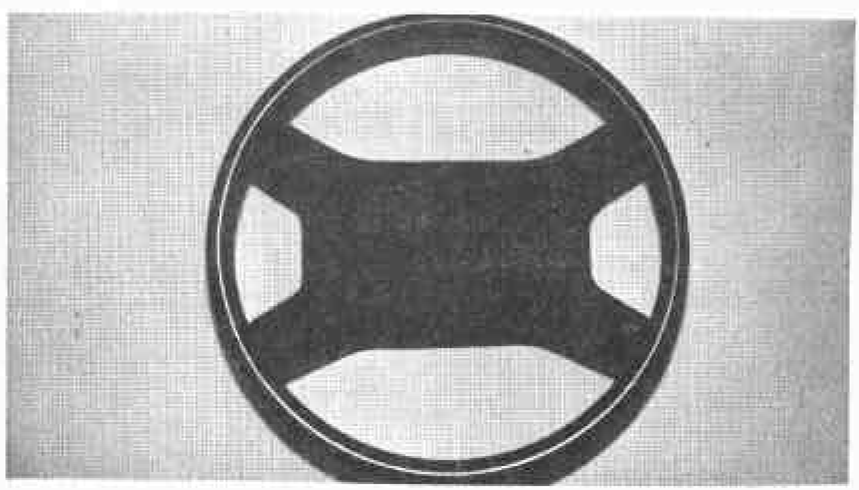
The LRSV driver system uses the GM ACRS wheel module assembly, with substitutions for the inflator and airbag. The GM module is shown in Figure 11-19 and consists of a (specially-designed) ACRS steering wheel, module pack, driver inflator, air cushion and bag cover. The module pack is basically a hard plastic box with a metallic rear surface; the rear surface forms the reaction plate and the front surface (which is formed with an H-shaped tear pattern) opens like flower petals during bag deployment. The inflator is bolted to the reaction plate and is linked with the airbag (also secured to the reaction plate) through an orifice in the plate. A textured outer cover is also secured to the reaction plate and is provided with an H-shaped tear pattern (seam) which matches the pattern in the



(a) ACRS Steering Wheel



(b) ACRS Internal Components



(c) Completed Wheel Assembly

FIGURE 11-19. LRSV DRIVER ACRS ASSEMBLY

module pack face. The inflator, module pack, air cushion and bag cover thus form a unit which bolts to the ACRS wheel.

In the LRSV module the GM ACRS inflator is removed and an uploaded inflator, identical to the RSV driver inflator, is substituted for it. The GM ACRS air bag is replaced by a vented (4.5 square inches) air cushion which has about 75 percent of the volume of the unvented GM ACRS bag (estimated at about 2.75 cubic feet). This modification speeds the coupling of the driver's upper body to the vehicle. This coupling is also facilitated by configuring the air cushion in a cylindrical pattern; it has two 18 inch (46 cm) diameter circular ends which are linked by a 9 inch (23 cm) long center. This construction encourages the inflated bag to take on more depth and less breadth, thus involving the driver with the airbag sooner.

Steering Column Assembly

The LRSV steering column assembly is similar to the RSV assembly. The principal areas of difference are:

- The LRSV column is oriented at an angle of 17 degrees from horizontal, while the RSV column is at an angle of 9 degrees.
- The EA unit of the RSV column has a second phase stroking force of 3300 pounds (1500 kg); the LRSV column strokes at 2000 pounds (900 kg).
- The sheetmetal bridge and retainer ring assembly linking the column mast to the steering wheel (see Subsection 4.2) was found to be unnecessary and was eliminated.

Knee Restraint Subsystem

The driver knee restraint system of the LRSV is configured similarly to that of the RSV. The essential difference is that the LRSV subsystem is designed to have a lesser EA capacity and to rely more on the yielding of the 20 gauge (0.037 inch; 0.93 mm) sheet steel knee restraint reaction plate. Thus the foam itself is only 3 inches (8 cm) thick and is faced with 1-3/8 inches (35 mm) of resilient EA foam (Ensolite, Type AH). The cover design is similar to that of the RSV.

The performance of the driver restraint system was defined in sled and crash tests. Table 11-2 summarizes the results from these evaluation tests (three sled tests and two barrier crash tests).

Test 1436 provided the best data for defining the performance of the system under the primary design condition. As is evident from the table, the system exceeds the requirements by quite a large margin. A comparison of the results of this crash test with those from the previously conducted sled simulation (Test 1411) indicates that the simulations quite closely match the barrier environment and suggest that the system possesses more than satisfactory repeatability. Sled Tests 1412 and 1416 indicate that the extremes of the driver somatotypes are protected at 40 mph, even though the 95th percentile male has little margin on the chest injury criterion. Further development could lower the chest injury measures for the 95th percentile male at 40 mph, at the expense of a tolerable increase in the corresponding injury measures for the 50th percentile male and 5th percentile female. This was not done because of time and money considerations.

Test 1509 is representative of the performance of the LRSV driver restraint system during oblique flat barrier crashes. Although there was 65 inches of crush on the driver side of the vehicle, the early sensing time, mild crash pulse, and low intrusion combined with the restraint system to produce very low injury measures.

11.3.3 LRSV Passenger Restraint System

The LRSV must accommodate three 50th percentile male adult occupants in its front seats. Consequently, the RSV passenger restraint system could not be easily adapted to the LRSV. We also found (by comparing high and low mount air cushion systems) that a system employing a knee cushion (low mount) would have advantages, including greater leg room and the potential to handle a wider range

TABLE 11-2. LRSV DRIVER TEST SUMMARY

Test No.	Test Description	Velocity (mph)	Squib Firing Time (msec)	Dummy Size	Dummy Injury Measurements			
					HIC	Chest Gs	Right Femur (pounds)	Left Femur (pounds)
1411	Sled simulation of perpendicular flat barrier impact	39.3	14	50M	130	36	1550	1450
1412	Sled simulation of perpendicular flat barrier impact	39.8	14	5F	259	40	875	725
1416	Sled simulation of perpendicular flat barrier impact	39.8	14	95M	435	57	1920	1500
1436	Perpendicular flat barrier impact	39.0	14	50M	174	37	1100	1150
1509	30^{o} Left oblique flat barrier impact	40.1	25	50M	248	32	1300	1000

of occupant sizes and seated positions. The RSV passenger restraint is a high mount (non-knee cushion) system.

The selected configuration is essentially a two-passenger adaptation of a so-called hybrid system developed for the Chevrolet Vega under another NHTSA contract (DOT-HS-6-01412). The term "hybrid" is used because the inflator is located relatively high on the dash, but (as in a low-mount system) a knee bag is used for lower body energy management.

The overall layout of the LRSV passenger restraint is shown in Figure 11-20. The system is comprised of an air cushion module, passenger seat and sensor system. The sensor system is described above; the other two subsystems will be described here.

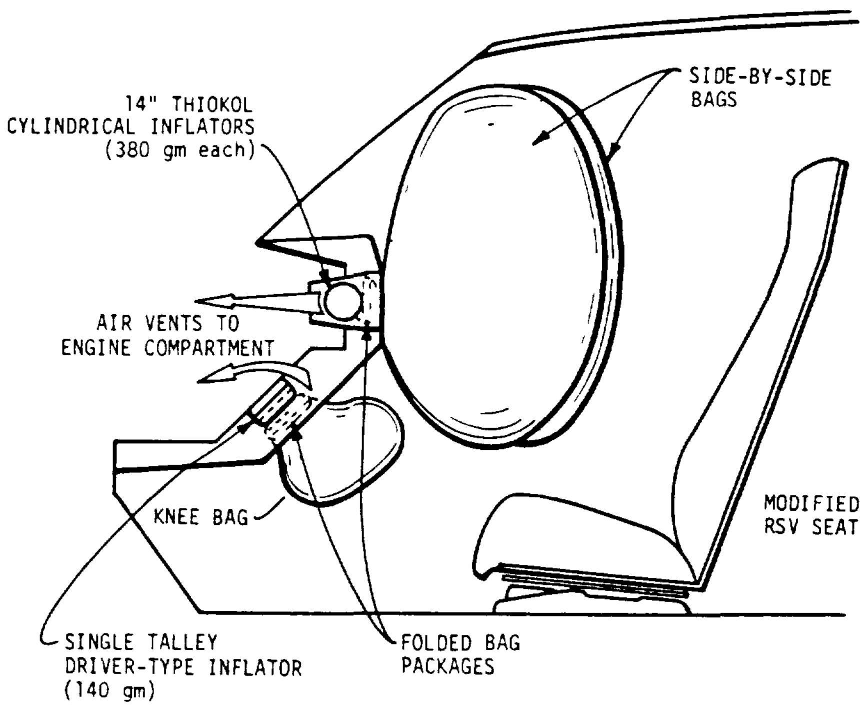


FIGURE 11-20. LRSV PASSENGER RESTRAINT SYSTEM

Air Cushion Module

The LRSV passenger air cushion module is comprised of a bag assembly, module pan, brackets, inflator and cover.

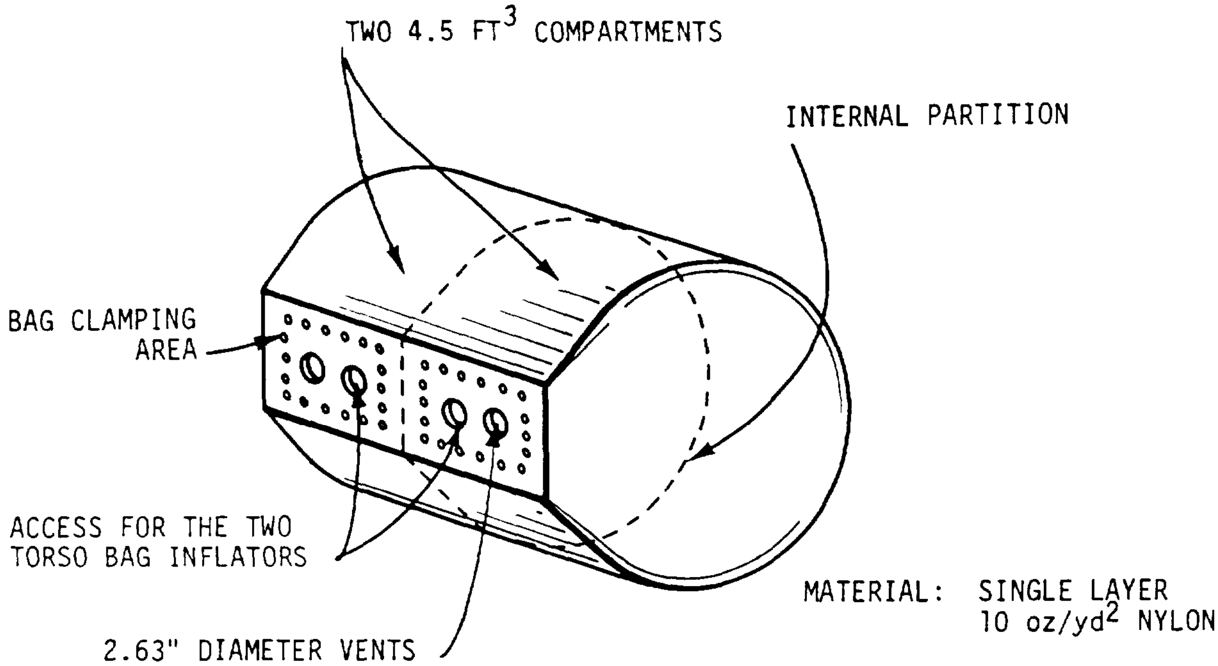
The LRSV airbag configuration is shown in Figure 11-21. Both the torso and knee bags are attached to the module pan via a bag clamping and backing plate system (as opposed to a "sock" attachment). The clamping assembly was used both to provide better bag stability and to allow the bag to vent directly through the module pan (as shown in Figure 11-20) into the engine compartment. This venting scheme insured that the high speed photographic coverage of the passenger response and restraint behavior during the development and evaluation testing was not obscured by vented gases. It also obviates issues about the effects of vented gas on crash victims.

A fabric partition divides the torso bag laterally into two chambers. This partition was installed primarily to give the rather wide bag a flatter aft (occupant side) surface. It would also allow for different venting to each chamber. This could be a desirable design feature, in that occupancy characteristics suggest that the middle seat, when occupied, is more likely to contain relatively small occupants (children, females). Thus there is reason for making the inboard chamber softer than the outboard cell by providing it with additional venting. In its present configuration, however, the two chambers have the same venting.

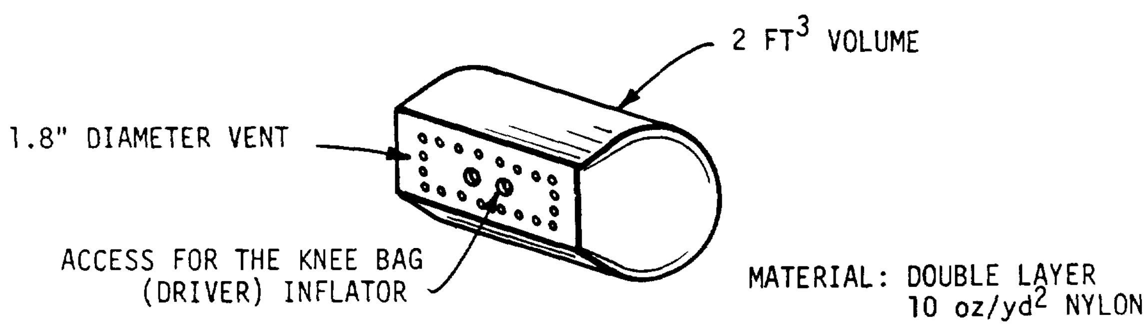
The module pan and bracketry are shown in the photographs of Figure 11-22. The module pan consists of a box-like upper structure (which houses the two torso bag inflators and torso bag) and a lower extension plate, to which is attached the knee bag and its inflator. This lower plate, because it serves as the knee bag reaction plate, must possess high structural integrity and must be well anchored to the compartment.

The rear surface of the module box and the lower plate are provided with orifices. These orifices primarily serve to vent gas, but they also allow some undetermined amount of engine compartment air to be drafted into the deploying air cushions. The torso bag vents are 5.43 square inches (35.0 cm^2); the knee bag vents are 2.54 square inches (16.4 cm^2).

The torso bag is inflated by the simultaneous initiation of two Thiokol small car passenger inflators. Each cylindrical unit is about 14 inches (36 cm) long and contains 430 grams of a sodium azide based propellant (in pellet form). The knee

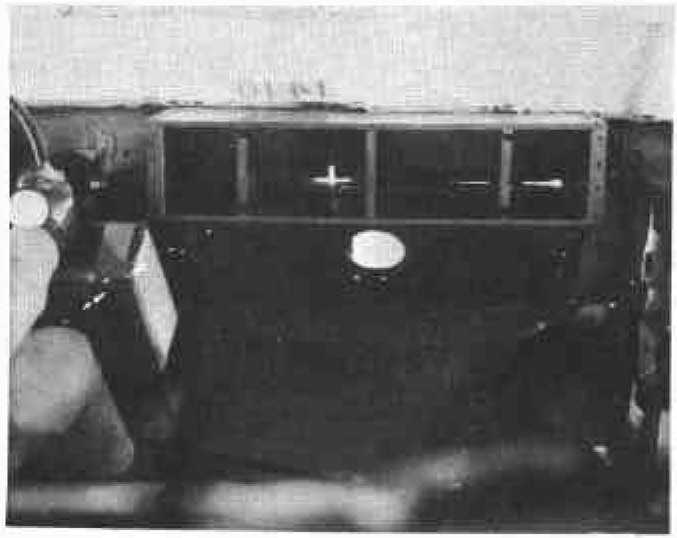


(a) Torso Bag

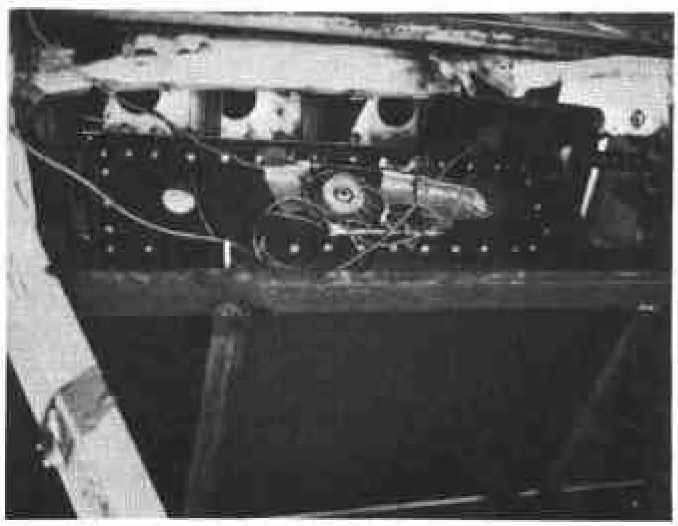


(b) Knee Bag

FIGURE 11-21. LRSV PASSENGER AIRBAG



(a) Passenger Restraint Bracketry



(b) Passenger Restraint Venting
(From the Engine Compartment)

FIGURE 11-22. LRSV PASSENGER RESTRAINT SYSTEM bag is inflated by a driver-type Talley Industries inflator containing 140 grams of sodium azide propellant.

The LRSV passenger system has two separate covers over the torso and knee bags. Both are configured in the same manner as the RSV passenger air cushion cover.

LRSV Passenger Seat

The LRSV has a split bench seat; the driver seat is separate from the two-passenger right front seat. The seats are constructed similarly, the passenger seat being a two-occupant adaptation of the driver seat. Both seats are modeled on the RSV front seats - with one important difference: there is no attachment of the LRSV seats to the roof. For this reason the seat backs had to be strengthened, since the ability of the Dodge van seat back structure to withstand occupant-induced rearward forces was judged to be exceedingly poor. This problem was resolved by reinforcing the connection of the seat back frame to the cushion frame.

The seat is constructed as a double seat with separate support springs (shown schematically in Figure 11-23). The separate cushion supports were found necessary in order to achieve a satisfactory degree of control over occupant H-points, as the weights of the two passengers would vary. The cushion frame was lowered 13 degrees to ensure that the center spring support does not interefere with occupant trajectory. A foam wedge was added to compensate for this lowering.

A 10 inch (25 cm) wide head restraint is provided for the outboard passenger by extending the seat back height locally. No head restraint is provided for inboard passengers, since (1) the seat is rarely occupied, (2) when it is occupied, it is frequently used by shorter occupants who do not need a head rest, and (3), most importantly, a center head rest would seriously compromise rearward vision.

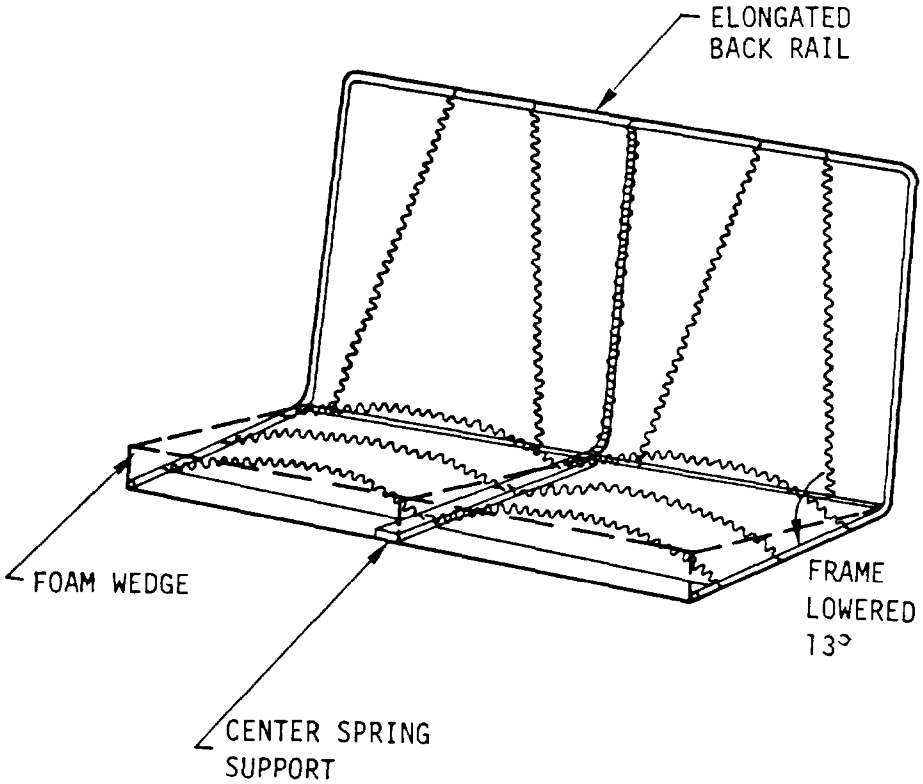


FIGURE 11-23. LRSV FRONT PASSENGER SEAT CONFIGURATION

Performance

Table 11-3 summarizes the sled and crash test results which define the performance of the LRSV passenger restraint system.

Sled Tests 1422 and 1437 were both conducted under the basic design condition and hence illustrate the excellent repeatability of the system. Test 1432, the objective of which was to evaluate the system under a reasonable light-load condition, produced excellent results.

Two vehicle crash tests were performed under FMVSS 208 conditions, but at a nominal speed of 40 mph. Test 1436, a perpendicular crash produced excellent results - lower in fact than those of the prior sled tests. In Test 1509, an oblique impact, the reinforced passenger seat back unexpectedly yielded while the LRSV was traveling to the barrier. This placed the dummies in a

TABLE 11-3. LRSV PASSENGER TEST SUMMARY

Test No.	Test Description	Velocity (mph)	Squib Firing Time (msec)	Dummy Size*	Dummy Injury Measurements			
					HIC	Chest Gs	Right Femur (pounds)	Left Femur (pounds)
1422	Sled simulation of perpendicular flat barrier impact	40	14	50M(C)	472	43	1000	725
				50M(R)	492	45	750	725
1432	Sled simulation of perpendicular flat barrier impact	40	14	None(C)	-	-	-	-
				5F(R)	571	37	275	400
1437	Sled simulation of perpendicular flat barrier impact	40	14	50M(C)	**	**	**	**
1436	Perpendicular flat barrier impact	39.0	14	50M(C)	169	30	1100	800
				50M(R)	178	30	1000	800
1509	30^{o} left oblique flat barrier impact	40.1	25	50M(C)	74	25	1200	600
				50M(R)	130	35	600	1250

*Center (C), Right (R)

**Uninstrumented dummy

significantly reclined position. Despite this detrimental condition, the injury measures were all well below the FMVSS 208 criteria. The excellent results in this test are a joint consequence of the restraint design, the early sensing time and the very low LRSV compartment decelerations in this crash mode.

11.3.4 LRSV Side Impact Padding

The LRSV side impact protection is provided by a structural system, designed to limit the velocity of the struck door, and a padding system, designed to limit near-side occupant accelerations. The specific goal was to limit the injury measures experienced by the Part 572 dummy in the FMVSS 208 test [conducted at a 25 mph (40 km/h) bogey velocity rather than the required 20 mph (32 km/h)] to the limits prescribed in FMVSS 208 – and also to hold the pelvic lateral accelerations below 80 Gs.

The padding system is composed of separate shoulder and hip pads attached to the door interior panel. Each pad consists of a sheetmetal case filled with energy-absorbing foam. Cross-sectional views of the pads are shown in Figure 11-24; the finished door interior is shown in Figure 11-25.

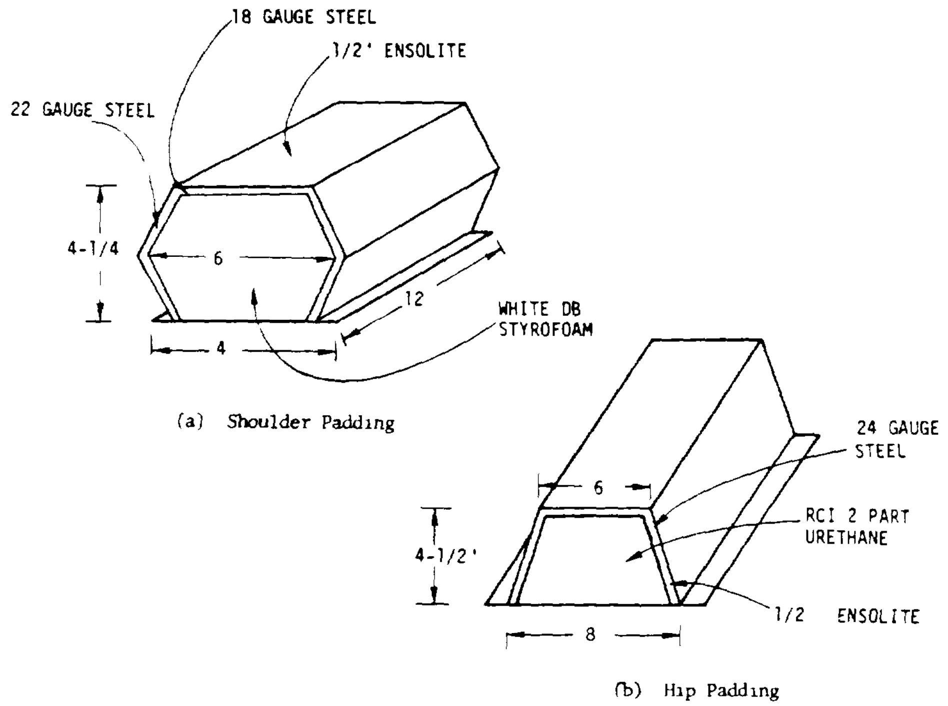


FIGURE 11-24. PADDING DESIGNS

FIGURE 11-25. LRSV DOOR INTERIOR

The door padding was developed by conducting sled test simulations of crash Test 1580. In that crash test a stationary LRSV (with stock Impala door padding) was impacted laterally by an FMVSS 208 flat-faced bogey moving at 30 mph (48 km/h). Initial sled tests simulated the door velocity found in the Test 1580 crash. The results indicated that satisfying the injury criteria at that crash velocity was feasible, but that it would require an unacceptable degree of padding (about 5 inches at each pad). Subsequently, we conducted a satisfactory sled test simulating a 25 mph bogey impact; in this test the pad thicknesses were reduced by about 1-1/4 inch (32 mm).

An evaluation crash test (Test 1711) was conducted to confirm the design. The results of this test were

Impact Velocity	25.6 mph (41.2 km/h)
Maximum Interior Intrusion (at B-pillar)	4-3/4 inches (12.1 cm)
HIC	132
Peak chest Gs	55
Pelvic Gs	55

11.3.5 LRSV Sensors and Diagnostic Circuitry

The LRSV sensor sytem consists of two Technar (Rolamite) sensors (Curve B) mounted on the bumper reaction surface. As in the RSV, each sensor is mounted at the rubric location, the rubric covering the sensor.

The diagnostic package is essentially the same as that used in the RSV (described in Section 4).

11.4 LRSV PROPULSION

An additional goal of the LRSV Program was to develop an engine that is feasible, affordable and producible in the mid-eighties and yet which can provide clean, fuel efficient propulsion for vehicles in the LRSV's inertia weight class. The goals were: exhaust emissions of 0.41 gm/mi HC, 3.4 gm/mi CO and 0.4 gm/mi NO_x

(maximum acceptable of 0.41 HC, 3.4 CO and 1.0 NO_x); combined EPA city/highway fuel economy of 27.5 mpg; and acceleration of 0 to 60 mph in 13.5 seconds (maximum acceptable of 20.0 seconds).

Minicars subcontracted the major portion of the engine development to the Volvo of America Corporation* (VAC) in Rockleigh, New Jersey. Volvo, in turn, issued a subcontract to DM Engineering, Inc. of Brookfield, Connecticut for hardware development and engine construction. Developmental fuel economy and emissions testing was conducted at the Brooklyn Air Resources Laboratory, at Automotive Environmental Systems, Inc. (AESi) in Westminster, California and at Custom Engineering in Garden Grove, California.

The Volvo B-21F 2.1 liter, in-line four cylinder engine was selected as the base powerplant. It runs on 91 RON unleaded gasoline and has a cast iron block, belt-driven overhead camshaft, and light alloy cylinder head of cross flow design. For emissions control, the engine incorporates Volvo's Lambda-Sond three-way catylist system, which monitors oxygen concentration in the exhaust and provides closed loop feedback inputs to a Bosch K Jetronic fuel injection system.

Volvo and Minicars evaluated several methods of improving the overall performance of the B-21 engine. In most cases the engine modifications were tested by steady state engine operation at various speeds (between 1600 and 2800 rpm) with a constant manifold vacuum of 13 inches (33 cm) Hg, which was chosen to simulate the EPA city cycle. By measuring the brake specific fuel consumption (BSFC), the effects of each modification could be assessed on a first order basis without running through the entire federal test procedure. The modifications and their effects are summarized below. It must be cautioned that these effects are not additive and may not be accumulative.

Displacement

As an initial step, the engine displacement was reduced from 2.1 to 2.0 liters. As expected, the fuel economy substantially improved; decreases in BSFC varied

*Appendix B contains a separate report describing Volvo's efforts.

from 3 percent at 1700 rpm to 8 percent at 4000 rpm. (In this case the BSFC was measured under wide-open throttle.)

Lubricant Pumping Losses

Two methods were employed to reduce the lubricant pumping losses: lowering the oil pump output pressure from 65 psi (719 kPa) to 35 psi (241 kPa) and switching to a low viscosity synthetic lubricant. The marginal fuel economy improvements which resulted from the lower pump output pressure did not warrant the possibility of reduced bearing life; consequently, that approach was discarded. The synthetic lubricant, however, accrued a maximum decrease in BSFC of 4 percent (at 2200 rpm), caused in part by reduced friction in the main bearing, rod bearings and cylinder walls.

Accessory Drive Speed

The alternator and water pump are the two accessories that are mechanically driven by the engine. By reducing their speeds 30 percent, we obtained a maximum decrease of 7 percent in BSFC (at 2200 rpm). The improved fuel economy in this case justified the reductions in excess engine cooling and electrical power generating capacity.

Multispark Ignition

A commercially available multispark ignition system was installed and set to spark repetitively over 30 degrees of crankshaft rotation. There was a substantial decrease in fuel consumption at speeds below 2500 rpm - at the cost of somewhat increased consumption at higher speeds.

Coolant Temperature

The cooling system was modified by replacing the engine driven fan with an electric fan controlled by the coolant temperature. The possibility of increasing the coolant temperature from 195°F (91°C) either to 210°F (99°C) or to 220°F (104°C) was investigated, but the small increases in cycle efficiency did not warrant the risk of increased thermal degradation of the engine. Therefore, the final system retained the electric fan, but with thermostatic setpoints of 210°F on and 200°F (93°C) off.

Turbocharging

At the start of the program, Volvo and Minicars felt that turbocharging the base powerplant might be necessary to meet the acceleration objectives. Consequently, a turbocharger was adapted to the B-21 engine to provide a positive pressure boost above 2500 rpm. Knocking was suppressed by incorporating a modulated water injection system, an independent manifold fuel injector and a vacuum ignition retard system. Turbocharging increased the maximum engine power (at 5000 rpm under wide-open throttle) from 100 hp (75 kW) to 122 hp (91 kW).

One serious developmental problem was the relatively long transport time (i.e., the time required for air to travel from the airflow sensor to the cylinder) that was evident when the air was routed through the compressor. Increasing the transport time lengthens the feedback loop controlling the air/fuel ratios and thus degrades fuel emissions performance under transient conditions. Although this was not an insurmountable problem (the turbocharged engine eventually met the maximum allowable emissions levels), Volvo and Minicars decided that the acceleration objective could be obtained without turbocharging, and development subsequently progressed with a naturally aspirated engine.

Other Modifications

We also investigated the possibility of reducing the engine inertia (by substituting a lighter flywheel, clutch and pressure plate), using matched fuel injectors to insure more consistent cylinder-to-cylinder air/fuel ratios, and incorporating negative crankcase pressure (by siphoning air to the intake manifold) to reduce piston pumping losses. The reduced inertia substitutions and the matched fuel injectors were retained in the final version of the engine.

The final engine was coupled to a Volvo chassis and drivetrain tested according to standard EPA test procedures. The results are listed in Table 11-4.

TABLE 11-4. LRSV ENGINE TEST RESULTS

	Objective	Maximum Acceptable	Test Results
Exhaust Emissions			
HC (gm/mi)	0.41	0.41	0.19
CO (gm/mi)	3.4	3.4	2.38
NO_x (gm/mi)	0.4	1.0	0.57
Fuel Economy			
EPA City (mpg)			22.8
EPA Highway (mpg)			36.5
EPA Combined (mpg)	27.5		27.4
Acceleration			
0-60 mph (sec)	13.5	20.0	14.5

Dynamometer setting = 10.8 hp at 50 mph

Inertia Weight = 3250 pounds

Transmission

Fuel economy, emissions and acceleration all depend on the selection of an appropriate transmission. For maximum efficiency, we limited the choice to manual transmissions. We originally specified the Lancia Beta five-speed transaxle, because of its easy integration with other LRSV front suspension components (which also are Lancia Beta parts). It soon became apparent, however, that the Lancia Beta's N/V (engine rpm/vehicle mph) ratio (54.1 in fifth gear with size 205-14 tires) was too high to achieve optimal fuel economy. Therefore, we replaced it with the Chrysler Omni/Horizon four-speed transmission (manufactured by Volkswagen) which has an N/V ratio of 44.9. Later in the program the GM X-body four-speed transaxle, which has an N/V ratio of only 36.1, became available and was integrated into the LRSV. In our judgment, this unit provides an optimal combination of fuel economy, acceleration and more than adequate durability.

SECTION 12
ACCIDENT ENVIRONMENT ANALYSIS

12.1 INTRODUCTION

The RSV design is based on the results of Phase I computer simulations which calculated the safety payoffs and benefit/cost ratios of alternative vehicle configurations. In all, 5040 different combinations of safety subsystems (structures, restraints, radar activated brakes, etc.) were assembled, and the most promising were evaluated in the projected 1985 automotive accident environment.

The analytical techniques used in this study were improved as the RSV Program progressed. While most of this later work did not directly affect the design of the RSV, the resulting techniques are important on two other counts: they are valuable for fully understanding the implications of proposed Federal mandates, and they introduce significant improvements in the benefit methodology available to assess benefits of new system and future conditions (which have recently been assembled). Thus the improvements in the analytical tools of the RSV Program are directly in line with one of the program's fundamental goals: to assist in understanding the effects of new systems in the potential future accident environment.

Early in Phase III, Kinetic Research* conducted a brief study of rear impacts. This was followed by a comprehensive study of some proposed passive restraint implementation scenarios. The model constructed for this study is suitable for a wide range of applications, so Kinetic Research subsequently refined it into a simpler, more flexible form: the Kinetic Research Accident Environment Simulation and Projection (KRAESP) model. Additional algorithms for property damage costs and advanced braking systems were devised to directly interface with the basic KRAESP model.

*Kinetic Research is a division of Minicars, Inc. It was a separate company, located in Madison, Wisconsin, when Phase III began.

Subsections 12.2 through 12.4 discuss the KRAESP model and its complementary algorithms, Subsection 12.5 discusses the rear impact study, and Subsection 12.6 discusses the passive restraint implementation study.

12.2 THE KRAESP MODEL

The KRAESP Model was developed to describe the future automobile accident environment and to evaluate the safety impact of changes in automobiles and automobile systems in that environment.

The outputs of the KRAESP Model are the expected numbers of fatalities and injuries at various levels of the Abbreviated Injury Scale (AIS).* These numbers can be presented for the

- Year of impact
- Vehicle size class
- Vehicle manufacturer
- Vehicle model year
- Impact mode (vehicle-to-vehicle or fixed object)
- Vehicle damage area (clock position)
- Occupant seat position.
- Impact crash severity

The model is capable of presenting output considering such variables as occupant age and body area of injury, but this degree of refinement has not yet been employed (in the absence of adequate input data to justify such detail).

Input

The user of the model must specify one or more implementation schemes. An implementation scheme consists of a specific mix of vehicle crash management systems for each occupant seat position and vehicle size class, manufacturer and

*Developed by the American Medical Association.

model year. A vehicle crash management system is a combination of the restraint system (belt, airbag, etc.) and the vehicle structural characteristics that affect the occupant during the crash (accelerations, force loads, etc.). Its performance is usually specified in the form of dummy injury measures, taken as functions of impact mode (IM), damage area (DA), crash severity and seat position (SP).

Crash severity is almost always measured by a vehicle's velocity change (delta-V) during an accident. In this section we will use the terms "delta-V" and "crash severity" interchangeably; but it must be remembered that other measures (such as vehicle crush) may, as well, be used to specify crash severity. The model also uses the following data:

- Vehicle population statistics and weights from 1952 to the present
- Vehicle population statistics and weights for new vehicles in future model years
- An injury severity (AIS) probability distribution in terms of vehicle class, impact mode, damage area, seat position and delta-V for unrestrained occupants
- A probability distribution that subdivides the total number of accidents into cells defined by relative velocity (V_{rel}), impact mode and damage area (referred to simply as a "V_{rel} distribution")
- Other pertinent data (occupancy rates, restraint usage rates, etc.).

The KRAESP program contains default values for many of these inputs. For example, future market shares are estimated by extrapolating data from the 1976 and 1980 model years, and AIS distributions are compiled from NCSS data. The selection of the data and default values are governed by the circumstances of each application.

Methodology

Table 12-1 presents a basic list of the KRAESP variables. (Reference 21 gives a complete description of the model.) The first column lists the primary variables used in the KRAESP program and in the complementary BRAKE and Property Damage

TABLE 12-1. KRAESP VARIABLES

Variable (Symbol)	Function Of:	Possible Values	Remarks
The following variables define the case vehicle and its safety systems:			
Case vehicle class* (VC)		Mini, Subcompact, Compact, Intermediate, Standard	Because safety performance may vary markedly between vehicle classes, KRAESP performs computations on a class-by-class basis. Automobiles are subdivided into classes according to interior dimensions.
Manufacturer* (M)		GM, Ford, Chrysler, AMC, Import	
Model year* (Y)		1952-1990	
Case vehicle weight** (m)	VC,Y,PD		Vehicle weight depends only on vehicle class, model year, and property damage system (PD). This means, for example, that all 1975 compacts have the same weight. Where weight data are available, KRAESP uses the average weight of all vehicles in a class. The model contains projections for future vehicle weights by class and model year.
Restraint system* (R)	VC,M,Y,SP		The user must specify the restraint system used at each seat position in the case vehicle. The manner in which restraint systems are phased in by class, manufacturer and model year is referred to as an "implementation scheme."

*These variables must be selected by the user. Specifying them narrows the scope of the investigation.

**KRAESP incorporates default values for these variables. The user may specify other values as desired.

(continued)

TABLE 12-1. (Cont'd)

Variable (Symbol)	Function Of:	Possible Values	Remarks
Brake system* (BS)	VC,M,Y		
Property damage system* (PD)	VC,M,Y		
The following variables specify the performance of the above systems:			
Usage** (U)	VC,R,SP	0.0-1.0	Usage is the probability that a given restraint system will be in use if an accident occurs. For instance, it might refer to the fraction of front seat passengers in intermediate cars who wear seat belts.
Dummy injury** (g)	R,SP,IM,DA,ΔV		Dummy injury is a measurement of restraint system performance derived from testing or theoretical considerations. Typically, test results take the form of peak acceleration versus delta-V curves for a given seat position and damage area.
Range* (r)	BS		Range is the distance at which a radar-activated braking system will sense an impending collision and apply the brakes.
Brake performance* (acc)	VC,M,BS		Brake performance refers to the deceleration capability of an advanced braking system.

*These variables must be selected by the user. Specifying them narrows the scope of the investigation.

**KRAESP incorporates default values for these variables. The user may specify other values as desired.

(continued)

TABLE 12-1. (Cont'd)

Variable (Symbol)	Function Of:	Possible Values	Remarks
Average repair cost ($\$_{ave}$)	VC,M,Y,PD, IM,DA,ΔV		$\$_{ave}$ is the average cost to repair a given case vehicle (VC,M,Y) equipped with a given bumper system (PD) which has sustained an accident of given type (IM,DA) and severity (ΔV). Typically, new bumper systems are evaluated on the basis of $\$_{ave}$ versus delta-V curves obtained from testing.
The following variables specify the environment of a given accident:			
Impact year* (I)		1952-1990	I is the year in which the accident occurs.
Seat position* (SP)		Left front, right front, left rear, right rear	Computations are done on a seat-by-seat basis, since injury level probabilities may be strongly dependent on seat position.
Abbreviated Injury Scale* (AIS)		0,1,2,3,4,5,6	Injuries are quantified by severity on a scale from 0 (uninjured) to 6 (fatality).
Impact mode* (IM)		Vehicle-to-vehicle, vehicle-to-fixed object, rollover	
Damage area* (DA)		1,2,3,4,5,6,7,8, 9,10,11,12	Damage area specifies the area of the case vehicle that sustains the most damage. The numbers refer to clock positions: 12 is the front of the car, 3 is the right side, etc.
Other vehicle weight (m_o)	VC_o		See remarks on case vehicle weight.

*These variables must be selected by the user. Specifying them narrows the scope of the investigation.

(continued)

TABLE 12-1. (Cont'd)

Variable (Symbol)	Function Of:	Possible Values	Remarks
Relative velocity (V_{rel})	r,acc		V_{rel} is the relative velocity between the case vehicle and struck object (or other vehicle) at the time of impact. A more complete definition is given in Reference 22.
Crash severity (ΔV)	V_{rel},m,m_o		Crash severity is the magnitude of the velocity change experienced by the case vehicle during impact.
Repair cost ($\$_R$)			$\$_R$ is the cost of repairing the case vehicle.
Other vehicle class (VC_o)		Mini, Subcompact, Compact, Intermediate, Standard, Small Truck, Medium Truck, Large Truck	"Other" vehicles are subdivided in the same manner as case vehicles, except that trucks are also included.
The following variables describe the overall or generalized accident environment:			
Total sales** (S_t)	Y		S_t is the combined sales of all models during a given model year.
Market share** (f)	VC,M,Y	0.0-1.0	

*These variables must be selected by the user. Specifying them narrows the scope of the investigation.

**KRAESP incorporates default values for these variables. The user may specify other values as desired.

(continued)

TABLE 12-1. (Cont'd)

Variable (Symbol)	Function Of:	Possible Values	Remarks
Case vehicle sales (S)	S_t,f		
Other vehicle sales (S_o)	VC_o,Y		
Survival rate** (s)	I-Y	0.0-1.0	Survival rate is dependent only on vehicle age.
Annual vehicle mileage** (VM)	I-Y		VM is the average yearly mileage driven by a vehicle, and depends only on vehicle age.
Number of accidents** (N_a)	I		N_a is the total number of accidents during the impact year I.
The following variables specify KRAESP probability functions:			
Case vehicle exposure (E)	S_t,S,s,VM	0.0-1.0	E is the ratio of case vehicle miles traveled to total vehicle miles traveled during a particular impact year.
Other vehicle exposure (E)	S_t,S_o,s_o,VM	0.0-1.0	See remarks for case vehicle exposure.
Occupancy probability* (P_{SP})	VC,I,SP	0.0-1.0	Given that an occupant is in a particular class of vehicle in a given year, P_{SP} is the probability of being in a particular seat position.

*These variables must be selected by the user. Specifying them narrows the scope of the investigation.

**KRAESP incorporates default values for these variables. The user may specify other values as desired.

(continued)

TABLE 12-1. (Cont'd)

Variable (Symbol)	Function Of:	Possible Values	Remarks
Mode/damage area probability** (P_{id})	IM,DA	0.0-1.0	P_{id} is the probability that an accident is in a given mode and has a given damage area.
Relative velocity probability** ($P_{V_{rel}}$)	IM,DA,V_{rel}	0.0-1.0	Given that an accident occurs in a particular mode and damage area, $P_{V_{rel}}$ is the probability that it occurs at a given V_{rel}.
Crash severity probability ($P_{\Delta V}$)	m,ΔV,m_o, $P_{V_{rel}}$	0.0-1.0	Given that an accident involving the case vehicle and a vehicle weighing m_o occurs in a particular mode and damage area, $P_{\Delta V}$ is the probability that it occurs at a given delta-V.
Injury severity probability (P_{xa})	R,g,SP,DA, AIS,ΔV,$P_{\Delta V}$	0.0-1.0	In an accident occurring at given delta-V, P_{xa} is the probability that an occupant will receive an injury of a particular AIS level, assuming his restraint system is operational.
Injury severity probability (P_a)	U,P_{xa}	0.0-1.0	P_a is identical to P_{xa}, except that it accounts for nonusage of restraint systems.
Repair cost probability ($P_\$$)	VC,M,Y,I,$\$_P$	0.0-1.0	Given that a case vehicle (VC,M,Y) has an accident, $P_\$$ is the probability that the repair costs will equal $\$_P$.

*These variables must be selected by the user. Specifying them narrows the scope of the investigation.

**KRAESP incorporates default values for these variables. The user may specify other values as desired.

(continued)

TABLE 12-1. (Cont'd)

Variable (Symbol)	Function Of:	Possible Values	Remarks
The following variables specify KRAESP outputs:			
Number of injuries/cell (n_i)	N_a, E, P_{SP}, P_{id}, $P_{\Delta V}$, P_a		n_i is the total number of injuries at a given AIS level in a particular cell during the impact year. A "cell" is a specific subset of the accident environment. It refers to a specific case vehicle (VC,M,Y), seat position, impact mode, damage area and crash severity.
Number of injuries (N_i)	n_i		N_i is the sum of all n_i's in all cells. It represents the total number of injuries at given AIS during year I.

*These variables must be selected by the user. Specifying them narrows the scope of the investigation.

**KRAESP incorporates default values for these variables. The user may specify other values as desired.

Algorithms. For input variables, the table specifies whether or not default values exist. The second column lists the dependent variables for each variable. (Note that some dependent variables also have dependent variables of their own.) The "Possible Values" column shows where limitations exist, but these limitations are, for the most part, nothing more than limitations in the present software. For instance, there is nothing inherent in the methodology that requires the use of five case vehicle classes – this number can easily be increased or decreased.

There is one facet of the methodology that merits special attention – the injury severity probability distribution (P_a). Past analyses of the accident environment simply assigned an average societal cost to a given set of accident parameters, thus limiting the chances of discriminating between injuries and fatalities. The KRAESP model provides outputs at each AIS, and therefore offers excellent flexibility for the interpretation of results. The technique for constructing AIS distributions is summarized below.

A P_a distribution is first assigned to each ΔV (for given IM, DA and SP) for unrestrained occupants. These distributions are based on accident data and might look something like those shown in Figure 12-1. The task is to construct similar distributions for restrained occupants without the aid of large data files, since none are available. To accomplish this, we assume that a specific P_a distribution exists for each dummy injury (g) level* independently of whether the occupant is restrained or unrestrained (though the delta-V at which it occurs will generally be different).

This technique is illustrated in Figure 12-1, which shows g versus delta-V performance data (typically from crash or sled tests) for a hypothetical System X and for unrestrained occupants. Our assumption simply states, for example, that an occupant protected by System X in a 25 mph delta-V accident has the same probability of being injured at any given AIS level as would an unrestrained occupant in a 15 mph delta-V impact. Figure 12-2 shows another set of P_a distributions, in three-dimensional form.

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*We use the letter "g" here to represent dummy injury measures because accelerations are typically used for this purpose. The symbol "g" could also represent something other than accelerations, such as HIC.

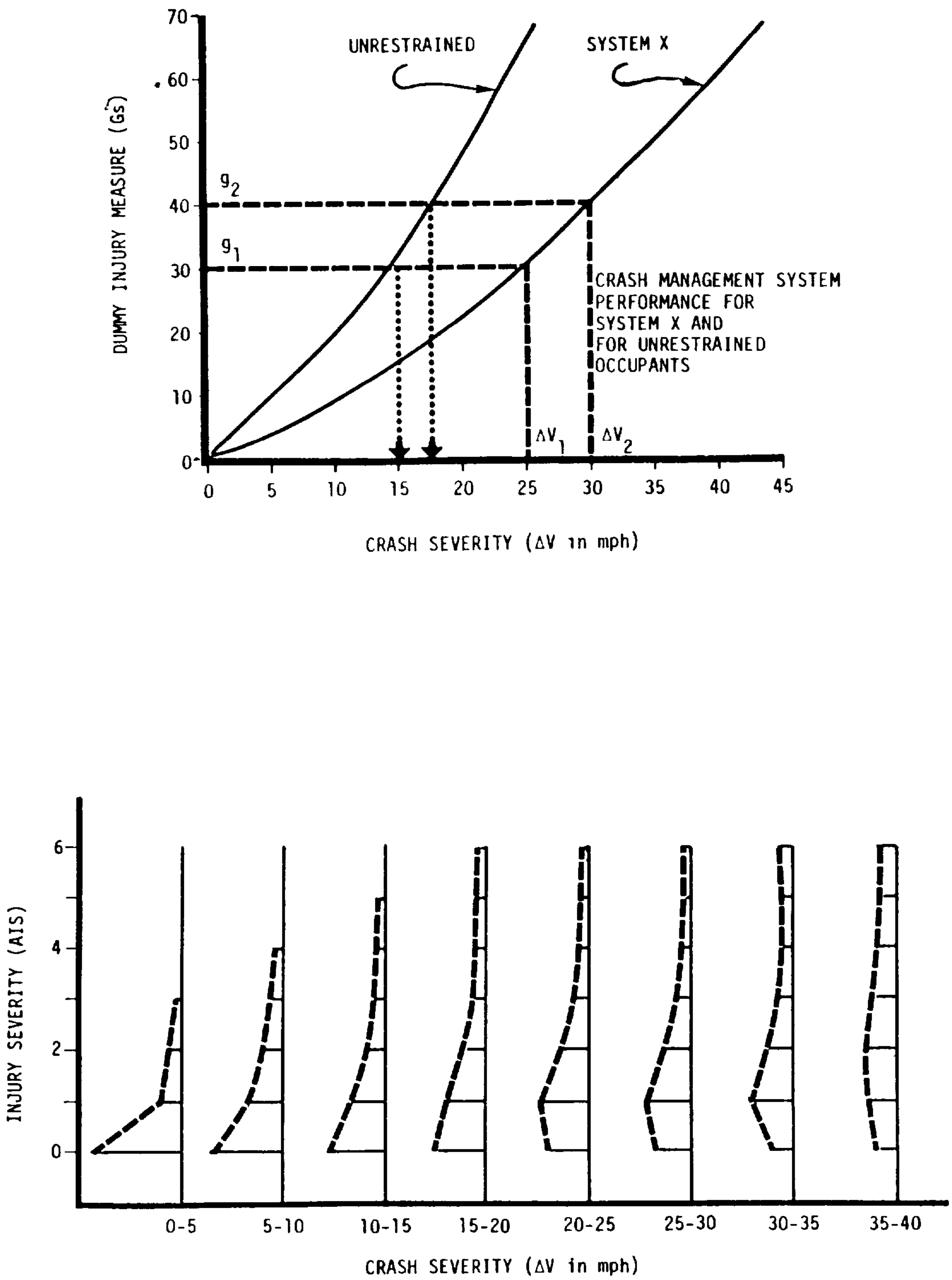


FIGURE 12-1. ILLUSTRATION OF THE COMPUTATION OF INJURY SEVERITY DISTRIBUTION FOR RESTRAINED OCCUPANTS

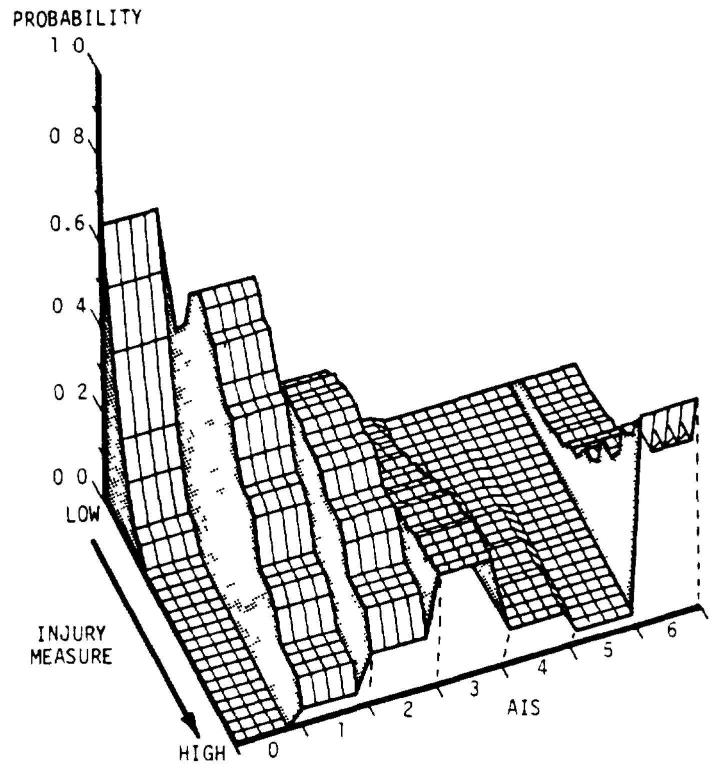


FIGURE 12-2. TRANSFORMATION BETWEEN DUMMY INJURY MEASURE AND INJURY LEVEL

12.3 BRAKE ALGORITHM

The Kinetic Research BRAKE Algorithm was designed to investigate the pre-crash environment of automobile accidents. BRAKE works in conjunction with the KRAESP model to determine to what extent advanced collision avoidance systems reduce impact speeds (or avoid accidents altogether) and to compute the estimated reductions of injuries and fatalities after such systems are introduced into the automobile population. The BRAKE Algorithm was especially designed to evaluate advanced, radar-activated braking systems similar to the one developed for the high technology RSV. Its input includes measures of the radar activation range and of the brake system performance (maximum deceleration). The algorithm makes a number of assumptions about how, when, and under what conditions the system operates, and is constructed so that these assumptions can be easily changed as circumstances dictate.

The algorithm processes a data file on a case-by-case basis. For every accident, BRAKE first determines if the advanced braking system would have had any effect, and, if it would, then calculates a new impact speed (which may equal 0). After evaluating each case, the algorithm compiles two V_{rel} distributions for the accident file - one with and one without the braking system. The user can use these distributions as they come out, or can input them into the KRAESP model (preferably after smoothing the data).

Some of the more important assumptions made by the BRAKE Algorithm are

- Only case vehicles (given VC,M,Y) are equipped with the system.
- The radar will activate the brakes only on straight, flat roads.
- The radar will activate the brakes only in collinear collisions. For a collision to be collinear, the case vehicle must have sustained its primary damage in the 12 o'clock position, and, in vehicle-to-vehicle impacts, the other vehicle must have sustained its primary damage in either the 6 or 12 o'clock positions.
- Other conditions being satisfied, the radar will activate the brakes at the range (r) specified for the system, assuming that they had not yet been activated at that time.
- The time measured from the instant braking begins to the moment of impact does not change when advanced braking is considered, except in cases where the brakes are radar activated.
- Damage areas and impact force directions are not affected in any case. (Of course, the severity of damage may be.)
- Each braking system has performance levels for wet and dry pavement.

These assumptions, and the BRAKE Algorithm itself, were constructed to process the MDAI file. Consequently, the algorithm includes adjustments to remove biases in those data. A number of changes would be required before using other data files.

12.4 PROPERTY DAMAGE ALGORITHM

Kinetic Research also developed an algorithm to estimate the effects of introducing specific property damage systems into the automotive accident environment. The property damage algorithm gives the KRAESP model the capability of calculating the combined repair costs of a fleet of vehicles (VC,M,Y) that are equipped with a specific property damage (e.g., bumper) system (PD) and operated over a given impact year (I). By comparing these costs with the repair costs of the same fleet equipped with a conventional system, we can make a benefit/cost analysis of the new system.

As mentioned in Subsection 12.2, the KRAESP model will compute injury level probabilities for a given accident. In conjunction with the property damage algorithm, it will also compute the average repair cost ($\$_{ave}$) for the case vehicle in that accident. The term "given accident" here refers to an accident of given mode (IM), damage area (DA), severity (ΔV) and year (I) involving a specific case vehicle (VC,M,Y) equipped with a given property damage system (PD).

Average repair cost is a strong function of delta-V, and we expect the relationship between the two to look something like Figure 12-3. Repair cost functions similar to Figure 12-3 may be constructed from either crash testing or theoretical considerations, and the user must supply them as inputs to the model. KRAESP will then use the repair cost functions, the delta-V distributions and the number of accidents (N_a) to compute the repair costs for the specific vehicle fleet.

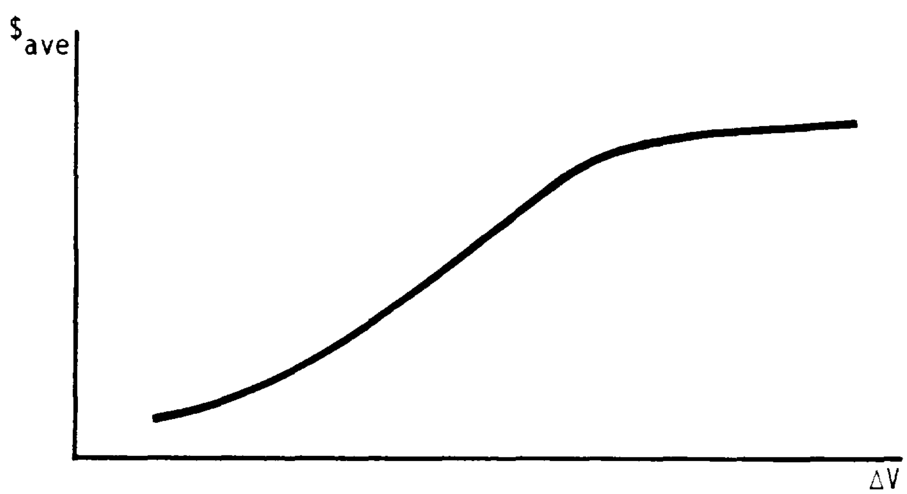


FIGURE 12-3. AVERAGE REPAIR COST VERSUS CRASH SEVERITY

There is an important consideration, however, which prohibits the use of conventional KRAESP delta-V distributions for repair cost calculations. In the analysis of injuries and fatalities, researchers generally use a V_{rel} distribution derived from towaway accident data. But a substantial amount of the property damage is incurred in non-towaway accidents. It follows that a towaway accident V_{rel} distribution would be too biased toward severe accidents to satisfactorily analyze property damage costs.

Kinetic Research therefore developed a technique to obtain a V_{rel} distribution from insurance claim data. (Insurance claim data are much more representative of real world property damage costs than towaway accident data – although they still are somewhat biased, because unreported accidents are not included.) The technique is as follows: a probability distribution ($P_\$$) of dollar loss for the case vehicle (such as shown in Figure 12-4) is compiled from insurance data and entered into the algorithm. The assumption is then made that the cost of repairing a case vehicle after an accident of given severity is always equal to the average repair cost for that severity. In the real world, of course, some losses will be greater and others less than the average. Nevertheless, this assumption is necessary for the analysis of the insurance claim data.

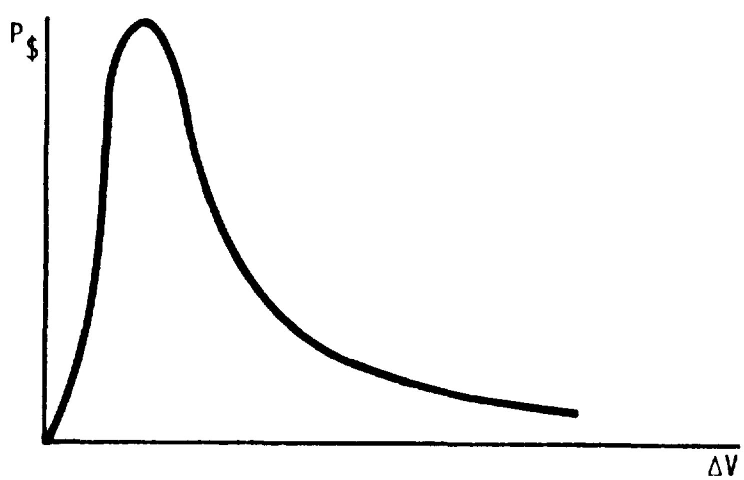


FIGURE 12-4. PROBABILITY OF REPAIR COST

If every ΔV is readily translatable into some $\$_r$, then the reverse also holds true. Given a $\$_r$, we can compute a ΔV (from Figure 12-3). Consequently, we can substitute ΔV for each $\$_r$ in Figure 12-4 and obtain the ΔV distribution shown in Figure 12-5.

FIGURE 12-5. CRASH SEVERITY PROBABILITY DISTRIBUTION

The final step is to convert the ΔV distribution into a V_{rel} distribution. This only requires that we know the weights of the case and "other" vehicles. Unfortunately, insurance claim data do not include the weights of the other vehicles, so they must be estimated. For the sake of simplicity, it is assumed that the other vehicle's weight is always equal to the mean weight of all vehicles. (Note: when KRAESP calculates ΔV distributions from the V_{rel} distribution obtained here, it will not make this assumption.) Therefore, V_{rel} can be calculated via the formula:

$$V_{rel} = \frac{m + m_{ave}}{m_{ave}} \Delta V \qquad ,$$

where m_{ave} is the average weight of vehicles in the period of the insurance claim data. Finally, the application of this equation to the function in Figure 12-5 yields the V_{rel} distribution in Figure 12-6.

Kinetic Research has compiled probability functions for repair costs from 1973 accident data that encompass four vehicle classes and three impact modes. These functions, and the results of a number of vehicle-to-vehicle crash tests, were input into the property damage algorithm. The algorithm output, tabulated in Reference 23, consists of a V_{rel} distribution for each combination of vehicle

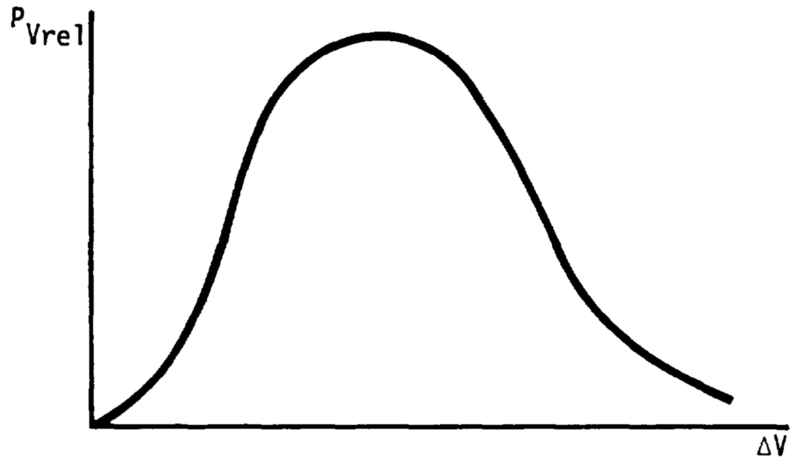


FIGURE 12-6. RELATIVE VELOCITY PROBABILITY DISTRIBUTION

class and impact mode. Each V_{rel} distribution can now serve as a basis for computing the repair costs of vehicle fleets whose property damage system characteristics are known.

12.5 REAR IMPACT STUDY

Early in the RSV Program, Kinetic Research constructed (on a quick response basis) a methodology to estimate the future societal costs of rear impacts. The relationship of losses to relative velocity and crash severity and the effects of increased rear seat occupancy were examined for compact (1400 to 2400 pound) cars in the 1985 accident environment.

The study's methodology, outlined in Figure 12-7, is similar to that of the KRAESP model. (This task was completed before KRAESP became operational.) A V_{rel} distribution, assumed to be independent of vehicle class and impact year, was obtained from adjusted MDAI data. The DeLorean estimates (Reference 24) of the 1977 and 1985 vehicle population distributions (by weight) were adjusted to include an earlier Minicars projection (Reference 22) of future truck populations. The study only considered cases whose primary horizontal damage, was in the rear of the car, was the result of a vehicle-to-vehicle impact, and was caused by an impact force with a direction from 5 to 7 o'clock.

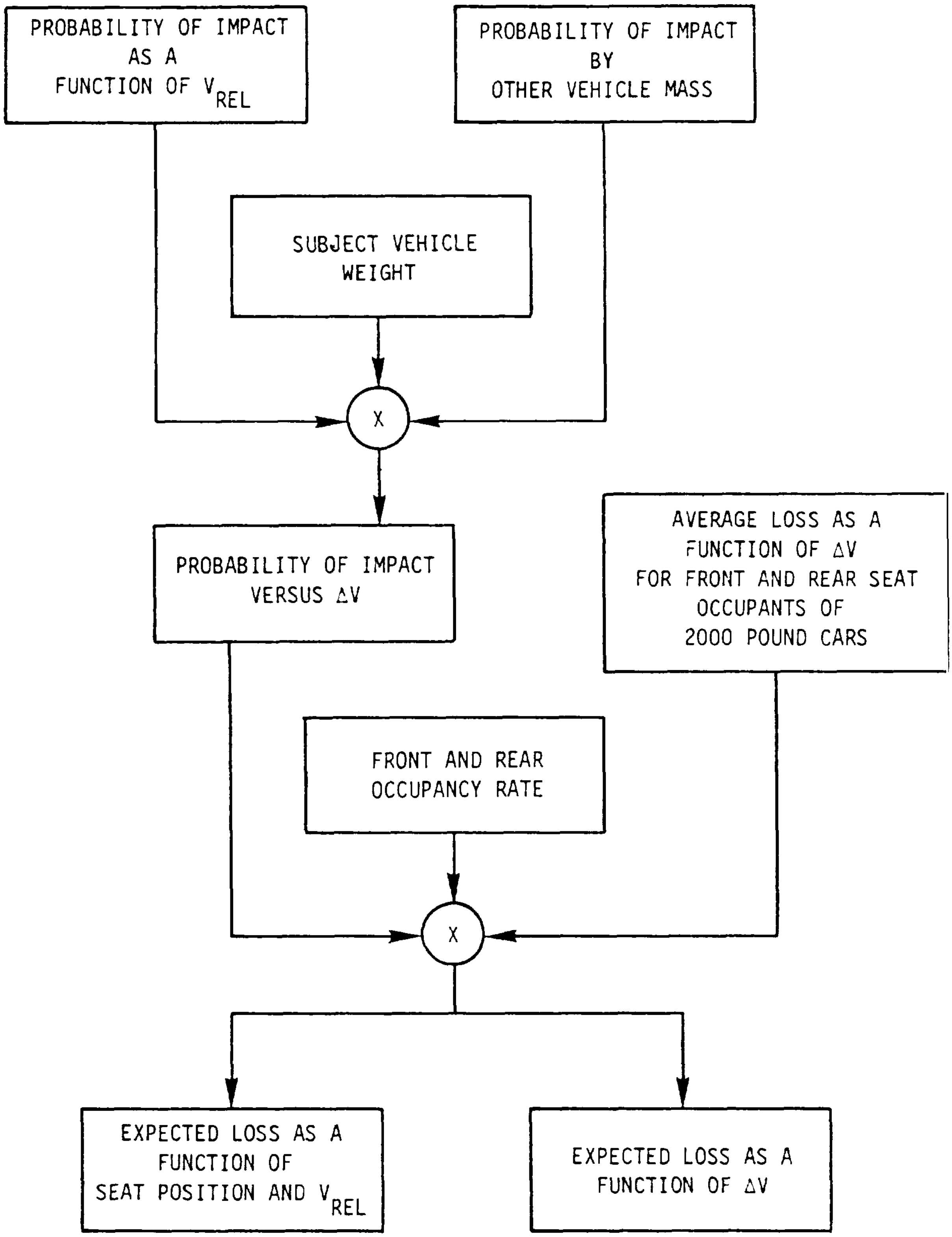


FIGURE 12-7. OUTLINE OF REAR IMPACT STUDY METHODOLOGY

By applying the above to these data, we computed the vehicle-to-vehicle rear impact delta-V distributions for compact cars in 1977 and 1985. An average loss (societal cost), obtained from earlier work in the RSV Program (Reference 22), was then assigned to each level of delta-V. These calculations were made for each seat position, so that the effects of changes in front and rear seat occupancies could be evaluated.

It was recognized that the study's validity was lessened by the scarcity of rear impact data in the MDAI file. Losses in rear impacts only accounted for 4.3 percent of the total societal loss in 1977, a fact that accounts for the RSV Program's emphasis on occupant protection in front and side impacts. We therefore caution against any excessive reliance on the results presented here and suggest that any further study of the rear impact environment be based on more comprehensive data, such as the NCSS or National Accident Sampling System (NASS).

Still, the rear impact study provided some interesting insights into the relationships between seat position, impact mode, and crash severity – for instance:

- For delta-V less than 25 mph, a front seat occupant will receive injuries of equal severity in front and rear impacts.
- For delta-V greater than 25 mph, a front seat occupant is likely to receive injuries of greater severity in rear impacts than in front impacts. At high delta-Vs, the average loss in a rear impact is 50 percent higher.
- For delta-V less than 20 mph, a front seat occupant is likely to be more severely injured than a rear seat occupant. This may be due to the presence of hard objects (windshield, steering wheel, etc.) in the front seat area; occupants often strike these objects in secondary impacts.
- The injury levels of rear seat occupants increase dramatically above 20 mph delta-V. At higher delta-Vs, in fact, a rear seat occupant can expect to receive the same high injury levels as would a nearside occupant in a side impact. This could be explained either by the

failure of front seat backs or the presence of intrusion into the rear passenger compartment.

The front and rear seat occupancy rates in 1977 were 1.43 and 0.22. Due to increasing automobile operating costs (and other forces encouraging car-pooling), it has been suggested that rear seat occupancy may increase in the future. Consequently, the rear impact study analyzed the 1985 accident environment for alternative rear occupancy rates of 0.22, 0.5, 1.0 and 1.5. In each case the front occupancy rate was held at 1.5.

For a rear occupancy rate of 0.22 we found that the total rear impact losses for compact cars should decrease approximately 20 percent by 1985. (The number of accidents was assumed to remain constant.) The total losses would decrease because the vehicles which strike compact cars will steadily become lighter, making the accidents less severe (from the case vehicle's point of view). But if the rear occupancy rate doubles to 0.5, the losses will climb about 20 percent. The larger increases in occupancy will increase the losses accordingly.

When front and rear occupancy rates are 1.50 and 0.22, only 13 percent of all occupants are in the rear seats. But even in this case the rear passengers sustain fully 40 percent of all losses in rear impacts. When both front and rear seat occupancy equals 1.5 (50 percent of the occupants in the rear), the rear occupants will sustain 81 percent of all losses. If rear seat passengers are indeed becoming more common, it would be worthwhile to place more emphasis on their protection in rear impacts.

A final objective of the study was to help specify appropriate rear impact test conditions for the RSV. Crash testing is sometimes conducted at the 75th percentile level - that is, at the speed below which 75 percent of all societal loss is expected to occur. Assuming 1.5 and 0.5 front and rear occupancy rates in the 1985 environment, a compact car accrues 75 percent of all rear impact losses at V_{rel} less than 40 mph and delta-V less than 25 mph. These levels can be achieved by striking a stationary 2000 pound test vehicle with a 3300 pound vehicle traveling at 40 mph. The conclusions about the test conditions are not affected significantly by changes in rear seat occupancy.

12.6 PASSIVE RESTRAINT IMPLEMENTATION STUDY*

While the KRAESP program was being developed, Minicars and Kinetic Research used it to study the effects of introducing passive restraints into the future automobile fleet. Only front impacts (11, 12 and 1 o'clock positions) were considered. This work, which was conducted early in 1977, aided the NHTSA in formulating the passive restraint mandate that was subsequently written into Federal Motor Vehicle Safety Standard (FMVSS) 208. The study is noteworthy because it was the first effort to analyze the simultaneous time phasing of a variety of restraint systems (having different performance and usage characteristics) throughout a range of vehicle classes and seating positions, and the first to quantify injury and fatality reductions based on the relationship of injury probability distributions to restraint structure performance quantified by dummy injury measures.

The study is not, however, the last word on the subject. While the methodology is quite thorough and complete, there are serious shortcomings in some of the data used. Most importantly, the work was based on the MDAI file, which contains a number of well known biases. Although we have applied the best available adjustments (Reference 4) to the data, other data bases, such as the NCSS files, should allow future studies to be even more realistic.

Traffic Environment Projections

Our study used traffic environment projections which were provided by the NHTSA (Reference 25), or which were derived from References 24, 26, 27, 28, 29 and 30. Between 1977 and 1990, total auto sales were projected to rise by 27 percent (a compounded rate of 1.9 percent per year), the number of autos on the road to rise by 22.8 percent, and the exposure of these vehicles to accidents to rise 23.5 percent. The market shares of sales showed a slight shift away from large cars (intermediate and full-size) toward small cars (minis, subcompacts and compacts): the small/large sales mix changed from 0.497/0.503 in 1977 to 0.514/0.486 in 1990. However, the weights of vehicles in all classes showed a remarkable decline by 1990 (due primarily to fuel economy pressures). The percentage changes in vehicle weights and accident exposures, by vehicle class, are shown in Table 12-2.

*This study was conducted in 1977.

TABLE 12-2. RELATIVE CHANGES BETWEEN 1977 AND 1990 BY CAR CLASS (PERCENT)

Auto Class	Weight of New Vehicles Sold	Exposure-Weighted Mean Weight for Car Population	Accident Exposure Rate
Mini	-3.30	-4.67	+350.00
Subcompact	-17.40	-6.56	+24.36
Compact	-17.38	-9.90	-10.50
Intermediate	-22.27	-17.44	+24.60
Full-size	-14.09	-16.60	-48.41

Implementation Schemes

We evaluated the benefits that would arise from the following hypothetical rule:

1. Passive driver restraints installed in all full-size cars in 1981
2. Full front (driver and passenger) passive protection in all minis in 1981
3. Passive driver restraints in all cars in 1982
4. Full front (driver and passenger) passive protection in all cars in 1983.*

Between 1977 and 1990 there might be any number of different restraint system designs that satisfy this rule. To make the problem manageable, we subdivided the designs into six categories. These categories were coded 0 through 5, as follows:

*The Department of Transportation eventually ruled that all cars manufactured after September 1, 1983 must have full front passive protection.

Code

0 Base three-point harness system (employed in current automobiles). Usage rates and performances of such systems are expected to remain at the 1976 levels. This is the only system that does not satisfy the passive restraint requirement.

1. 1972 GM Air Cushion Restraint System (ACRS), which was engineered for limited mass production and built into 10,000 full-size General Motors cars between 1974 and 1976. This system would be the easiest to design into existing cars, and thus would represent the earliest air cushion systems used by manufacturers.

2. Modified 1972 GM ACRS is the same as Item 1, but also includes recent technological developments that can be incorporated without extensive redesign.

3. Advanced ACRS uses near state-of-the-art technology, which could be designed into cars with sufficient lead time (presumably at model changes). Minicars has demonstrated that air cushions can provide occupant protection (as defined by FMVSS 208) at speeds in excess of 40 mph in most automobile classes.

4. Passive belt system, as used in the Volkswagen Rabbit. We expect that in the near term most manufacturers will use similar systems in small cars.

5. Advanced passive belt system uses near state-of-the-art passive restraint technology. Minicars has demonstrated that occupant protection is possible at speeds in excess of 30 mph.

We refer to Systems 1, 2 and 4 as "prior technology" systems, even though they may now be in production. Systems 3 and 5 are "current technology" (1977) systems, even though they are not yet in production. "Advanced technology" systems with still higher performance levels were not considered in this analysis, although the RSV Program has already demonstrated their feasibility.

Performance estimates for each of these systems were obtained through a combination of experimental (car crash) results, computer simulations and engineering judgment (Reference 31). The latter two were needed because crash data for existing systems did not cover the required velocity range, and because certain systems have not yet been engineered into all of the vehicle classes.

Estimates were made for three classes of vehicles: mini, compact/subcompact and intermediate/full-size. The expected performance (measured in chest acceleration levels) of the "prior technology" and "current technology" air cushion systems is shown in Figure 12-8.

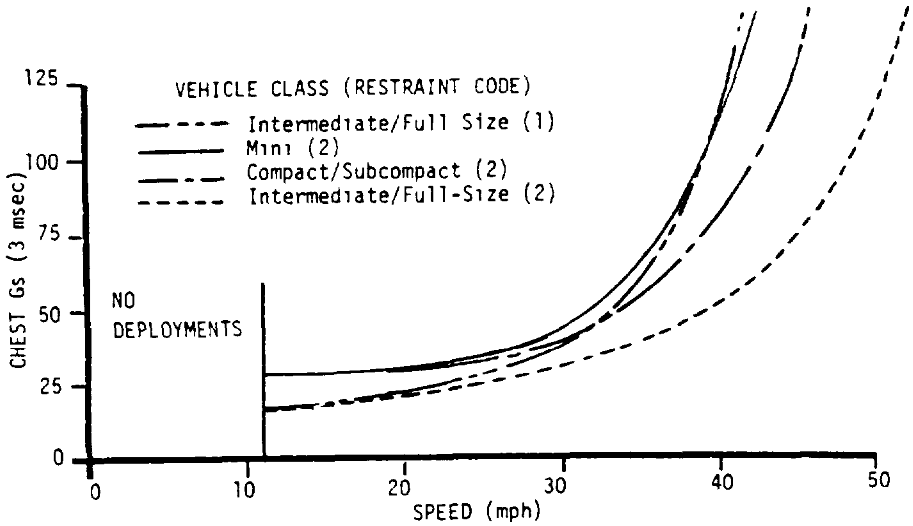
Because costs and benefits vary significantly between systems, it is important to know which ones the automakers will use to satisfy the passive restraint mandate. Unfortunately, the manufacturers themselves did not know which systems will go into their cars in the mid-1980s. Therefore, in addition to evaluating different passive restraint mandates, we also evaluated different responses to those mandates (Reference 31).

We first formulated a "prior technology" implementation scheme. This scheme is based on the assumption that manufacturers will use prior technology restraint systems (Systems 1, 2 and 4) to comply with the mandate, but, once the mandate is satisfied, will choose not to incorporate more advanced systems into later models.

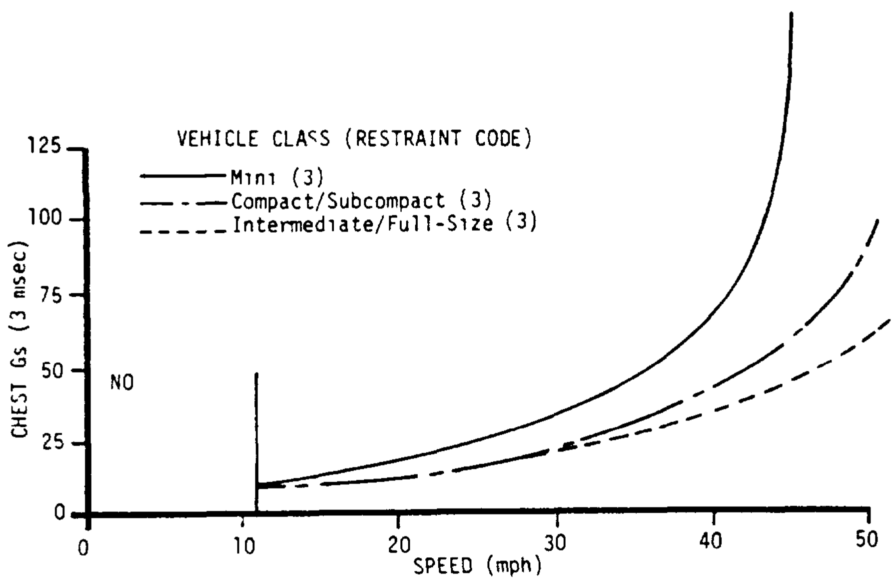
The second scheme was a more ambitious "current technology" approach. This scenario is similar to the first scheme in the mandate's early years, but later the manufacturers turn to systems with higher performance levels (using Systems 3 and 5). For instance, industry might choose, on their own initiative, to upgrade performance to provide their customers with greater value or reduced costs. Alternatively, they might be forced to do so by a revised passive restraint mandate.

The third implementation scheme was based on System 1. Here, the manufacturers would comply with the mandate simply by installing, in all automobiles, systems with the characteristics of the 1972 General Motors ACRS. This scheme was formulated in order to compare the predictions of benefits with other estimates that have been made.

The three implementation schemes are illustrated for the driver side only in Table 12-3. The schemes for the passenger restraint systems are identical to those for the driver, except for the short delay in implementation allowed by the rule. Some of the considerations affecting the formulation of the schemes were:



(a) "Prior Technology" Air Cushion System



(b) "Current Technology" Air Cushion System

FIGURE 12-8. AIR CUSHION SYSTEM PERFORMANCE

TABLE 12-3. DRIVER RESTRAINT IMPLEMENTATION SCHEMES

	Current Technology							Continuously Upgraded							1972 GM Passive Restraint						
	1977 1980	1981	1982	1983	1984	1985	1986 1990	1977 1980	1981	1982	1983	1984	1985	1986 1990	1977 1980	1981	1982	1983	1984	1985	1986 1990
<u>GM</u>																					
Mini	0	4	4	4	4	2	2	0	4	4	4	4	3	3	0	1	1	1	1	1	1
Subcompact	0	0	2	2	2	2	2	0	0	2	2	2	3	3	0	0	1	1	1	1	1
Compact	0	0	1	1	2	2	2	0	0	1	1	3	3	3	0	0	1	1	1	1	1
Intermediate	0	0	1	2	2	2	2	0	0	1	3	3	3	3	0	0	1	1	1	1	1
Full	0	1	2	2	2	2	2	0	1	2	2	2	2	3	0	1	1	1	1	1	1
<u>Ford</u>																					
Mini	0	4	4	4	2	2	2	0	4	4	4	4	4	3	0	1	1	1	1	1	1
Subcompact	0	0	4	4	2	2	2	0	0	4	4	3	3	3	0	0	1	1	1	1	1
Compact	0	0	1	2	2	2	2	0	0	1	2	2	2	3	0	0	1	1	1	1	1
Intermediate	0	0	2	2	2	2	2	0	0	2	2	2	2	3	0	0	1	1	1	1	1
Full	0	1	2	2	2	2	2	0	1	1	1	1	3	3	0	1	1	1	1	1	1
<u>Chrysler</u>																					
Mini	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subcompact	0	0	4	4	4	4	4	0	0	4	4	4	4	5	0	0	1	1	1	1	1
Compact	0	0	4	4	4	4	4	0	0	4	4	4	3	3	0	0	1	1	1	1	1
Intermediate	0	0	1	1	1	1	2	0	0	1	1	1	1	3	0	0	1	1	1	1	1
Full	0	1	1	1	1	1	2	0	1	1	1	1	1	3	0	1	1	1	1	1	1
<u>AMC</u>																					
Mini	0	4	4	4	4	4	4	0	4	4	4	4	4	5	0	1	1	1	1	1	1
Subcompact	0	0	4	4	4	4	4	0	0	4	4	4	4	5	0	0	1	1	1	1	1
Compact	0	0	1	2	2	2	2	0	0	1	1	1	3	3	0	0	1	1	1	1	1
Intermediate	0	0	1	1	1	1	2	0	0	1	1	1	1	3	0	0	1	1	1	1	1
Full	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<u>Foreign</u>																					
Mini	0	4	4	4	4	4	4	0	4	4	4	4	4	5	0	1	1	1	1	1	1
Subcompact	0	0	4	4	4	4	4	0	0	4	4	4	4	5	0	0	1	1	1	1	1
Compact	0	0	2	2	2	2	2	0	0	3	3	3	3	3	0	0	1	1	1	1	1
Intermediate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
Full	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

<u>Legend</u>

0 = Base three point harness
1 = 1972 GM Air Cushion Restraint System (ACRS)
2 = Modified GM ACRS
3 = Advanced ACRS
4 = Current passive belt system
5 = Advanced passive belt system

- Whenever possible, the manufacturers will phase in new restraint systems at model changes. Our estimates of the timing of model changes are, of course, highly subjective.
- The larger manufacturers will be the first to bring more advanced technologies into production.
- The low seat belt usage rates and the public's rejection of the seat belt/ignition interlock rule suggest that the public may reject passive belts as well. This concern will cause industry to favor air cushion systems, despite their higher costs. We also feel that the price elasticity of federally mandated safety systems will be low, as has been observed with emissions systems. This consideration will likewise tend to negate the cost advantages of belts.
- Foreign automakers will tend to favor belts over airbags because belt systems will already be designed for the cars they sell outside the United States.

The benefits of passive restraints are measured by the reduction of injuries and fatalities that would occur if they were implemented into the automotive fleet. Accordingly, it is necessary to know how many injuries and fatalities would occur without a passive restraint mandate. We therefore specified a baseline implementation scheme in which the current three-point harnesses (System 0) are retained in all vehicle classes indefinitely. Of course, the baseline does not correspond to current injury and fatality levels, because these levels will continue to change (as functions of total sales, market shares, vehicle weights and vehicle usage).

Benefit Calculations

Our results for the three schemes are shown in Figures 12-9, 12-10 and 12-11. The widths of the bands represent uncertainties in relating dummy injury measurements to the probability of human injury severities. (These uncertainties are partially due to differences in torso load distribution between unrestrained occupants, belted occupants and airbag protected occupants.) The cumulative (1977 to 1990) reductions in injuries and fatalities are shown to the right of each curve.

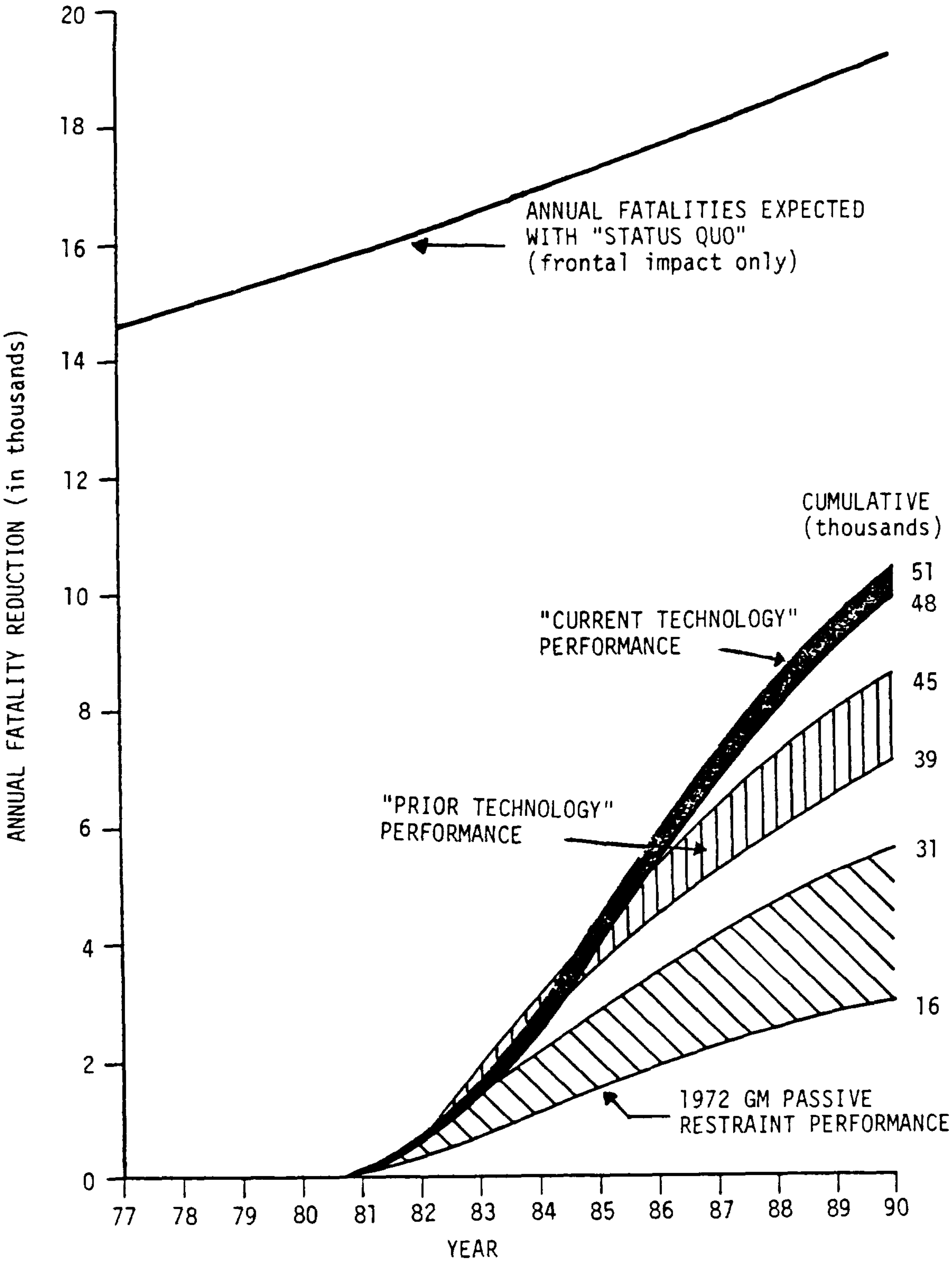


FIGURE 12-9. FATALITY REDUCTIONS

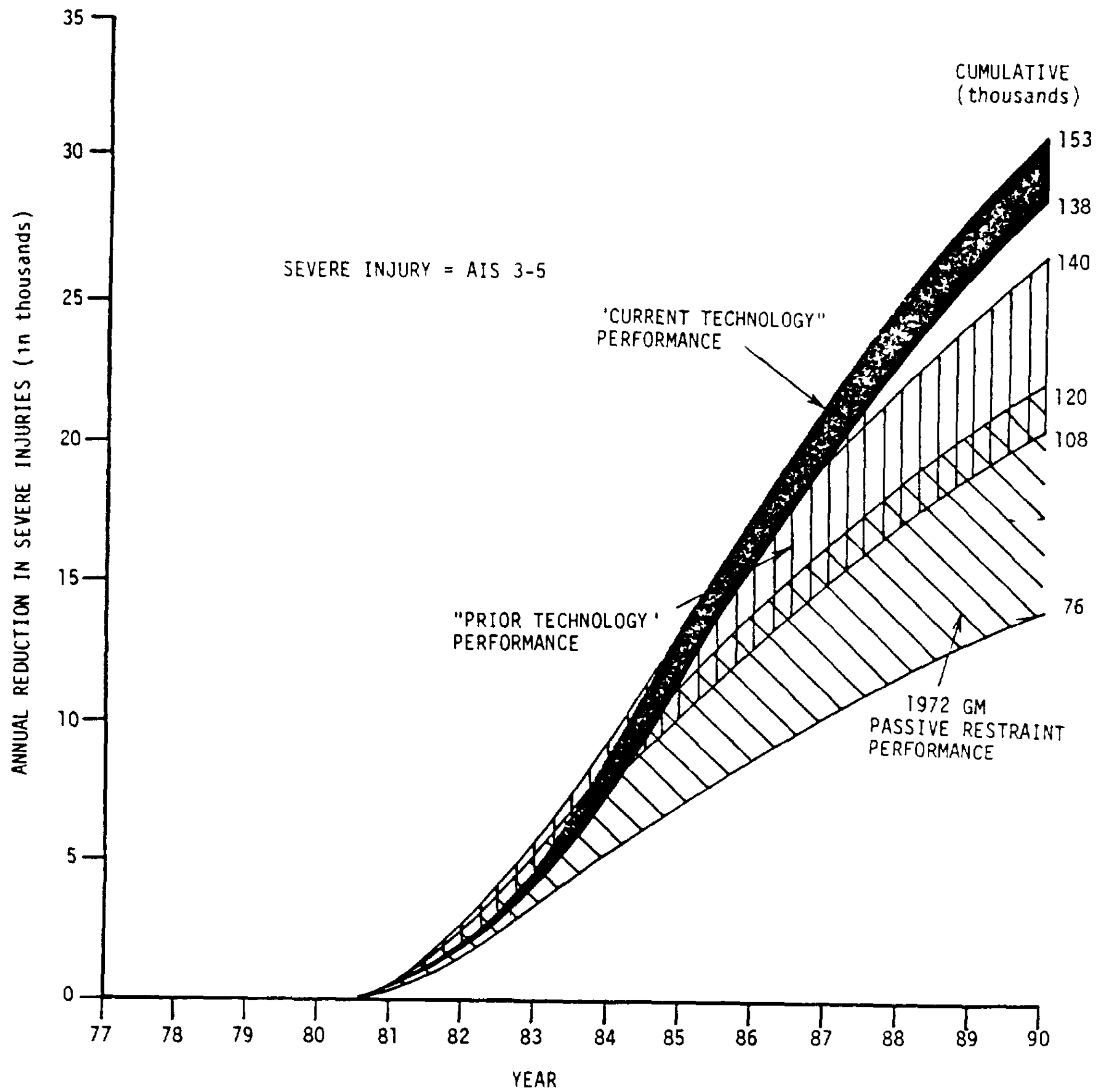


FIGURE 12-10. SEVERE INJURY REDUCTIONS

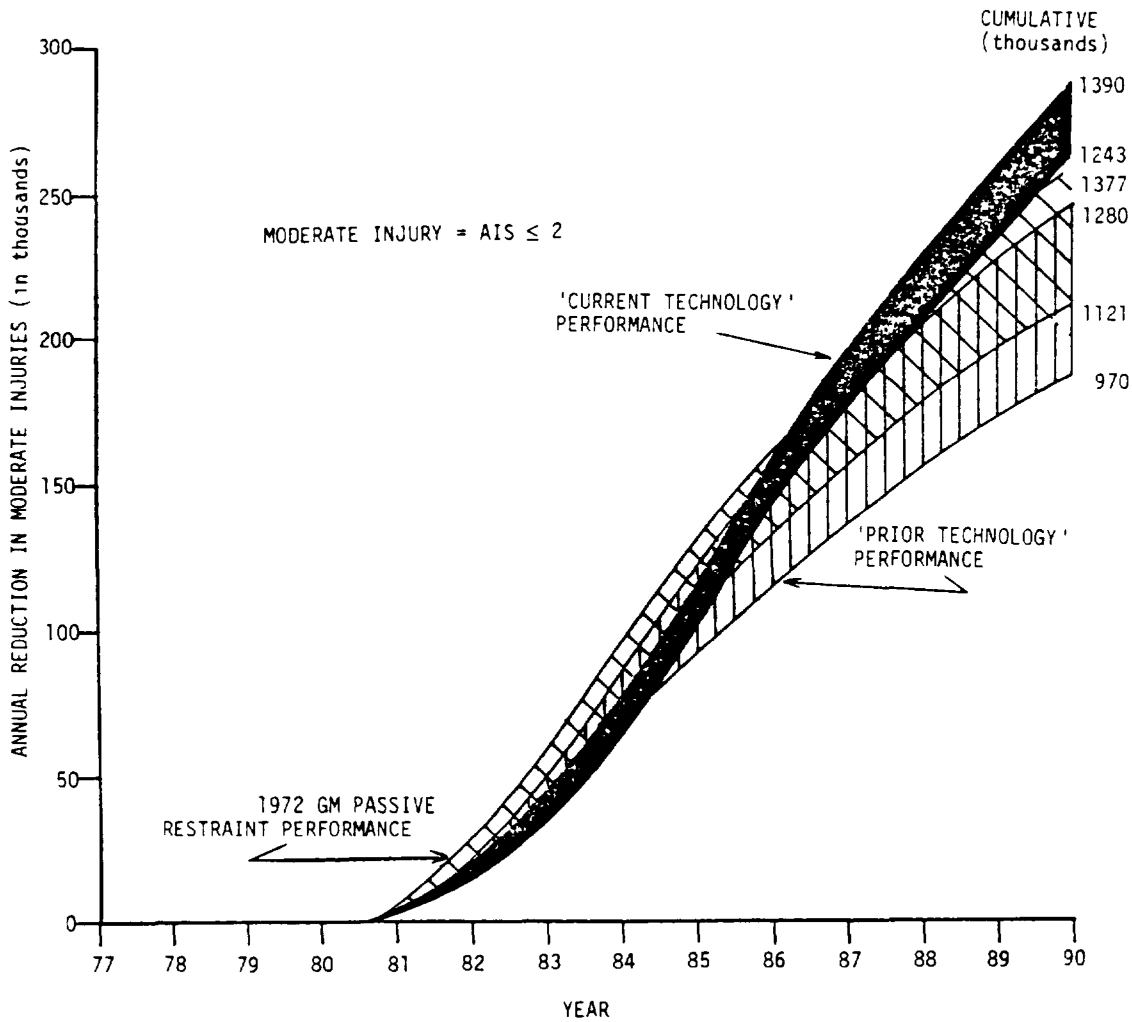


FIGURE 12-11. MODERATE INJURY REDUCTIONS

We would like to point out that these calculations are based on 1976 statistics, which show 1.4 million automotive injured.

It is important to note that none of the benefits – fatality, severe injury or minor injury reductions – reaches a steady-state condition by 1990. Even if vehicle sales, market shares and weights were static after 1985, the benefits would not reach a steady-state condition until at least the year 2000, because of the time required to move old vehicles out of the vehicle population. (The scrappage of any given model year actually extends over a 25 year period.) Obviously, the steady-state benefits (as estimated in other studies) should exceed the transient benefits calculated in this study.

It should also be noted that the benefits calculated here were wholly for front impacts; no benefits were calculated for side impacts, rear impacts or rollovers.

SECTION 13
RSV PROTOTYPE PRODUCTION

The RSV prototype production differed considerably from high volume production. The RSV prototypes were virtually hand built, and the investment in equipment and tooling was minimal. Consequently, it took approximately 3000 labor hours to complete an RSV from the ground up (and that does not include the manufacture of the engine, transmission, suspension and other Original Equipment Manufactured (OEM) parts).

The Budd Company and Response Motors conducted high volume production studies of the RSV. Both showed that the RSV production methodology already incorporated a number of innovative features that would be easily adaptable to high volume production: the extensive use of straight sheet metal sections in the body in white, the use of sheetmetal that is primarily of a single gauge, the metal-foam integral structure, and the reaction injection molded body glove parts (including the front and rear fenders and fascias).

On the other hand, some designs caused considerable difficulties in prototype production. The best example is the gullwing door. This door still has to be thoroughly production engineered to improve its producibility.

The RSV prototype production consisted of five major operations:

Body in white manufacture and assembly
Foaming and priming operations
Subsystem fabrication and assembly
Painting operations
Quality control inspections.

The first four operations took place sequentially. The fifth was conducted throughout the manufacturing process. Then, after each RSV was complete, it went through a final road test and inspection before being presented for acceptance to the NHTSA. All of the production procedures and quality control tests and results were checked and accepted by an on-site NHTSA representative.

13.1 BODY IN WHITE MANUFACTURE AND ASSEMBLY

The body in white is composed of 335 semi-finished metal parts, formed primarily by press brake. These parts may be divided into underbody members, body subassemblies, and roof sections. The body in white is carefully inspected after each of its assembly stages, and, when the structure is complete, it is fully primed and sent on to the foaming process.

13.1.1 Underbody

First the floor pan is fabricated from sheet steel. To this pan are welded hat section stiffeners running longitudinally along the bottom of the pan. The forward tunnel, rear tunnel, front seat riser, rear seat riser, transmission control mounting bracket and fuel cell cover are then fabricated separately (with doubling and reinforcement panels installed) and welded together to form a "spider" of sections that compose the upper surfaces of the floor pan. This spider is aligned with the floor pan using jigs, squared, then riveted in place and welded.

The floor pan serves as the foundation for the remaining parts of the body in white. The vehicle is built up, more or less vertically, from the floor pan to the roofline. The first parts to be welded to it are the firewall, the rear suspension forward mounts, the various brackets and mounts for the fuel pump, the rear seat restraint, the battery compartment, etc. After the forward bulkhead assembly is fabricated, it also is jigged to the floor pan, riveted and welded to the front of the pan. Then come the vertical side rails, which run from the front of the bulkhead through to the rear suspension rear mounts, and the upper section of the rear seat riser, which ties the side rails together laterally.

13.1.2 Body Subassemblies

To the rear end of the side rails is attached the rear subassembly, which both stabilizes the ends of the side rails and begins the structure that will enclose the engine. The hatch crossmember is then welded (through four vertical posts) to the top of the subassembly, the rear quarter panels fabricated and welded to the side rails, the subassembly and the hatch crossmember, and the rear seat upper welded between the quarter panels, thus closing the sides of the engine compartment.

Before the rear quarter panels are attached, the rocker panels and A and C pillars are fabricated and welded to the outsides of the side rails. The rear quarter panels then have forward attachment points on the C pillars, thus forming the rear interior compartment walls.

In the front, the floor of the trunk is first welded to the side rails and other front bulkhead members, the front spring well and the vertical wheelhouse panel are fabricated and welded to the outside edges of the trunk floor and side rails, and finally a close out panel on the front of the section closes the compartments so that they may be foam filled. The vertical wheelhouse panels link the A pillars to the firewall, thus starting the integration of the front section of the interior compartment. Horizontal flat panels are then welded to the edges of the spring wells and the outsides of the vertical wheelwell panels to form the tops of the wheelwells. To these panels are attached two three-panel sections forming trapezoidal boxes above the wheel houses. These boxes will also be foam filled, to form the upper loading members that provide protection in front crashes.

With these assemblies, the main body sections of the body in white are complete. The remaining panels and parts are brackets and close out panels, the latter being used primarily to finish the box sections that will contain the crushable foam.

The front nose assembly is fabricated as a separate bolt on section (bolted on so that it may be removed easily when damaged in 10 to 20 mph crashes). This assembly is composed of four closed compartments (again, for foam filling) that surround the radiator. The radiator brackets and the mounting plates for bolting the nose to the vehicle are attached, but the nose is not bolted on until after the vehicle is painted, near the end of the car's production. In the meantime it is treated as a separate part of the car, being foam filled, primed, painted and detailed when the rest of the car goes through these processes.

13.1.3 Roof Sections

Before any of the roof panels or upper pillars are installed, the entire body is mounted in a jig specifically constructed for precisely locating the door openings. In this jig the inner and outer panels of first the A pillars (and their headers), then the B pillars (and their headers), and finally the C pillars (and the hatch opening frame) are welded on the body.

The basic roof structure is constructed as a subassembly with side rails, hat sections and door hinge plates. The subassembly is welded to the pillars while they are still in the positioning jig. The roof structure is covered with the roof skin only after an inspection shows that the structure matches the design. The jig may then be removed.

The body in white is completed by welding on the windshield and rear window fences and pillar covers.

13.2 FOAMING AND PRIMING OPERATIONS

13.2.1 Foaming

When the body inspection is complete, it is sent to the foaming facility. There the crushable compartments in the structure are filled with energy absorbing foam. The foam used throughout the RSV body structure has a density of 2 pounds per cubic foot.

The chemicals are mixed in a specialized foam production machine. The machine delivers liquid foam per unit of time, not volume or weight, so the volumes of the compartments to be filled are carefully calculated and the times needed to fill them are precisely measured during the foaming operations. The mixing process is quite temperature and humidity sensitive. Thus our procedure is to conduct pour tests immediately before a car is foamed and to use those tests to determine the density and rise characteristics of the foam under the prevailing conditions. Usually the conditions in the plant vary only minimally, but for large compartments there can be significant differences in the time required to fill without overfilling.

The foam is produced by an exothermic reaction between isocyanate-papi-27 and six part resin that causes the mixture to rise. The foam mixing machine used at Minicars is an Admiral Equipment Company Model K500 2p equipped with an ATC Model 4000 control/delivery head. The machine is calibrated for the correct mixture before each foaming operation. The chemicals are delivered unmixed but in the correct proportion (143.8:120 resin:ISO) from the delivery head. The pour times are calculated from a flow rate of 159 to 161 grams per second (a 3 second pour produces about 3 ounces of foam). Immediately after filling we cover the entry hole with tape and check the sight holes and bend relief holes for foam.

The major problem with the process is the leakage of foam from the compartments. Bend relief holes at or near the bottoms of voids are certain to leak, as are most spot welded seams (especially improper welds containing even very tiny penetration holes). Most of these areas have to be caulked (and sometimes taped) before foaming. The caulking is done with a standard caulking gun and fast drying vinyl or latex compound. The caulk is allowed to dry 60 minutes before taping. The foaming process can start immediately thereafter.

All foaming procedures are conducted under carefully regulated safety conditions. The workers are fully covered in protective suits, including hoods with filtration masks. It is a special precaution that all vapors are fully filtered before anyone is allowed to smoke a cigarette in the area. (When isocyanate vapors pass through a burning cigarette, cyanide gas is created.)

In full production manufacturing there would be no need to inject the foam directly into the vehicle structure. The liquid foaming process was employed in the Minicars prototype production chiefly for the convenience of research and experimentation. It allowed, for instance, the foam densities in different parts of the car to be readily varied for specific tests. As it turned out, however, the advantages of varying densities were minimal, and a constant 2 pounds per cubic foot was determined to be optimal throughout the RSV.

Further, optimal energy management during crashes does not require a bond between the foam and the metal, nor does it require that every nook and cranny of every compartment be filled. Consequently, the foam could be preshaped from any of various externally gassed foams (such as styrene foam), and the whole procedure of filling the compartments of the car with liquid foam could be avoided.

13.2.2 Priming

The priming process starts with a metal etching of all of the surfaces of the body with a dilute acid solution and a wipe down with an abrasive to give good primer adhesion. The entire body is then covered with a nonsanding sealer, followed by three coats of catalyzed enamel. The enamel is color coded to the final color of the particular car. After the third coat the body receives a full inspection of the paint quality and coverage. Any deficient areas are thoroughly redone. Before the body in white returns to the manufacturing process, its lower sections receive a complete undercoat with an antirust tar-based undercoater.

13.3 SUBSYSTEM FABRICATION AND ASSEMBLY

Suspension and Rack and Pinion Steering

Once the vehicle is primed, the suspension and lower steering components are mounted. First the front struts are bolted in the shock towers, the attachment brackets mounted on the underside of the car, and the strut and control arms bolted to the brackets. None of the bolts are torqued at this time; torquing to specification occurs later in the assembly sequence.

The procedure with the rear suspension is much the same. The brackets are mounted and the struts bolted, but not torqued, in place. The passenger side A-arms are not attached until the engine is installed.

The rack and pinion oil level is checked (it requires 8 ounces of 90 weight gear oil), and then the rack and pinion is bolted to its bracket assembly. The assembly is then passed into the steering tunnel (a box compartment formed through the foam-filled compartments in the front structure) and bolted down. The tie rods are attached to the front pillars, but the steering linkage is left unfinished until the steering column is installed.

Radiator Assembly

The coolant tubes are installed (using 'adel' clamps) along the left and right undersides of the vehicle and hoses are clamped to the pipes at the engine compartment ends of the tubes. The nose section can then be bolted to the vehicle and the radiator installed, or the radiator installed in it independently. In either case the procedure is to first install the lower radiator brackets, then mount the radiator on them, and finally attach the upper brackets to both the radiator and the nose. The fan assembly and wiring harness must be installed after the radiator is mounted. When the nose is attached to the vehicle, the front radiator hoses can then be cut to size and attached.

Parking Brake

First the brake pulley mount is installed at the end of the central tunnel of the RSV body. Blind nuts are welded in the body in white for this pulley. After the brake indicator lamp switch is mounted on the brake handle assembly, the assembly is installed on the body in white. Finally, the cable assembly is attached between the pulley and the rear brake calipers and the connector cable between the handle and the pulley.

Brake Master Cylinder and Booster

The master cylinder is attached to the vacuum booster, the booster to the mounting bracket, and the bracket, in turn, to the firewall. Care must be taken that the tubing inserts in the brackets are aligned and that the top bracket is adjusted for steering shaft clearance. The front bracket is then attached between the booster and the trunk floor.

The pedal assembly is installed and adjusted so that the pedal and the bell crank do not touch the firewall at the end of the pedal stroke. The brake lines are individually measured and attached from the wheel ends back toward the master cylinder. These lines are only flared after they are firmly attached and matched to the appropriate brake line hoses. The two rear lines attach to a T fitting at the engine end of the central spine. The single line then runs up the spine on the pasenger side of the shift mechanism, through the firewall and meets the front brake line at the proportioning valve.

After the brake lines are installed, the vacuum line must be run back to the engine and attached at the base of the carburetor. When all of the lines are firmly mounted, the brake reservoirs may be filled, the brakes bled and the brake pedal travel adjusted.

Fuel System

The lower cover of the fuel cell is aligned with the floor pan and the mounting holes are match drilled into the pan. After a thorough inspection, the fuel cell is installed and the filler tube, gas line and vent line are attached.

Gear Shift and Accelerator Pedal

The shift assembly and gas pedal are slightly modified OEM parts that are directly mounted on the body in white. The cables connecting them to the transmission and engine are routed through the central tunnel. Because the RSV is a rear engine car, all of the cable connections from the front to the rear of the car had to be specially designed and manufactured. At times this required a sizeable amount of research and experimentation, especially when it came to the requirement that the gear shift lever have good, firm control. The resulting cable mechanism is clearly superior (in this application) to even rod-and-balljoint designs.

Steering Column Support, Clutch Cylinder and Pedal Assembly

The column support is temporarily bolted to four welded tube inserts in the top of the cowl. The pedal assembly bracket is then bolted to the firewall and to the brake booster brackets attached to the forward side of the firewall. After the pedal assembly is modified and aligned in position, the access hole to the front compartment is marked and cut in the firewall. The rod end of the pedal assembly will pass through this hole. After the pedal assembly support is bolted to the assembly, the mounting holes are marked on the steering column support. The column support is then removed, the holes drilled, blind nuts welded on, the impact slides attached and the unit reinstalled. The impact slides must be inclined at 9 degrees from horizontal.

Heater Hoses, Antenna Cable and Speedometer Drive Cable

The heater hoses are routed from the engine compartment through the center tunnel to the heating-ventilation-air conditioner (HVAC) unit under the dash. The feed hose, which has the inline water valve for temperature control, is connected to the engine on the output side of the water pump. The return hose, which has an inline T fitting installed to allow coolant to be added to the surge tank is connected to the input side of the water pump.

The antenna cable reaches from a lead off the antenna (mounted in the right rear fender) through the engine compartment and central tunnel to the back of the radio in the dash.

The speedometer cable also passes through the tunnel to a 90 degree adaptor attached to the speedometer. A small spring cup holds the other end of the cable in the transmission.

Wiring Harnesses

The engine compartment harness is a large Y with one long leg. The base of the Y ties into the passenger compartment harness in the central tunnel and branches left (shorter leg) to all of the electrical equipment on the driver's side of the engine compartment. The right side connects to the tail and rear marker light assemblies. All electrical components are color coded and have connectors that mate to the harness.

The passenger compartment wiring runs from the engine compartment harness in the tunnel to the firewall, where it attaches to the luggage compartment harness, connecting to the instrument panel and steering column harnesses along the way. The luggage compartment harness connects to the front marker lights on both sides of the car. The radiator shroud must be installed when the luggage compartment wiring is attached, because the harness passes through the shroud.

The restraint harness leads from the comparator circuit in the left front strut tower to the front and side impact sensors. One leg of the restraint harness leads through the firewall to the steering column wiring and another to the passenger airbag diffuser.

Engine Compartment Components

The fuel pump, fuel pump cover plate, fuel filter, charcoal cannister, backup warning buzzer, coolant surge tank, emissions control box, voltage regulator and ignition coil and resistor are all mounted on appropriate brackets in the engine compartment before the engine is installed.

Rubrics and Bumpers

Sections are cut out of the foam bumpers to house the rubrics, which are laminated devices that stiffen the bumpers sufficiently to prevent damage in low speed (up to 8 to 10 mph) accidents. The rubrics (two front, two rear) are bolted directly to the removable nose and to the rear subassembly, and the bumpers are mounted over them.

Horns, Parking Lights and Other Electrical Accessories

The horns, lights, radiator relays, wiper drive, washer, etc. are all installed on appropriate brackets mounted on the body in white.

HVAC, Hood Latch Control

After the control bracket is installed on the top of the cowl, the HVAC unit and the heater hoses, heat control valve, control cables, defroster diffuser and ducts are all installed, in that order. Before the dash can be mounted, the door ajar warning buzzer must be mounted on the control bracket.

Fuse Block, Side Impact Sensor, Comparator Circuit

The fuse block is installed in the trunk compartment and the side impact sensor in the left front strut tower. The restraints diagnostic warning light emitting diode (LED) is installed in the center console of the passenger compartment

Restraints

First the column mount is bolted to the firewall, then the steering column is attached to its mount, with the heads of its bolts passing through the shear capsules. The knee restraint reaction pans are installed at 45 degrees and the foam knee restraints inserted over them. On the passenger side the knee restraints are installed after the air bag mounts are attached, then the air bag assembly itself is attached (with its diffuser precisely 15 degrees below horizontal). The air bag is hand folded and secured in place by tape.

The steering column is a specially designed, specially fabricated energy absorbing column that is described in the Occupant Protection section of this Final Report.

Engine, Axles and Exhaust

The engine is assembled and bench tested before installation. The RSV requires the engine to sit at a different angle than the angle for which the engine (a Honda) was designed. We therefore install an aluminum wedge between the carburetor and the intake manifold to level the float bowls in the carburetor. That and the exhaust system (because a front engine is now moved to the rear) are the primary engine modifications required.

Before installation, the engine cradle is mounted and torqued on the engine, the carburetor removed, the transaxle attached, and the package finally installed through the right rear side of the engine compartment. The right rear A arm and strut can be installed only after the engine is in place. The hoses, wires and carburetor are then attached.

After the engine is mounted, the axles can be assembled and installed. The passenger side axle is installed first and checked to make sure the half shaft snaps into its retainer clip (else an oil leak will result). The passenger side tire and wheel can now be installed. For the driver side, the left rear pillar must first be detached from the shock assembly and A arm. Otherwise the installation procedure is the same as the left side.

The exhaust is assembled and then bolted to the support brackets. The clearance with the fuel pump cover plate and the engine cradle must be checked carefully.

Dash and Instrument Panel

The dash is based on a single piece of vacuum formed plastic. This material is upholstered with vinyl fabric that matches the interior of the specific car. For show purposes the passenger airbag and steering wheel hub are covered with a different material, to clearly distinguish where the restraints systems are located. In standard production, of course, these areas would typically be covered with the same upholstery as the rest of the dash, specifically to deemphasize the existence of the restraints.

The dash is attached at its front edge by four clips that catch corresponding brackets mounted on the windshield fence. The lower left and right surfaces are mounted on brackets that attach to the A pillars. The ends of the duct hoses are then pushed into place in the dash.

The holes for the gauges, lights, etc. must be cut into the instrument panel and the gauges matched to them. The Sonealert is tested before being installed in the dash. Then all of the rest of the cables and harnesses are attached.

Steering Wheel and Driver Restraint

The steering wheel is mounted with the horn buttons on the top and the tires straight. The airbag module is then mounted (with a "T" that is stamped on its back centered at the top of the steering wheel).

Hatch, Engine Cover and Rear Vent Ducts

The hinge is attached to the engine cover, the cover is attached to the rear seat riser and the hold-open latch then installed. The locking mechanism, hinges and supports are mounted on the rear hatch and the hatch also installed. Finally, the rear vent ducts are attached to the vent boxes and routed between the wheelhouse and the body glove through to the rear grills.

Rear Seat Belts and Battery

The coil force limiters are fabricated (a special tool is required for winding the force limiting tapes) and mounted on special brackets. The belts themselves are modified Honda belts.

The battery is mounted in a compartment beneath the right rear passenger seat.

Body Glove and Hood

In the rear the body glove components require largely trim and fit operations. The rear panel and fenders are primarily bolted on. The quarter panels, air scoop backplates and forward edges of the fenders are riveted in place. The light brackets are bolted in and the grilles are held on by Allen head bolts. The rear spoiler is simply aligned and screwed on.

In the front the fiberglass panel must be slotted for the headlight adjusters. Beyond that, the panels (including the complete front glove) are simply fitted and mounted with either rivets or bolts. The determining checkpoints for the body glove are its centering on the parking light assembly and on the air scoop.

The (front) trunk lid is a sandwich of 4 pound per cubic foot foam between fiberglass panels. After the panels are attached together, the hinges, latch and opening brace must be aligned with the appropriate plates on the body. The hood can then be mounted on the body.

The fiberglass wheelwell liners are fabricated specifically for the RSV, but final fitting must be done on each vehicle. Each well is riveted in place along all of its edges, and their centers are secured by special brackets.

Doors

The doors are the most complex parts of the body. They are integral parts of the side restraint systems, yet they must also be lightweight, so that they can be supported easily while fully open. The doors are composed of aluminum panels with foam filling in the lower sections and fiberglass reinforcements in the supports around the windows. The windows themselves (which are installed after the doors are mounted on the car) are bonded to the doors to provide as much strength as possible; only small central windows slide open for ventilation. The doors are supported by gas struts.

While the doors are being fabricated they are carefully matched to female jigs. The male counterparts of these jigs are used to align the door frames while the bodies in white are being constructed. These measures are made necessary not only by the required lightness of the doors (making every reinforcement critical), but also by the fact that the door designs include compound curves, making them harder than most to fabricate accurately.

Once the doors are carefully aligned with the body, the striker pins, latches, handles, locks and control linkages must be installed and adjusted. Then the rigid plastic cover panels, trim panels and pull straps are installed, and the gas springs are attached between the doors and the interior roofline. Only then can the stationary windows and slider assemblies be installed.

Lights

The head lights, tail lights, courtesy lights and Knaff light are all mounted in standard OEM assemblies and attached completely according to standard automotive manufacturing procedures.

Interior Trim and Carpeting

Ensolite is glued onto the interior metal pieces (such as the A and B pillars) and the interior upholstery then glued to the Ensolite. Welting that matches the dash cover material is attached along the sides of the instrument panel to fill any gaps. The same procedures are used for the rear interior quarter panels. The floor and side sills are fully carpeted, as are the engine cover, the surrounding deck and the floor of the luggage compartment. Finally, the headliner is installed and trim is clipped to the cover over the bases of the gas springs.

The Vehicle Identification Number plate is riveted in place approximately 1 inch forward of the left side of the windshield fence.

Window Installation

The windows are bonded in place following conventional American automotive practice. After the vehicle has been painted, the surfaces to be bonded are cleaned with a chemical cleaner. The bonding surfaces of the glass and the metal frame are then coated with a primer and a bead of urethane sealant is applied to the body using an air driven caulking gun. The glass is then installed and taped in place, and water is used as a catalyst to cure the sealant. The sealant is then allowed to dry a minimum of 24 hours.

Center Spine (Tunnel) Cover

The front and rear spine covers are single vacuum formed pieces (each much like the dash) that are covered with an upholstery appropriate to the interior of the specific vehicle. Both are installed after the carpeting is in place, but before the seats are mounted.

Seats

The seats are specially modified Dodge van seats. The modifications include reinforcements to prevent deformation in crashes and force limited clear plastic head restraints that attach to the RSV roof. The head restraints help prevent whiplash and seatback collapse in rear end collisions.

The seat tracks of the front seats are first mounted on the seats and then the seats are installed on the body structure. The upper ends of the head restraints are bolted and glued on to specially fabricated brackets.

The rear seat is fabricated specifically for the RSV using standard American automotive techniques. The back of the rear seat is aligned and installed first, then the seat bottom (after the appropriate brackets are mounted).

Wheels and Tires

The wheels and tires are Dunlop Runflat tires mounted on Dunlop Denloc rims. The wheel lug nuts are torqued to 80 foot-pounds, and the tires are inflated to 30 to 35 psi.

The front wheels are then aligned (the primary adjustment on a McPherson strut suspension is the toe-in) and the car sent out to its complete inspection and road test.

13.4 PAINTING OPERATIONS

After all of the subassemblies (including the body glove parts) are installed, the RSV undergoes its final painting. Because the doors are aluminum, they must first be painted with zinc chromate primer (required for aluminum); the standard laquer can then be applied over this primer. The fiberglass and flexible urethane parts pose different problems. Fiberglass is covered with gelcoat when it comes out of the mold, so it has to be thoroughly cleaned with grease and wax remover, then sanded, primed and sanded again, until smooth. The flexible urethane parts (including the fenders, the front glove and the rear bumper cover) have a different coating, which must be removed with methalyene chloride. These parts must also be sanded smooth (with flexible sanding blocks) before being painted. Because we were conducting only a prototype operation, all of the flexible parts were left in their natural (beige) color. In final production these parts could be impregnated with the color of the particular car, thereby significantly reducing the amount of painting effort required for the final car.

After the body parts were all thoroughly cleaned and primed, they were painted with three coats of flexible laquer. The entire bodies (including the nonflexible parts) were covered with the flexible paint because laquers will change color when flex agents are added. A flexible clear urethane coating was applied over the laquer on all of the showcars.

13.5 QUALITY CONTROL INSPECTION AND ROAD TESTING

During its construction, each RSV underwent a large number of inspections. In fact, when each vehicle was complete and fully approved, a 110 page checklist report was issued. The report included notations from all inspections and the signatures of approval at each stage of the manufacturing process.

The inspections began with a review of the conformance of the floor pan to the appropriate design drawings (and a direct check of the sizes of the cuts, bends, holes, etc. against the specifications listed in the drawings) and ended with the acceptance driving test of the fully completed vehicle. Along the way there were inspections of (and quality assurance inspection reports issued for) the

- Floor pan
- Firewall
- Side sill subassemblies
- Rear quarter panels
- Stage I BIW -- after the quarter panels were installed
- Stage II BIW -- after the spring towers were installed
- Stage III BIW -- after the roofline was in place
- Nose assembly
- BIW -- complete, less doors
- Foam and clean-up -- including doors
- Priming -- prepaint and undercoat
- Stage I assembly
- Stage II assembly

Stage III assembly
Stage IV assembly
Complete vehicle non-driving acceptance test
Complete vehicle acceptance road test.

The non-driving acceptance test itself required 31 pages of checklists and testing procedures to be followed step by step and checked off as each system (from the cigarette lighter to the operation of the rear hatch) passed its tests. The acceptance driving test required another 10 pages of inspections and tests to be conducted over a prescribed on-the-road driving course.

There also were full inspections and inspection reports for the major subsystems that either were entirely fabricated or extensively modified by Minicars. These included the:

Electrical harnesses
Engine modifications
Pre-installation engine run-in
Front and Rear suspension A arm and spring modifications
Driver restraint system and steering column
Fuel cell
Seat fabrication
Door assembly.

13.6 MANUFACTURING DIFFICULTIES

The RSV prototype production difficulties can be classified into four categories: design, tooling and equipment, accessibility and serviceability, and weight increase.

13.6.1 Design

A straightforward production engineering of the vehicle would solve the design difficulties (as well as the problems with the accessibility and serviceability of the components and subsystems). In addition, the weight increase was a direct result of the fact that the vehicle structures were completely hand built, using minimal tooling and equipment. A fully production engineered RSV, manufactured with dedicated tooling and equipment, would not, therefore, have experienced the production difficulties described below.

Because of a buildup of tolerances in the body in white assembly, the door fit, for instance, varied from car to car. This could be prevented by the use of more extensive jigs and fixtures than were possible in the prototype construction. (The construction of such jigs would, of course, be included in the production engineering of the car.)

There were limitations imposed by the simple fact that the RSV had to be designed to accept components that were already in production. For example, because the engine used was from a front wheel drive car, the shift linkage to the transmission was mounted on the rear of the engine. When this engine is moved to the rear, the connection is still on the rear, on the opposite side of the engine from the driver. The linkage from the shift handle to the transmission thus had to pass under the engine to reach the transmission connection. Obviously production engineering would move the connection to the front of the engine and thereby eliminate the extra parts. The use of a production (though modified) steering column caused a similar problem: the steering linkage had to pass through two U-joints, when one would have been sufficient if the whole system could have been redesigned.

There were some difficulties caused by late changes made in other parts of the design. A change to Dunlop Denovo run-flat tires produced interference problems; special lock nuts, studs and spacers were required for a correct fit. Changes in the head restraints caused difficulties for their attachment to the roofline. Delays in the actual production of the cars caused the aluminum door parts to remain on the shelf too long, allowing them to age harden, and thus to become much harder to weld.

Finally, there were design difficulties that were simply discovered too late to be completely redesigned. The doors are difficult to upholster. The windows are bonded directly to the body of the car, so body flexing at times causes them to crack. (This could be solved by more flexible mountings.) The fuel inlet hose can too easily be stretched during installation, allowing it to crack under the pressure of a fuel nozzle or wear caused by vibration. The trailing arms and the suspension attachment points must be reinforced. Redesign of all of these would take a very short time in the production engineering of the car.

13.6.2 Tooling and Equipment

The manufacturing process would be greatly improved by the development of complete jigs and fixtures for the body in white greenhouse assembly, the door assembly and fitting, and the rear hatch fitting. There also were difficulties with the preciseness of the environment and mixture required for foaming, ripples in the RIM urethane components, and the matching of the paint colors and finishes on the metal, fiberglass and RIM urethane parts.

13.6.3 Accessibility and Serviceability

There also is a need to redesign to improve the accessibility and serviceability of the bumpers, front nose, radiator, wiring, heater hoses, heaters, wiper arms, battery and instrument panel. The primary problem here is that, at times, too many extra pieces have to be detached to gain access to a particular part. For instance, the wiring harnesses run down the central tunnel of the vehicle. To check these harnesses, too many cover plates and sections of upholstery must be removed.

13.6.4 Weight Increase

Because the vehicle is hand built, many weight saving measures available in full production could not be used. For instance, most of the bends in the body in white were straight angle bends, ones that could be rounded (less material, hence less weight) in production. Thus the RSV weighs much more than it would in production. This has consequences on the vehicle's acceleration, braking performance, handling -- and even the gas struts and hinges of the doors.