Calspan/Chrysler Research Safety Vehicle Front Impact Structure Development

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ABSTRACT

The Calspan/Chrysler RSV is a practical safety vehicle for the 1980's that can be produced within the projected limits of technology and materials at a rate of 300 000 units per year. It must have consumer appeal and has the major restriction of a base vehicle weight less than 3 000 pounds.

Within these limits the front impact structure is being developed to maximize occupant protection for both the striking and struck vehicles.

This paper describes the front impact structural concept and details the complete vehicle static crush and computer impact simulation work accomplished to this point in the development.

The computer simulation based on complete car static crush data is verified through comparisons of simulated versus actual impact data for the Simca 1307 base car.

The value of the analysis method in defining structure that must meet high speed front barrier impact criteria as well as front to side vehicle impact compatibility and pedestrian impact requirements is demonstrated. The static crush and analysis of two modified vehicles is described in detail.

BACKGROUND

The Calspan/Chrysler Research Safety Vehicle (RSV) development program is currently in the second phase of a three phase total program. During this phase, the structural concepts developed in Phase I must be demonstrated through vehicle testing. At this point in Phase II *static testing* and computer simulations used to develop the structure have been completed. Dynamic impact testing of modified vehicles has not started but is scheduled to begin by the time this paper is published. Phase III of the program will consist of final development of Phase II concepts and building the developed RSV in sufficient quantities for thorough evaluation.

FRONT STRUCTURE CONCEPT

The front end structure of the RSV has been developed to provide three distinct zones of protection [1]. The front 10-inch (254 mm) zone I provides improved pedestrian protection and damage protection. Zone II has the primary purpose of providing compatibility with the side and rear of struck vehicles. From a total vehicle systems standpoint, zone II becomes a necessary part of the side and rear protection structure, controlling impact force levels for compatibility with these parts of the struck vehicle. Zone III is the primary energy absorbing section, providing the higher forces necessary to prevent passenger compartment intrusion in high-speed impact while limiting maximum *g*'s to levels compatible with the occupant restraint system. The relative locations and lengths of the three zones are shown in figure 1.

PERFORMANCE GOALS

Zone I

The front 10 inches (254 mm) must provide pedestrian protection up to 20-mi/h impact speed. This is accomplished by developing a front end shape to control struck pedestrian kinematics and limiting front end stiffness to approximately 20 psi. Performance demonstrations have consisted of three dimensional computer simulations using the CAL-3D occupant model and a laboratory 22-mi/h impact by a 100-pound, 9-inch diameter cylinder in which accelerations are limited to less than 60 *g*'s. The pedestrian protecting bumper is the subject of a separate paper.

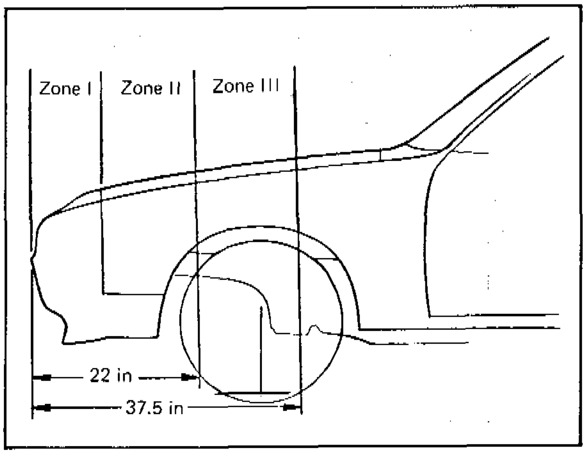


Figure 1. Front structural concept.

Zone I must also provide 8-mi/h barrier property protection. The requirements of current U.S. bumper standards have been waived in favor of a systems approach providing equivalent car-to-car impact compatibility while maintaining compatibility with the soft front required for pedestrian protection. Car-to-car, front-to-rear impact damageability goals are set at a closing speed of 13 mi/h. This level is achievable with current 5-mi/h rear end systems.

Zone II

This zone has the primary purpose of providing intervehicular compatibility during front-to-side and front-to-rear collisions [2]. Primary emphasis is on front-to-side compatibility since this mode has greater importance based on accident statistics. All structures for side impact protection must be duplicated on both sides of the vehicle generating large weight increases for each improvement in impact capability. Transferring a portion of this burden to the front end results in greater weight efficiency.

It has been projected that cars in the 1985 era will have 20 *g* or 60 000-pound side crush capability for cars in the 3 000-pound category [3]. Zone II force levels must be limited below this level to assure front end crush, and thereby reduce side structure intrusion and impact *g* levels.

Zone III

The front end structure immediately forward of the dash or passenger compartment must provide the bulk of the energy-absorbing capability and prevent excessive passenger compartment intrusion while limiting *g* forces to a level compatible with the restraint system.

The RSV front barrier impact goal is 50 mi/h with a minimum of 40 mi/h where performance is based on front seat occupant injury criteria.

The 50-mi/h impact objective is considered the maximum possible within the 3 000-pound total vehicle weight objective. The total weight budget for the vehicle was assigned on a priority basis to the various structural systems required. Systems with the highest life saving potential received the largest allocation. Based on the weight available for the front system and the expected energy absorption per pound of weight added, the energy of a 50-mi/h barrier impact was the maximum that could be achieved. The performance requirements for the three zones are summarized in table 1.

BASE CAR SELECTION

In an effort to reduce design and construction costs as well as assure basic producibility and feasibility, it was determined that a current production car should be chosen as a base for modification.

During the early stages of the program, many current production vehicles were analyzed to determine the highest degree of compliance to the RSV specifications of crashworthiness, interior dimension, fuel economy, producibility, and weight. The

Table 1. Performance requirements

Zone	Major consideration	Crush (in)	Acceleration (*g*)	Energy absorption (X 1 000 ft/lb)
I	Pedestrian protection and minimum vehicle damage	4-6	6-10	7-10
II	Side and rear compatibility with other vehicles	6-10	15-20	40-55
III	Occupant protection frontal collisions	18-22	30-40	150-200

final analysis showed that the Simca 1307 offered a high level of overall compliance to the RSV specifications. The 1307 was chosen as the base structure. The elements of the selection process are detailed in the Calspan Phase I RSV reports.

Within the general confines of the base car geometry, the task of developing a front end structure capable of achieving the interacting performance goals described above was begun.

DESIGN PROCEDURE

Previously, the typical approach to designing front structure for increased barrier performance was the buildup of modified cars and dynamic testing. The results are then compared to the design criteria. This approach can be effective when the design criteria is to limit the total body crush or passenger compartment intrusion, but does not yield the relatively detailed information required to design the three zones of the front structure as specified for the Calspan/Chrysler RSV.

The force levels and the interaction of the major front structural components must be known to effectively design the three levels of energy management characteristics desired in the front structure. For this reason the design procedure used for the RSV front structure consists of static crush testing of the major components for their individual force-deflection properties, a computer math modeling technique for simulating impact and finally dynamic impact of the developed structure. The design process is depicted in figure 2.

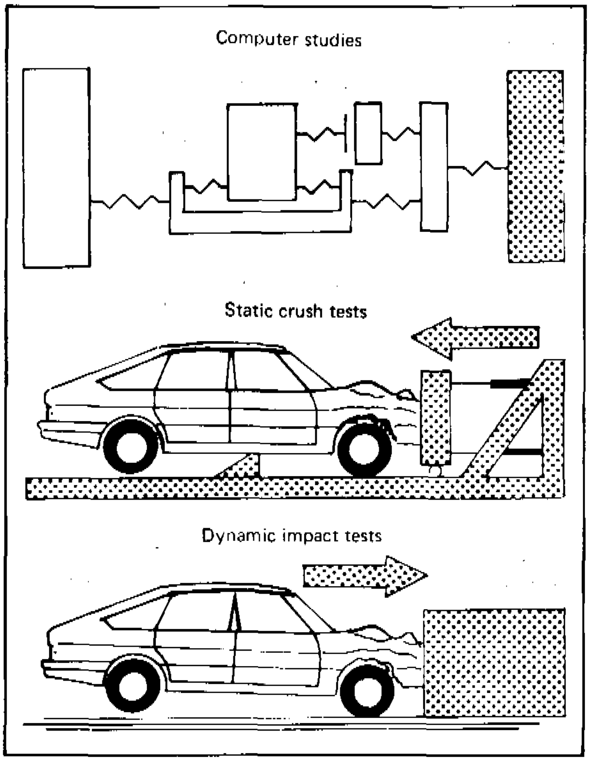


Figure 2. Design process.

BASELINE TESTS

Static Test

A Simca 1307 was statically tested on the Calspan Corporation static crush machine to determine the force deflection properties of the major front structural components. The following components were tested:

- Front of front rails—from engine mounts forward
- Rear of front rails and dash—from engine mounts rearward
- Sheet metal—from A-pillar forward
- Radiator and engine crush—structure forward of engine
- Engine mounts—forward and rearward

The static force-deflection properties for the components are shown in figures 3 through 9.

The test setup and test method are shown in figure 10. The body minus the engine and transmission is positioned on the crusher rails and reacted as shown. The ram, which is hydraulically controlled, has four loading plates. The horizontal split between the upper and lower plates is positioned so that the lower plates will record the rail force and the upper plates will record the sheet metal force. All five reactions are present for the front of front rail and sheet metal test. For the rear of the front rail and sheet metal test, the engine and transmission are installed and reaction number two is removed. The radiator and engine crush

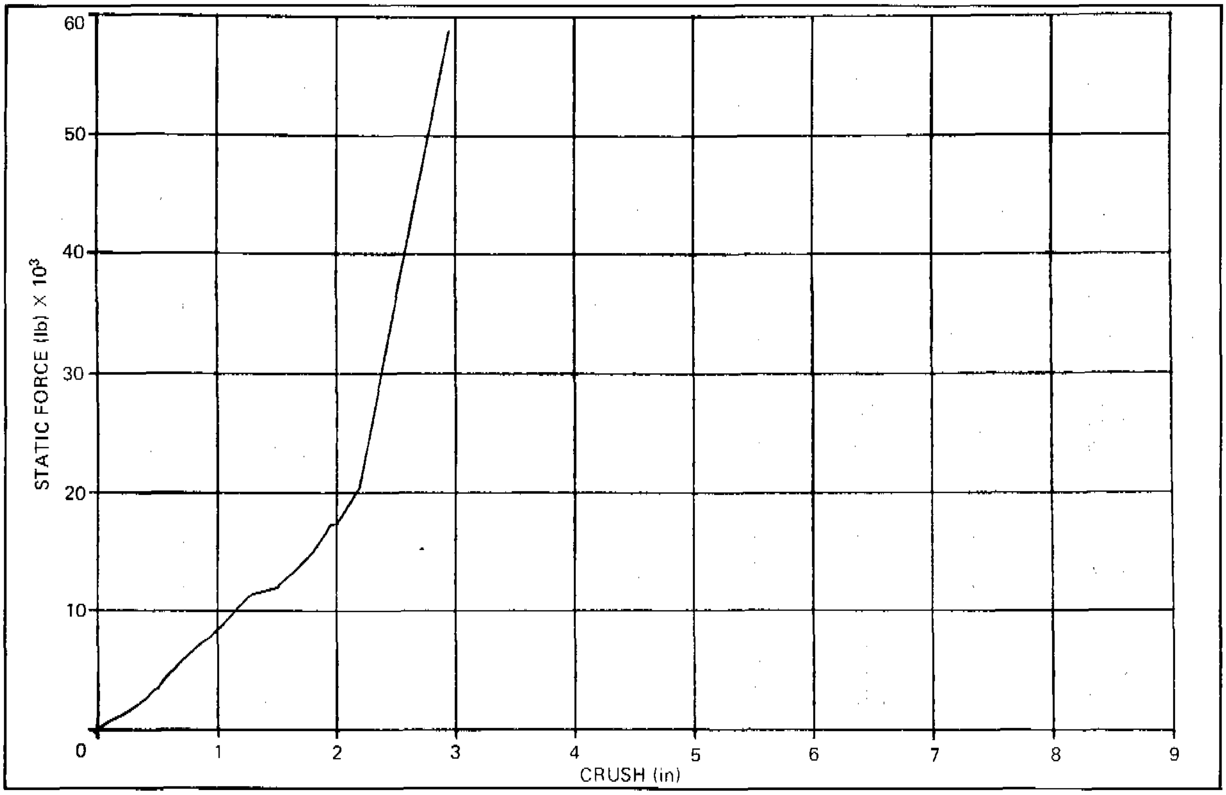
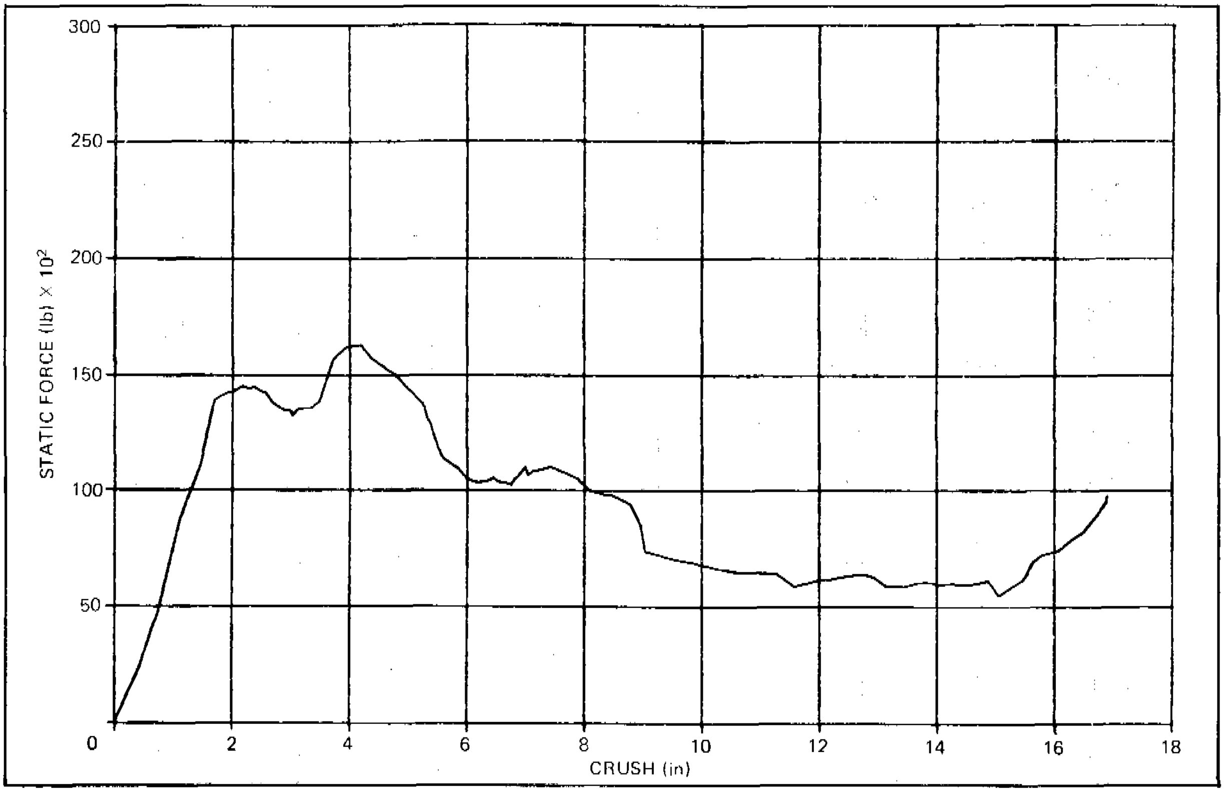


Figure 3. Simca 1307 engine mount rearward static force deflection properties.

Figure 4. Simca 1307 front of front rails static force deflection properties.



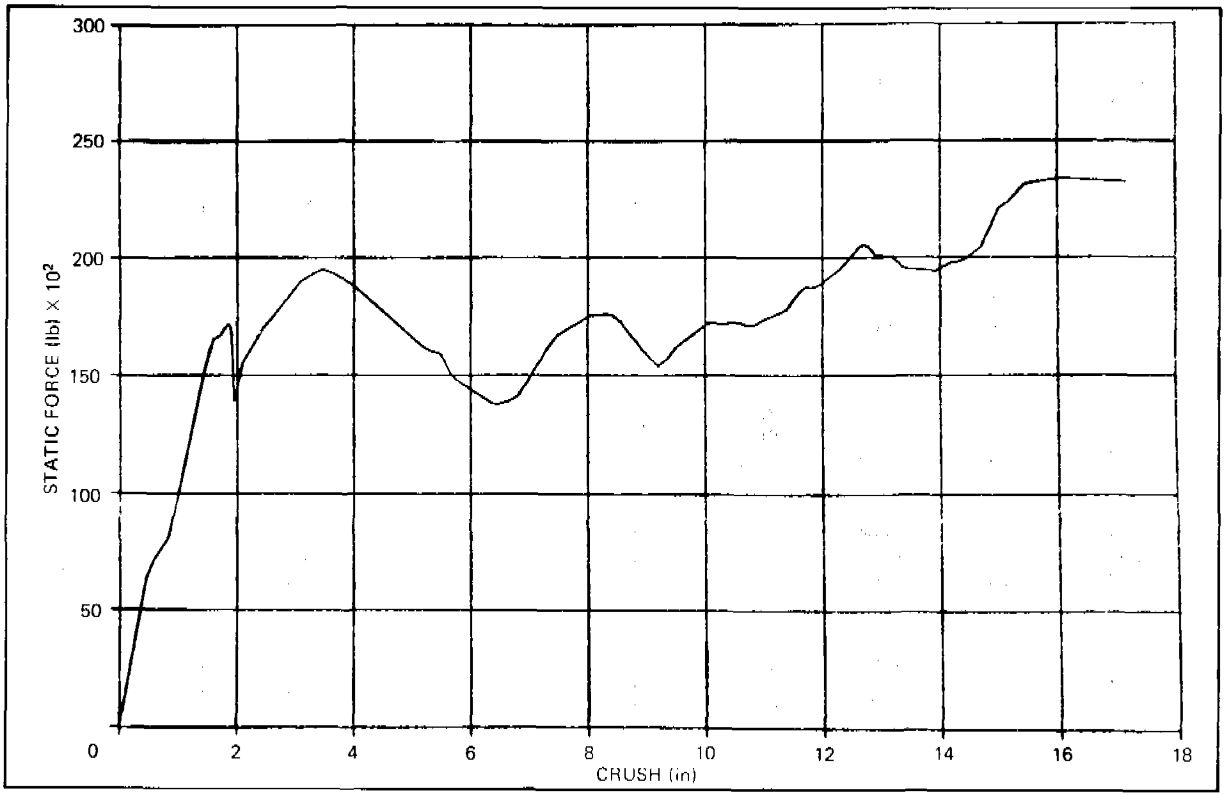
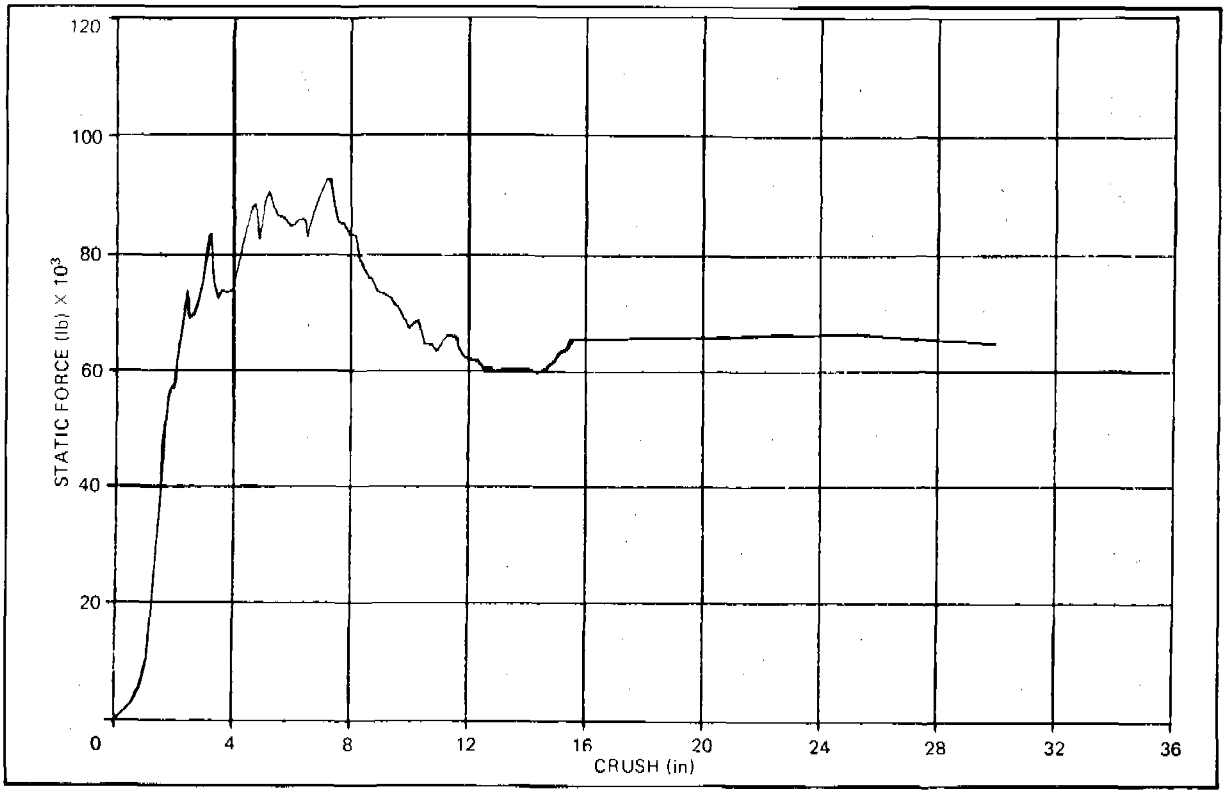


Figure 5. Simca 1307 rear of front rails static force deflection properties.

Figure 6. Simca 1307 front sheet metal static force deflection properties.



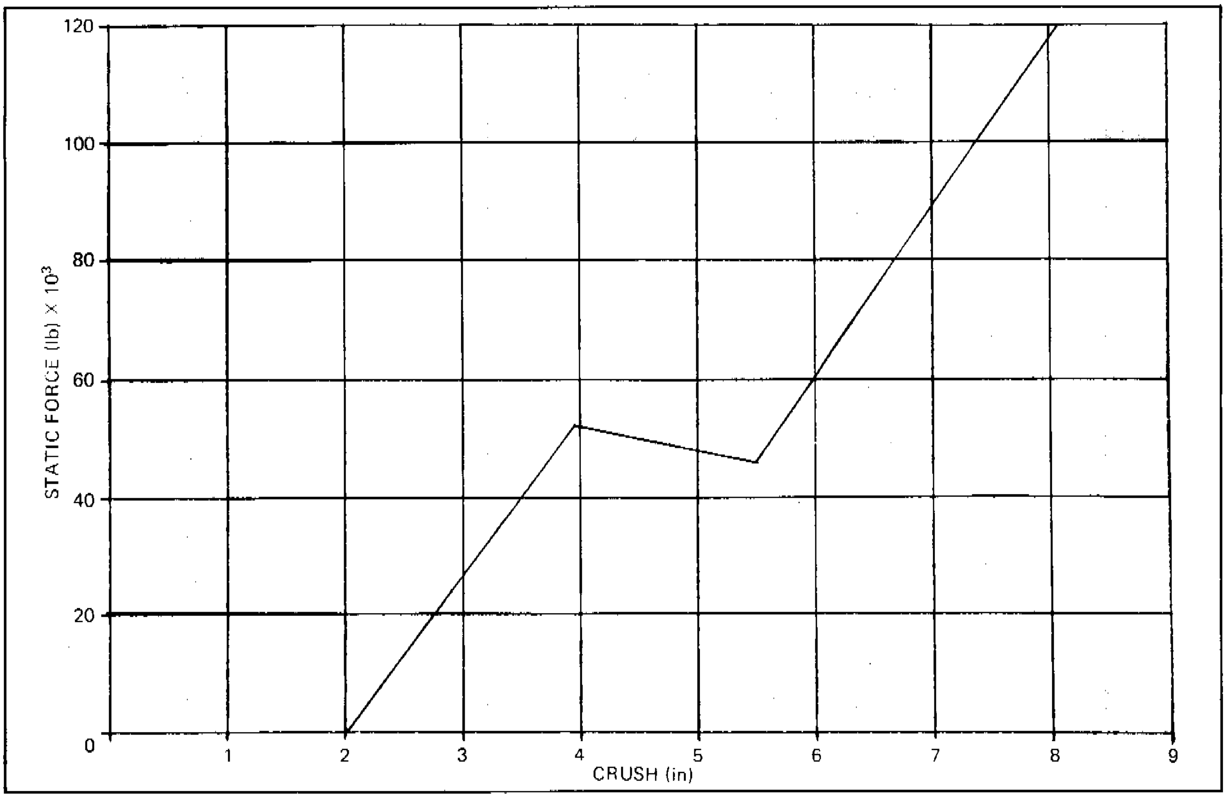
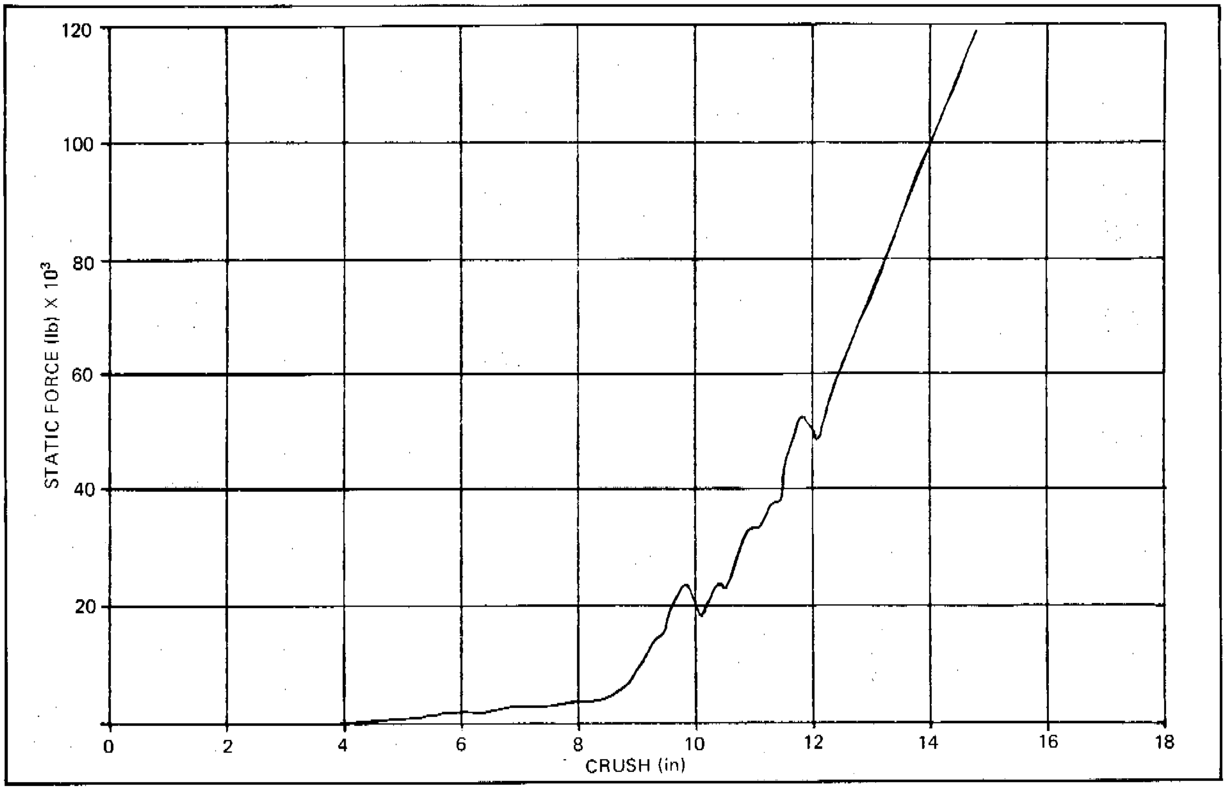


Figure 7. Simca 1307 engine crush static force deflection properties.

Figure 8. Simca 1307 radiator crush static force deflection properties.



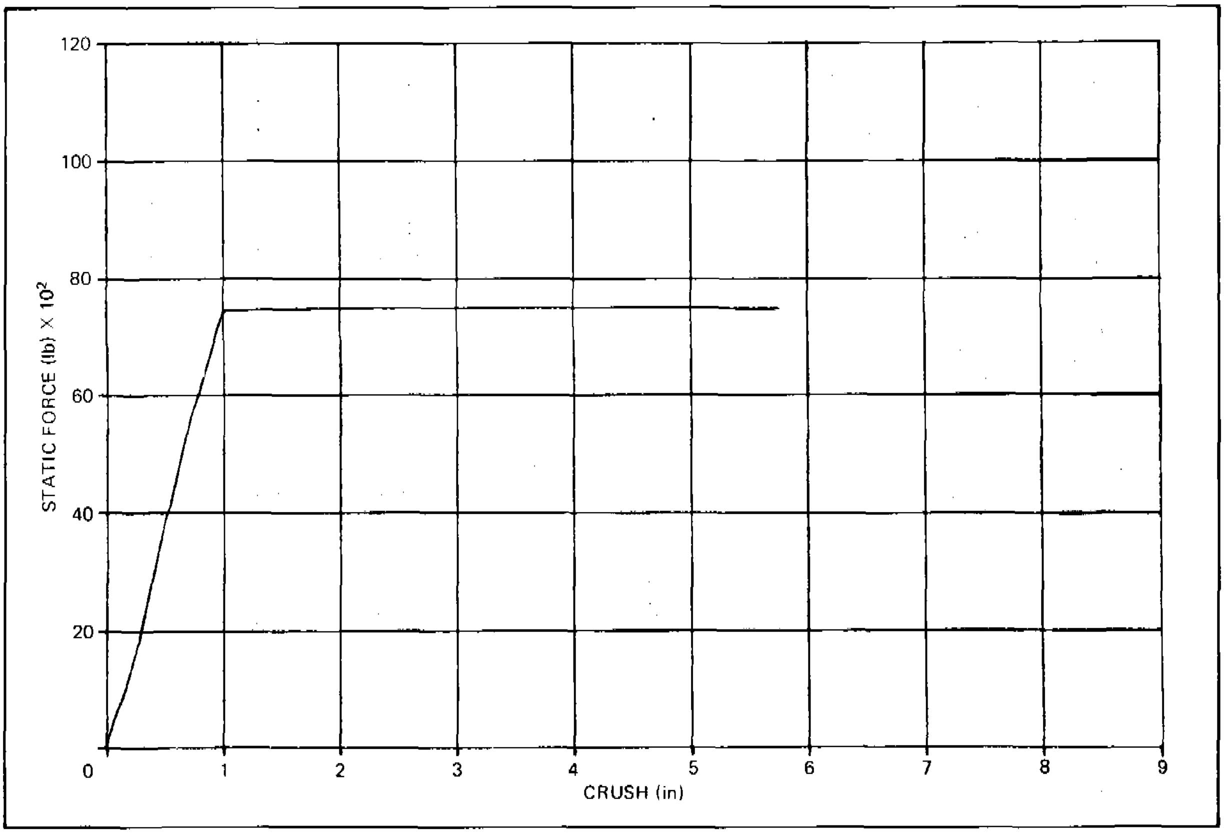


Figure 9. Simca 1307 engine mount forward static force deflection properties.

force are obtained by pushing the engine into the front grille and radiator structure. The engine mounts are tested as a separate component in both directions.

Dynamic Test

A dynamic flat-barrier test was conducted on the baseline Simca 1307 at 35-mi/h impact speed. The purpose of this test was to determine the base vehicle's ability to meet the RSV specification of occupant egress (half of the doors should open manually) and injury criteria at all seating positions at a barrier impact speed of 30-35 mi/h. The base vehicle did satisfy these conditions. The second purpose was to obtain the necessary data for correlating the computer math model to the base car barrier impact.

Baseline Vehicle Computer Simulation

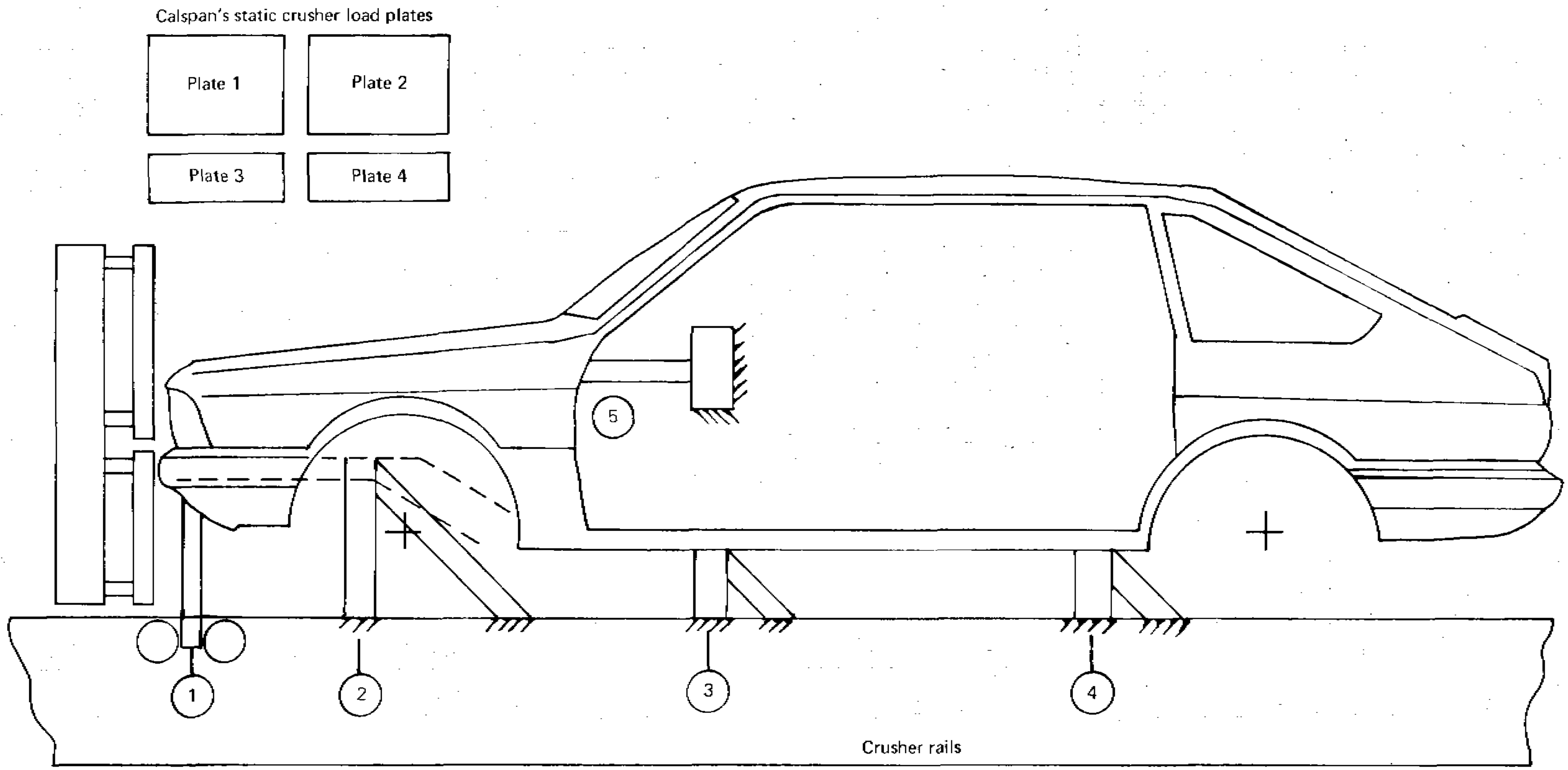
A computer math model was constructed to verify that a model could be used to reproduce the barrier test results.

The computer program MINIBASH [5] is a general dynamic impact model that can be used for both barrier and car-to-car impact simulations. A general model consisting of up to 10 masses and 20 resistances can be simulated. Nonlinear static force-deflection properties can be specified for each resistance. The mass displacements, velocities, accelerations, and forces are calculated at each increment. The static force, dynamic force, and crush are also calculated at each time increment for each resistance. The MINIBASH solution for each time increment is as follows:

- Calculates new mass displacement from previous displacement, velocity, and acceleration

$$X_{new} = X_{old} + V_{old} (\Delta t) + 1/2 a_{old} (\Delta t)^2$$

- Calculates relative position of all masses and determines the crush of each resistance



LEGEND

1. Vertical reaction only—at front bumper
2. Front rail reaction—at front engine mount attachments
3. Front body reaction—aft of torsion bar attachment and sill
4. Rear body reaction—forward of rear suspension member
5. A-pillar reaction and load cell location

Figure 10. Calspan's static crush machine—reaction system.

- Calculates static force of each resistance and applies specified dynamic rate factor to calculate dynamic force in each resistance
- Sums the dynamic loads (including inertia loads) on all masses and calculates the mass acceleration

$$a_{new} = \Sigma F\ dyn/m$$

- Calculates velocity for all masses

$$V_{new} = V_{old} + \frac{(a_{new} + a_{old})}{(2)} \Delta t$$

These equations define the system at each time increment.

A MINIBASH front impact model (fig. 11) was constructed consisting of five masses and seven resistances. The five masses are the body, engine and transmission, suspension and crossmember, radiator and yoke, and the barrier mass. The seven resistances are the front of front rails, rear of front rails, sheet metal, engine, radiator, engine mount forward, and engine mount rearward.

The front impact model was executed for the same speed and weight as the baseline dynamic test. The results comparing the test and simulation are shown in table 2 and in figures 12 through 17.

RSV Front Structure Force Levels

Using the impact model we now can arbitrarily change any or all of the front structural components and determine what effect the changes have on the vehicle dynamic response.

The RSV math model (fig. 18) has one additional resistance between the yoke and barrier mass. This resistance represents the soft front bumper that will be used for pedestrian protection in the zone I structure. The rest of the model is the same as the base Simca 1307.

The preliminary force-deflection properties were assumed to be square wave curves estimated from the available crush distance of each resistance and the amount of energy each resistance had to dissipate. The model was exercised repeatedly with adjustments to the components until the desired vehicle dynamic response was achieved.

The next estimate for the static force-deflection properties was more realistic in the shape of the force-deflection curves. Typically, a steel member loaded in compression will have a peak elastic load with a load drop as it deforms plastically. From previous testing of beam members in axial compression, the load drop from the peak

Figure 11. Simca 1307 MINIBASH front impact model.

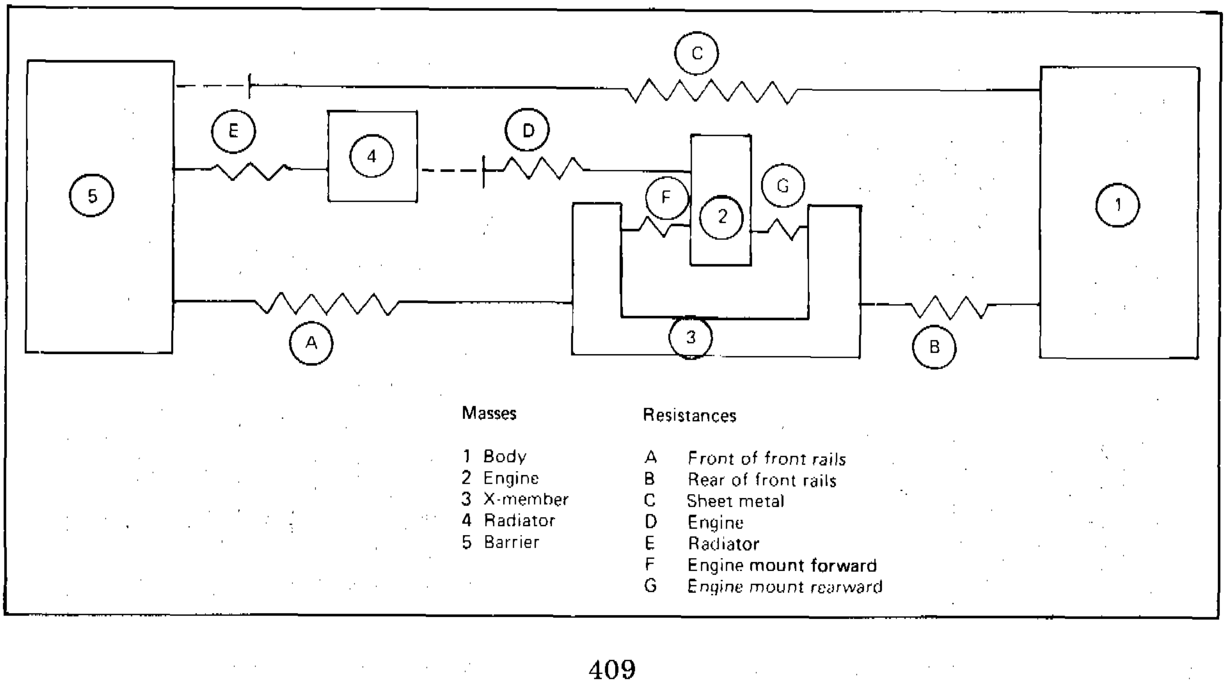


Table 2. Base Simca 1307 35.3-mi/h front barrier impact—comparison of dynamic test results with computer results

Item	Test	Simulation	Difference (%)
Body dynamic crush (in)			
Right sill, 33.0	33.8	33.1	2.1
Left sill, 30.4			
Rear deck, 34.5			
Center console, 32.4			
Average, 33.8			
Engine displacement (in)	14.2	14.2	0
Dash crush (in)	12.0	13.4	11.6
Front rail crush (in)	16.7	16.5	1.2
Rear rail crush (in)	17.1	16.6	2.9
Duration (ms)	108.0	96.0	11.1
Peak deceleration > 3 ms (*g*)	27.0	22.0	18.5

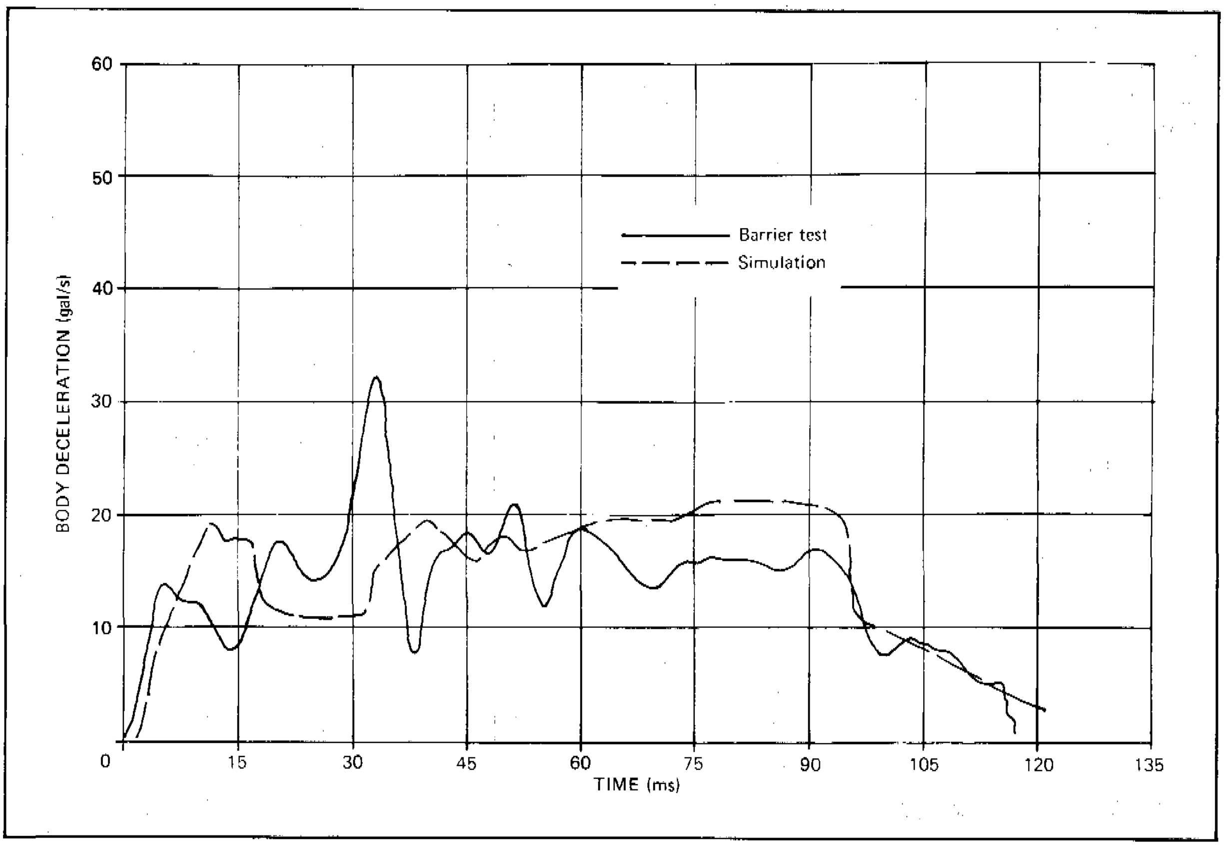
value has been approximately 50 percent. The base line static test results and a one-quarter scale drawing of the front structure were used to determine the physical stackup and interaction of the different components. Final estimates were then made for the static force-deflection properties. These estimates were then fed into the model and adjusted until again the desired vehicle dynamic response was obtained. The estimated force levels that must be built into the front structure are shown in figures 19 through 26.

Sizing of the Front Structure

The force levels of the front structure are now known. The next step is to size the front structure to achieve the desired loads. Because of the significant force level difference in zones II and III and the limitation of the base Simca 1307 environment, the sizing was accomplished with a combination of section shape, size, material properties, and structural configuration.

The Chrysler developed computer program SECRIP was used as an aid in obtaining the section shape, size, gage, and material selection.

Figure 12. Simca 1307 body deceleration comparison.



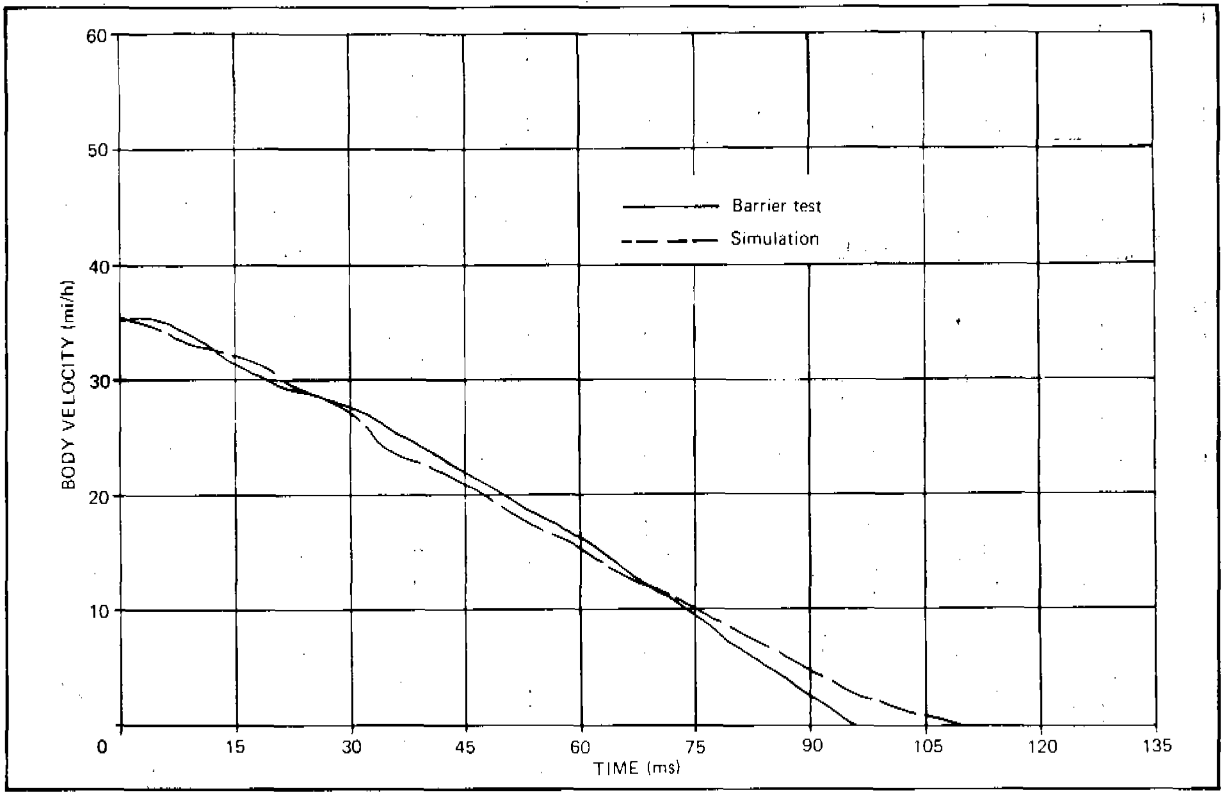
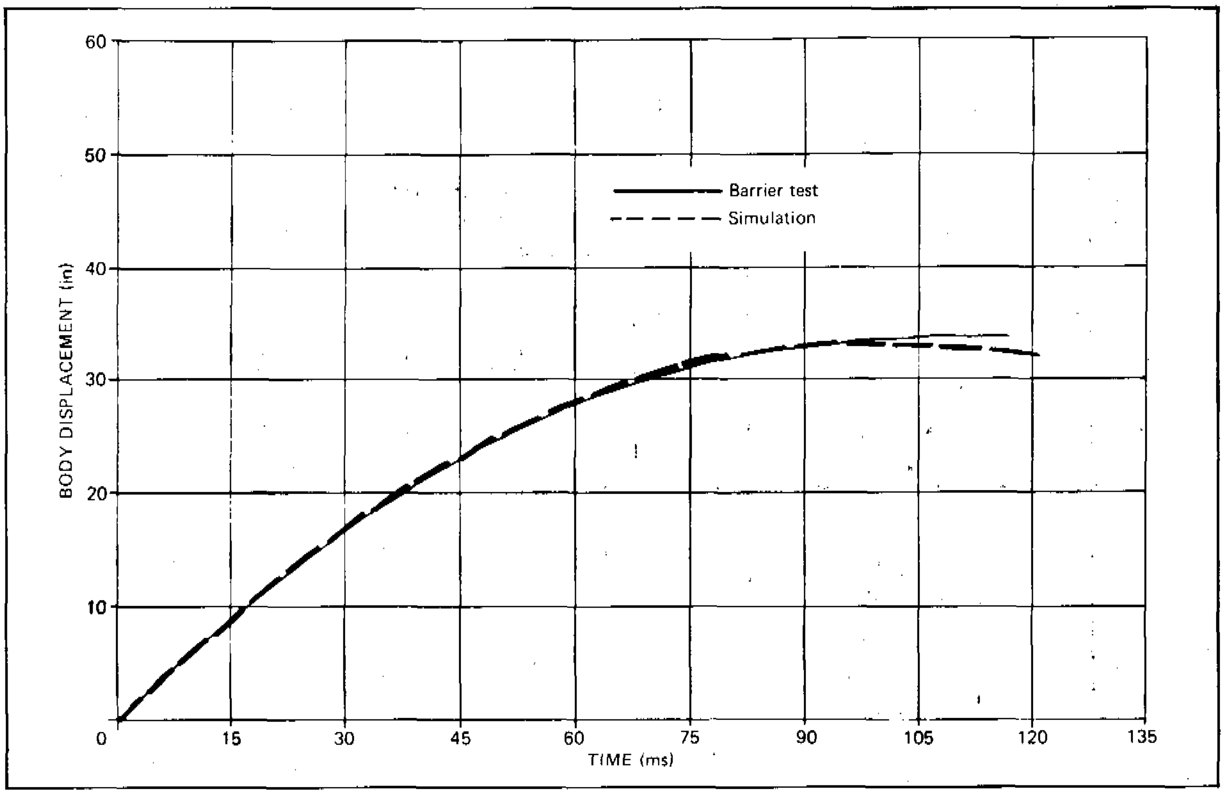


Figure 13. Simca 1307 body velocity comparison.

Figure 14. Simca 1307 body displacement comparison.



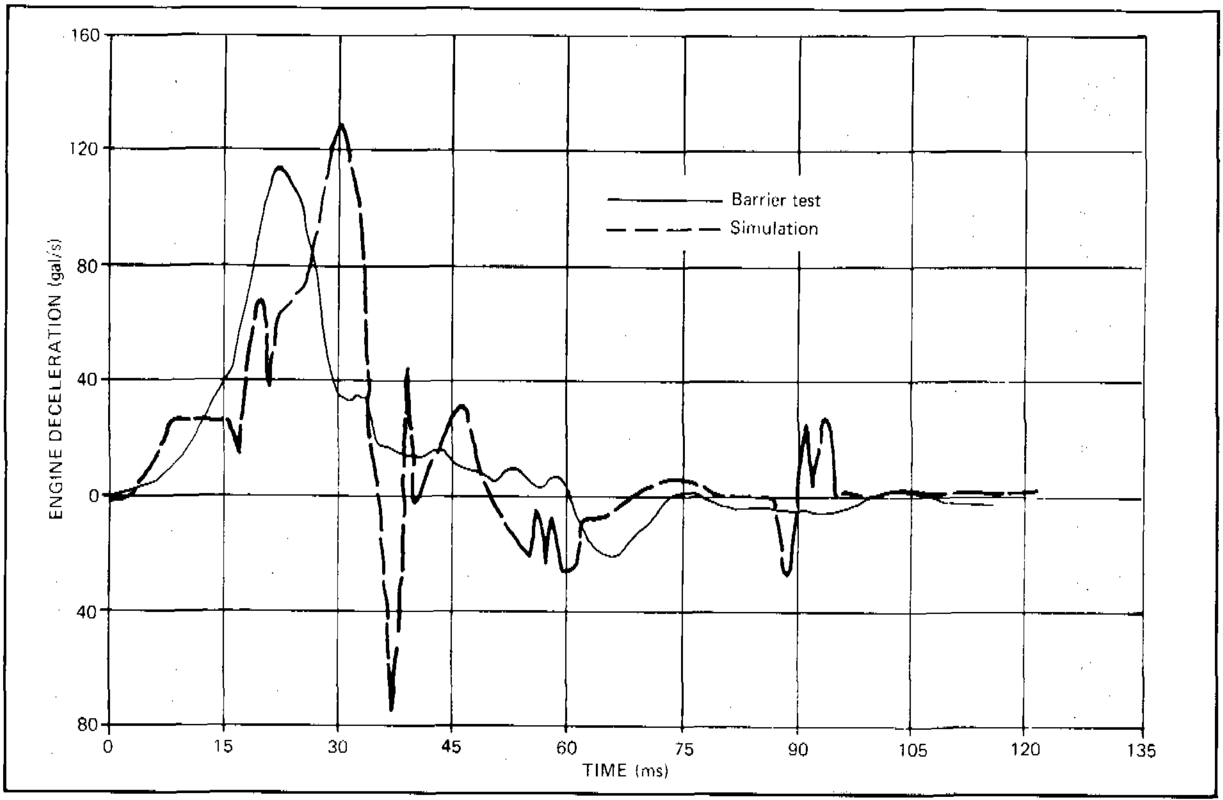
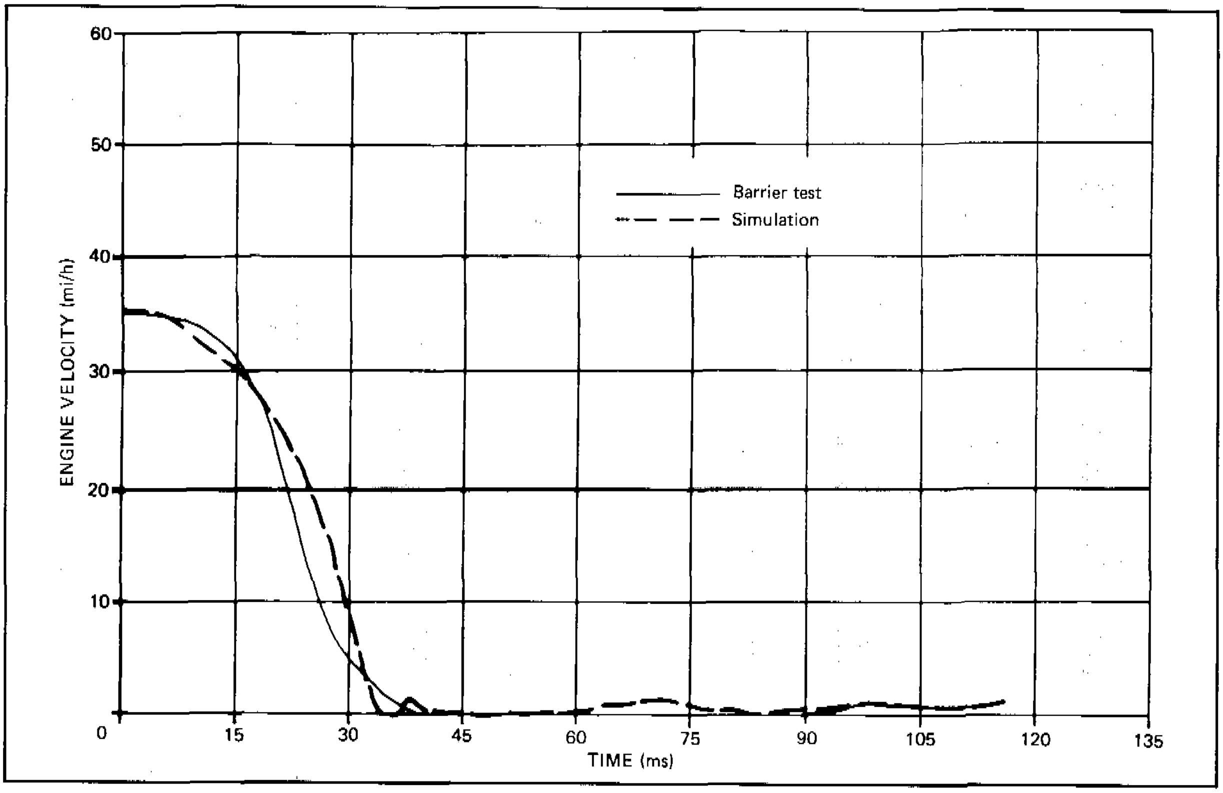


Figure 15. Simca 1307 engine deceleration comparison.

Figure 16. Simca 1307 engine velocity comparison.



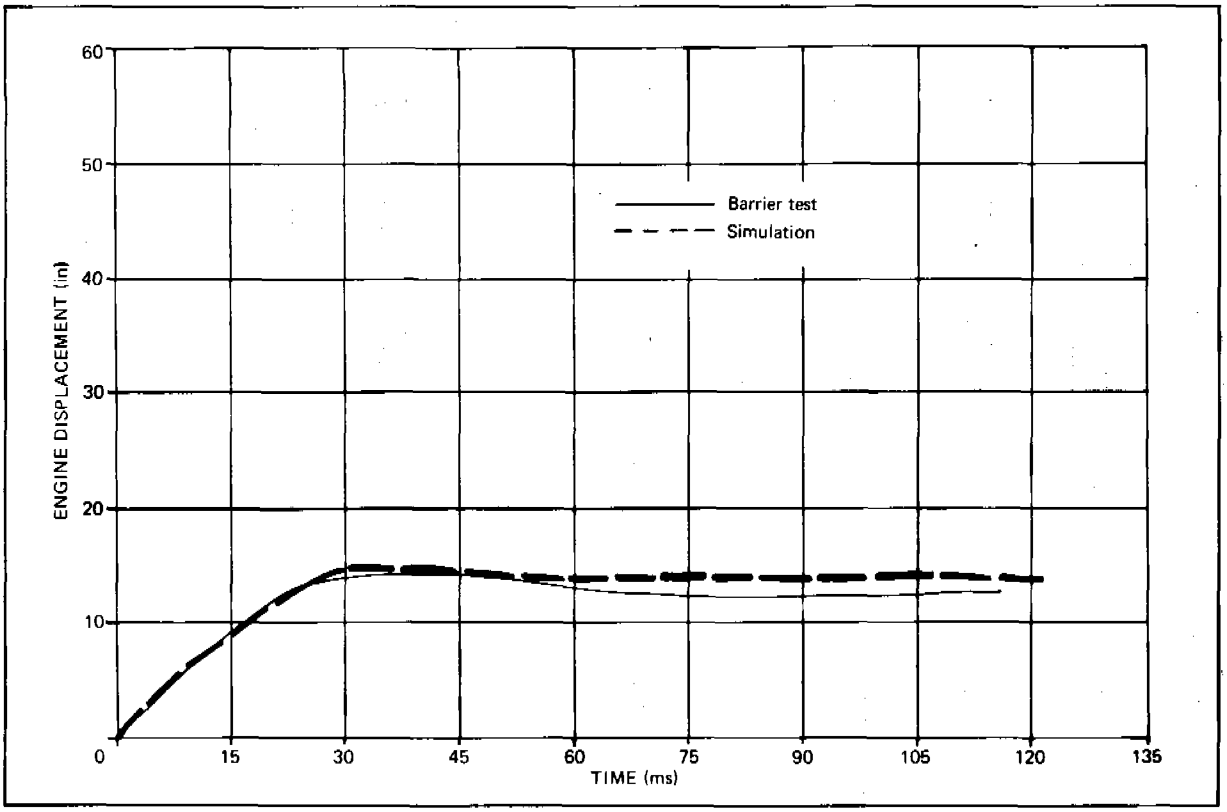
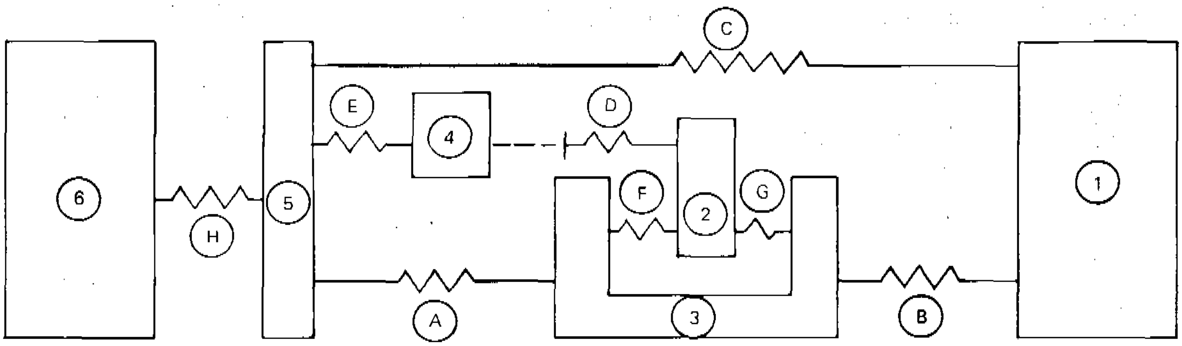


Figure 17. Simca 1307 engine displacement comparison.

Figure 18. RSV MINIBASH front impact model.



Masses	
1	Body
2	Engine
3	X-member
4	Radiator
5	Yoke
6	Barrier

Resistances	
A	Front of front rails
B	*Rear of front rails*
C	Sheet metal
D	Engine
E	Radiator
F	Engine mount **forward**
G	Engine mount rearward
H	Bumper

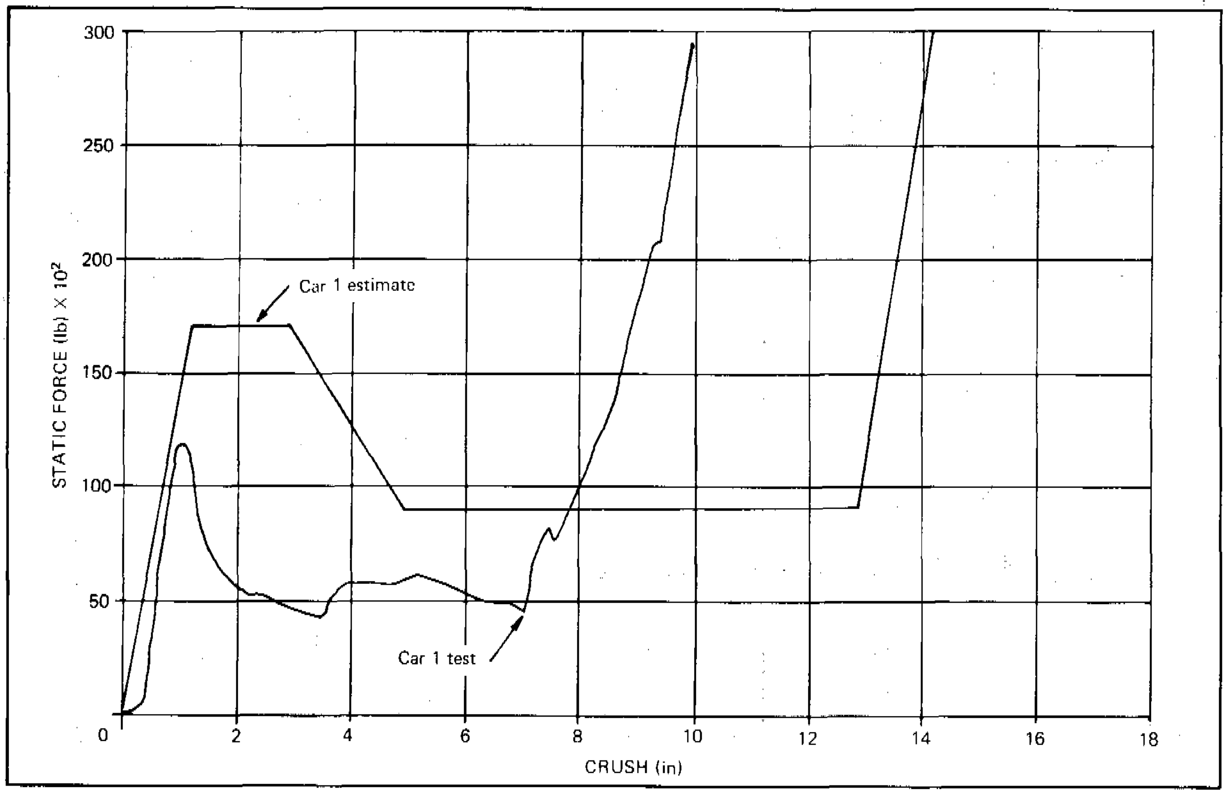
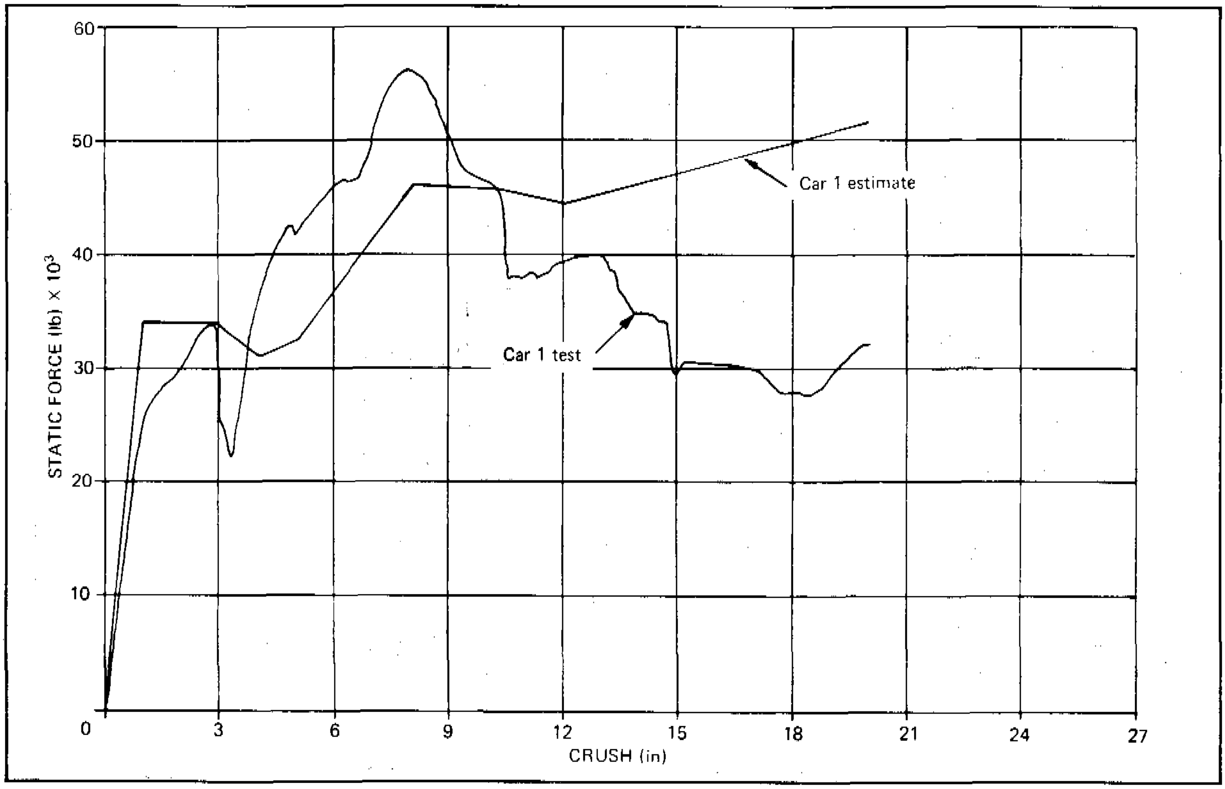


Figure 19. RSV Car 1 front of front rail static force deflection properties.

Figure 20. RSV Car 1 rear of front rail static force deflection properties.



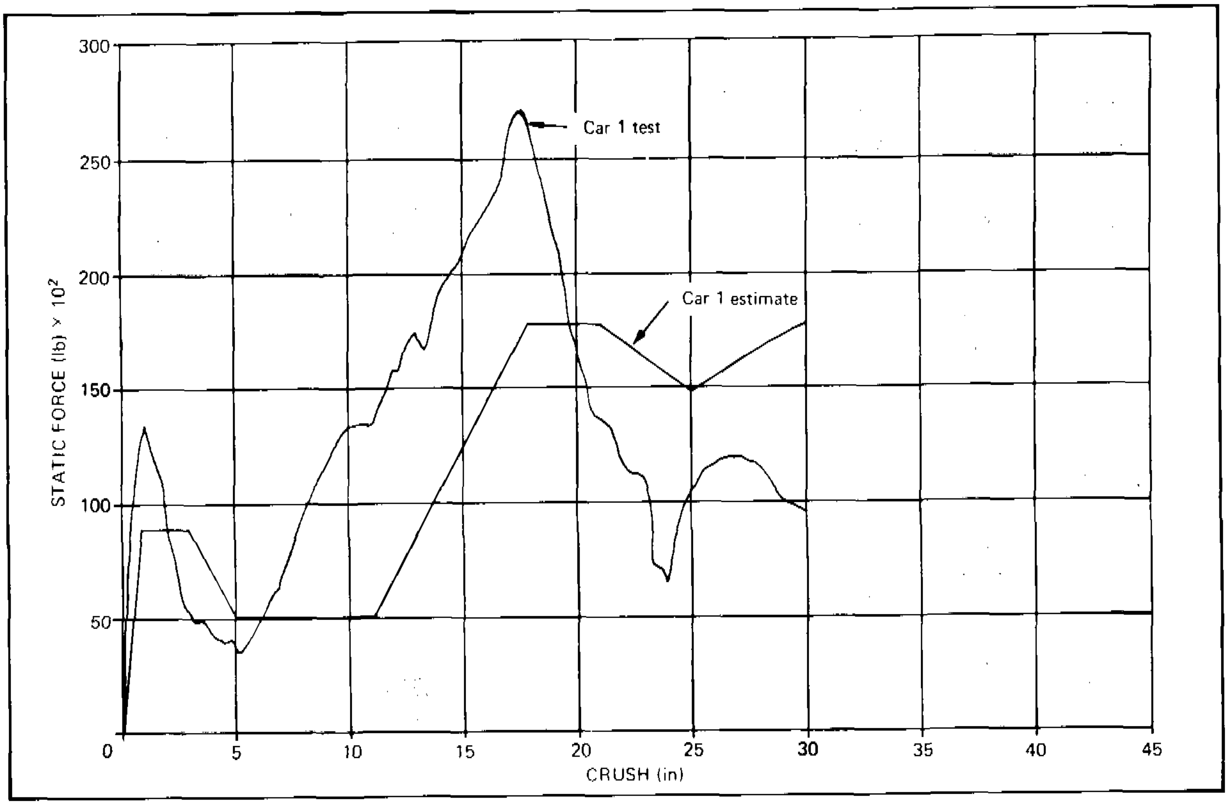
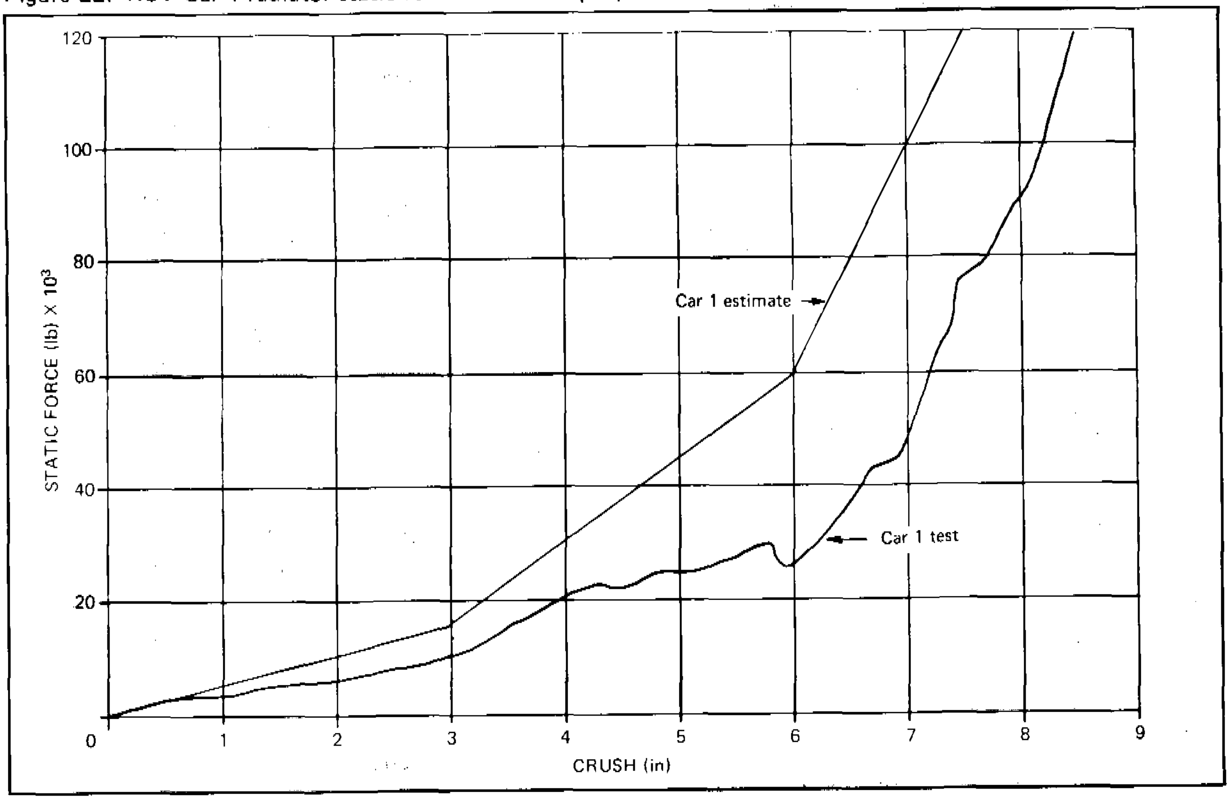


Figure 21. RSV Car 1 front sheet metal static force deflection properties.

Figure 22. RSV Car 1 radiator static force deflection properties.



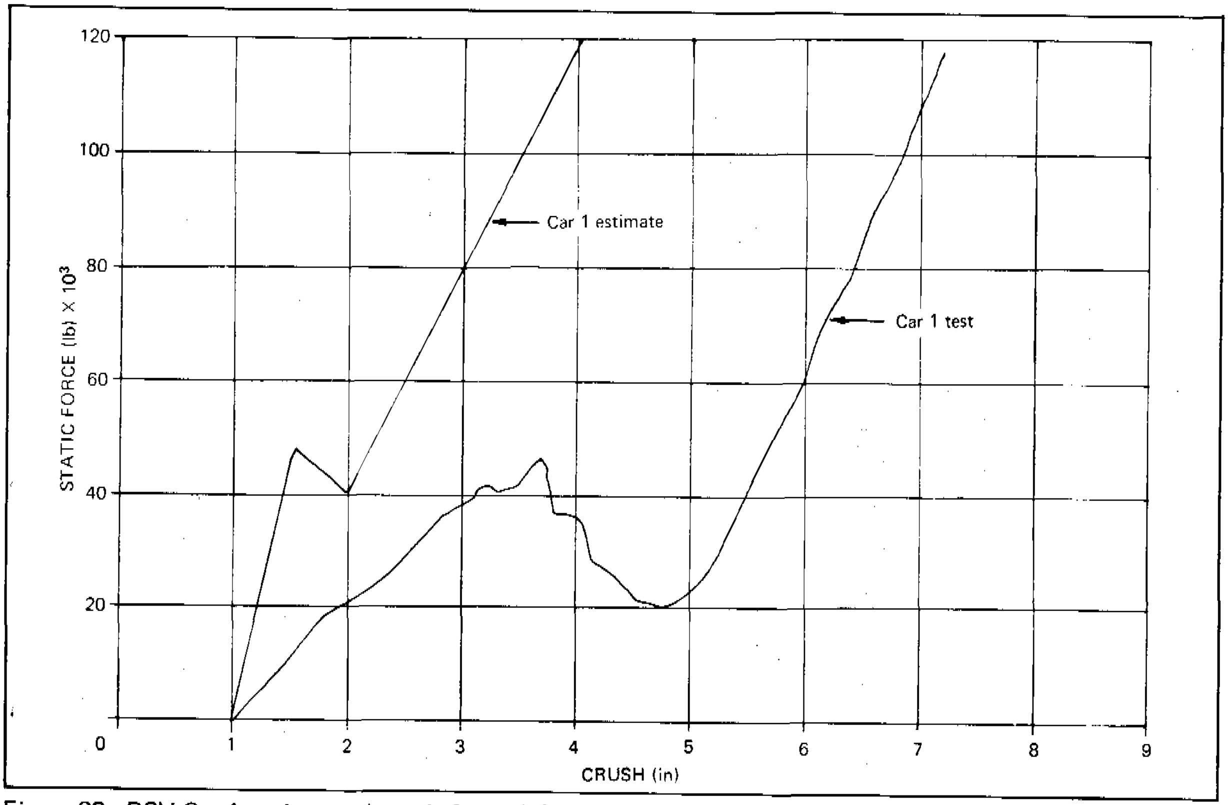
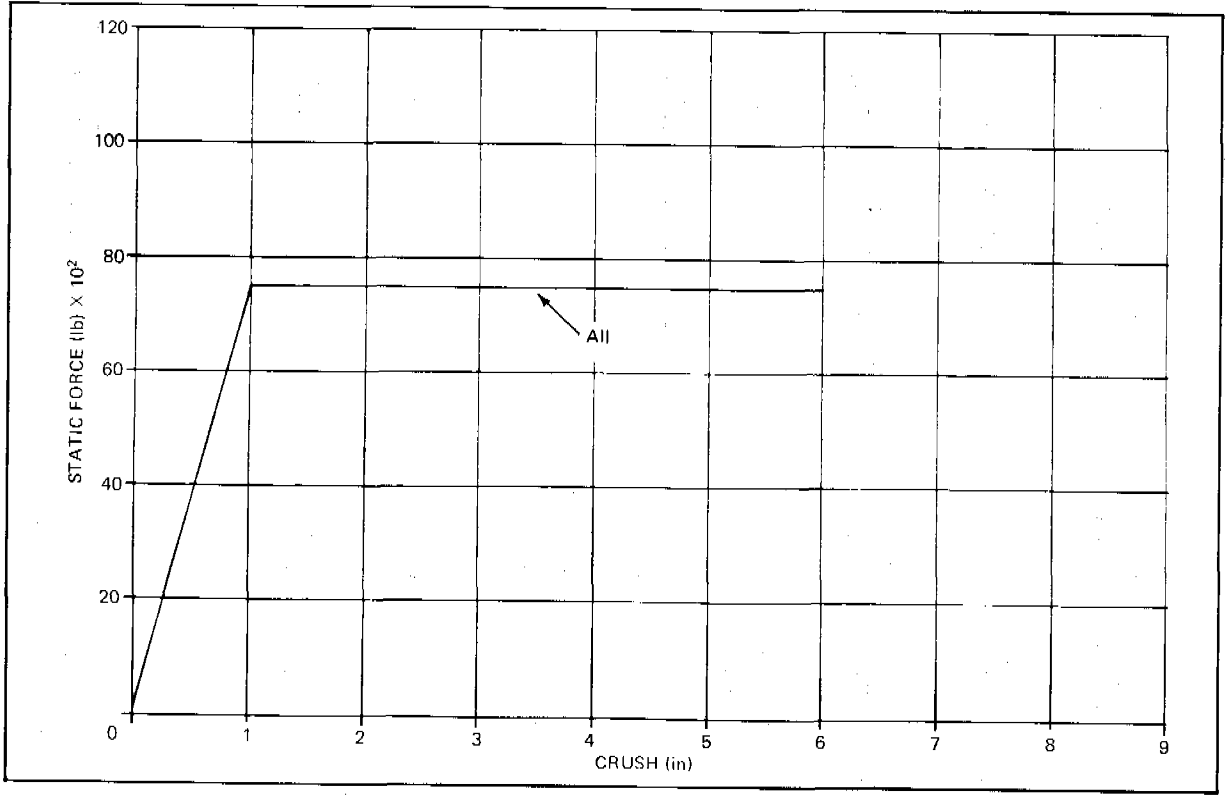


Figure 23. RSV Car 1 engine crush static force deflection properties.

Figure 24. RSV Car 1 engine mount forward static force deflection properties.



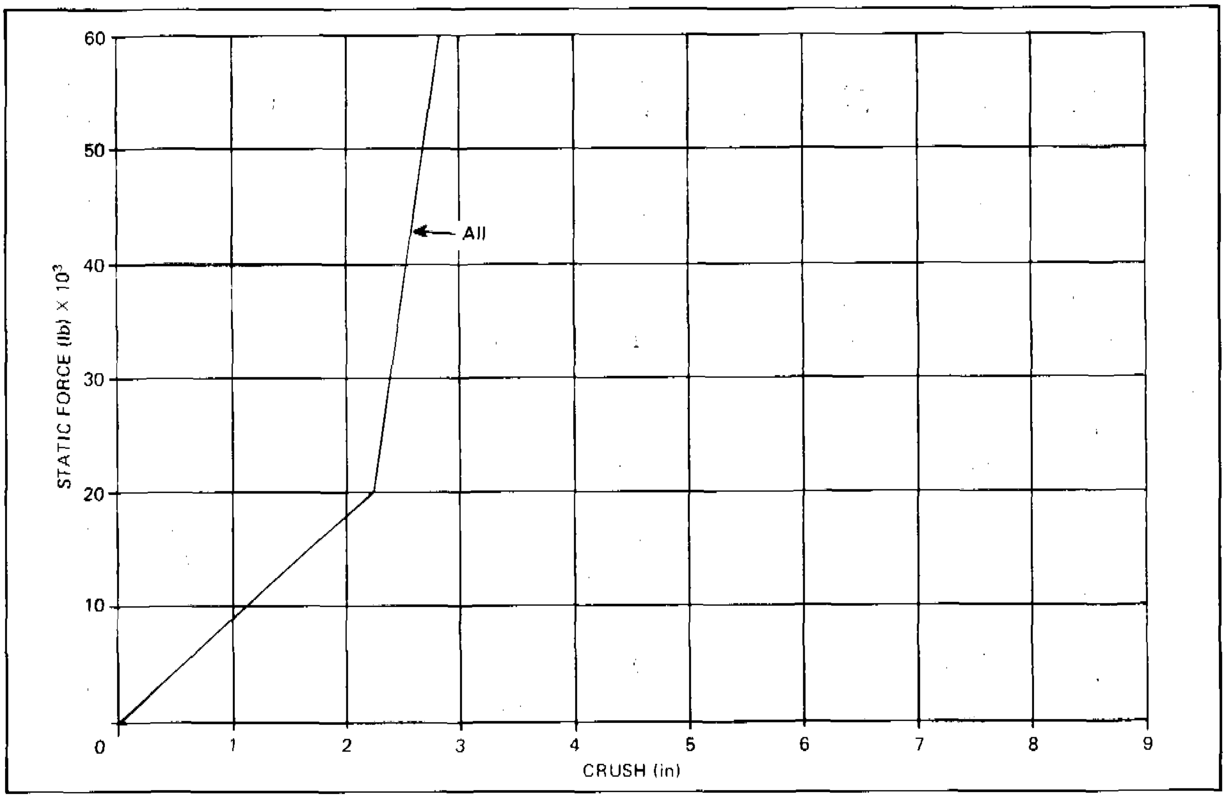
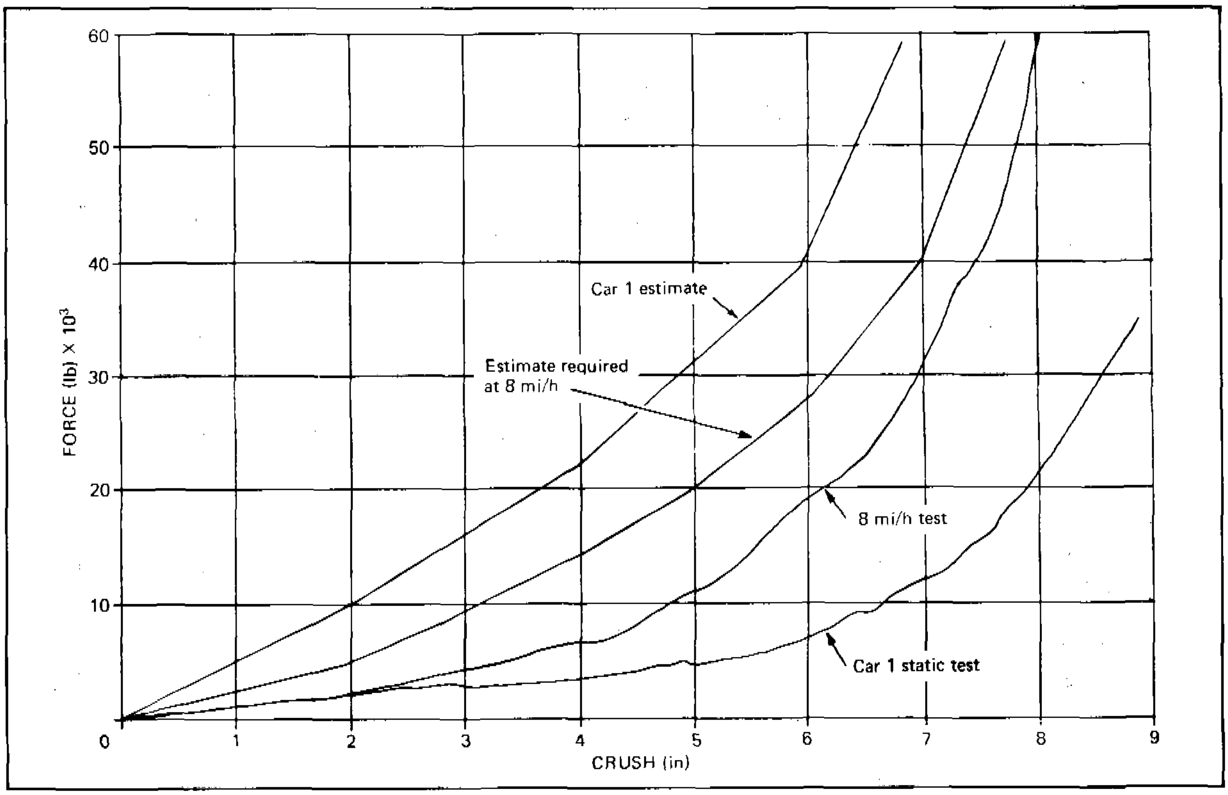


Figure 25. RSV Car 1 engine mount rearward static force deflection properties.

Figure 26. RSV Car 1 soft front bumper static and dynamic force deflection properties.



Computer program SECRIP calculates the allowable axial load and allowable bending moments about the horizontal and vertical axes for any thin-walled section that can be defined by a series of flat and/or curved elements. Empirical data are used to determine the allowable loads accounting for local type failures inherent to thin-walled sections. The basic allowables are determined for the geometric shape, then corrected by a material correction factor determined from the specific material compressive stress allowable and compressive modulus of elasticity. Because each cross-sectional element is calculated individually, a mixture of materials can be calculated in the same section.

Program SECRIP will calculate the peak elastic load in a beam element for a combined axial compressive load and moments about two orthogonal axes. The program calculates the allowable internal resisting moments which allows for a nonlinear bending stress across the section (plastic bending moments). When the point of external load application is known exactly and all external supports are accounted for, the predicted loads from the computer program have consistently been within a ±10 percent of the test results. For a complicated structure where the external point of load application can only be approximated and the external supports (such as a sheet metal panel welded to the beam) are ignored, the predicted results will likely deviate by a greater percentage from test results. The peak elastic load is the only load obtained from the program. Any sustained plastic crush must be estimated by other methods.

Using program SECRIP, the front structure for the first modified vehicle was identified. Figure 27 shows the areas of modification.

The front portion of the front rails was left open and the upper load beam was cut short to keep the force levels within the zone II requirements. For the zone III structure full rail and upper load beam sections were used. Additional structure was added in the center floor pan area to resist engine and steering rack rearward motion. Side structure was added to provide a load path for the increased upper load path forces. The side structure provides both longitudinal support for front impact loads and lateral strength for side impact modes.

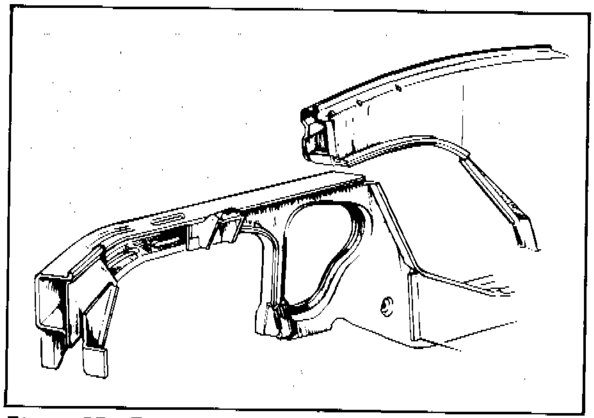


Figure 27. Front rail and upper load path modifications.

Build of First Modified Front Structure

The modified vehicles were built by Modern Engineering in Troy, Michigan. Temporary tools were built and used in stamping the unique parts (fig. 28).

The front longitudinals or front rails, which are all-new, were made from HSLA steel. The longitudinals are approximately 3 inches (80 mm) longer than the base 1307 part. The increased length was added to the wheelbase forward of the dash. The engine and suspension were moved as a unit forward. The length increase was based on early Phase I simulation studies which showed the need for additional sheet metal crush to manage the energy of a 40- to 50-mi/h barrier crash.

The front yoke panel was revised to provide attachment for the soft front end. A flat plane is provided with two lateral and two vertical reinforcements.

The upper load path beam is made from two stampings. The beam was tooled full length from yoke panel to dash to provide for flexibility in structural definition. The beam can be cut to any length providing significant variation in sheet metal force level.

The floor pan center tunnel reinforcement welds directly to the HSLA floor pan. The small clearances to the lower suspension crossmember and steering rack are provided to support these members and hold them off the dash panel during impact. The tunnel reinforcement provides a third major load path into the floor pan to supplement the paths provided by the front longitudinals.

The sills have been extended to the chain clearance line for this front-drive vehicle. After only a small rearward motion of the front wheels, the tires load the sill extensions and heavily reinforced structure of the sill.

The front structural modifications have been developed with close attention to typical assembly line techniques. The assembly process of the 1307 is disturbed only by the additional parts and the increased welding required. Current welding practices have been followed with spot welding as the primary attaching means. Special precaution and increased weld nugget size are necessary in joining HSLA parts to other HSLA components.

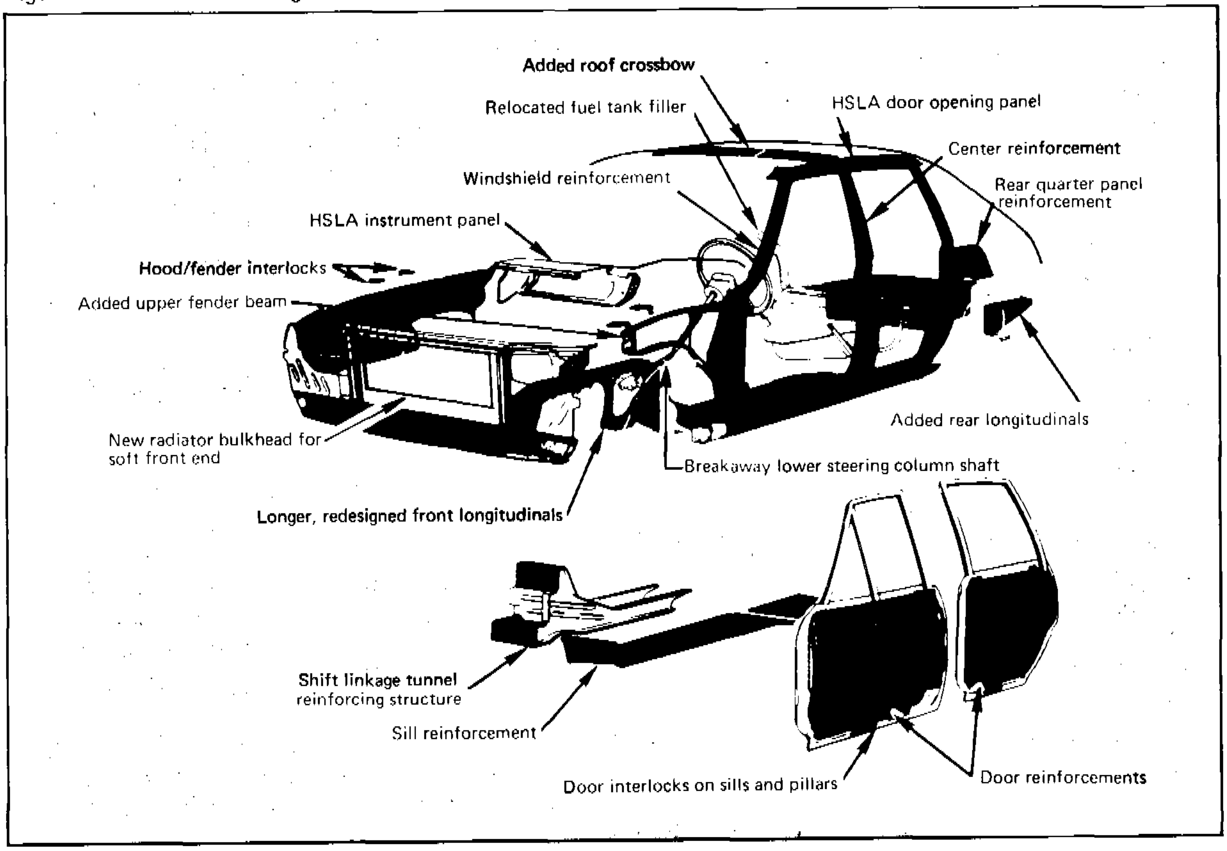
Front Static Test of First Modified Structure

A static front crush test was conducted on the modified structure. The test setup and procedure was the same as the base Simca 1307. The RSV actual force-deflection properties are shown in figures 19 through 26 along with the estimated curves.

There were several areas in the front structure that did not yield the desired load. The front rail elastic force was lower than expected and had a much higher plastic load drop than desired (fig. 19). This was because the rail was an open section with additional slots in the top and bottom flanges. The plastic crush load was much lower than the assumed 50-percent drop from the elastic peak load.

The rear of front rail force peak value was approximately as estimated; however, the floor pan between the rail and sill sheared from the sill before the peak rail force was

Figure 28. Structural changes.



reached. The end of the rear rail curve was lower than estimated because the sill was no longer loaded. The static force-deflection curves for the estimated and actual test results are shown in figure 20.

The sheet metal peak force was higher than estimated. Due to material availability, the upper beam was made from .048-gage material instead of the specified .038 gage. As a result, the A-pillar and cawl side structure was not capable of reacting the upper beam force. There was excessive A-pillar and cowl side crush that was not considered acceptable. The static force deflection curves for the estimated and actual test results are shown in figure 21.

The radiator crush, engine crush, and engine mounts, which are not significantly different from the base car, are shown in figures 22 through 26 along with the estimated curves.

Structure Definition for the Second Front Static Test Vehicle

During the first front static test the A-pillar reaction loads were recorded utilizing load cells at reaction number 5 (fig. 10). Before the second front static test vehicle was built, a side structure vehicle was tested in the longitudinal direction to determine at what force level the side structure was capable of reacting at the A-pillar belt line. With the front static test and the longitudinal test information available, the front structure was adjusted to bring the vehicle dynamic response within the desired envelope.

The front rail was boxed and the lower two slots were removed from the front rail to increase the force level and maintain a higher average crush load. Figure 29 shows this change.

The following changes were made in the structure which are included in the rear rail resistance. A notch was added to the bottom of the rail at the steering linkage access hole to promote rail buckling in this area. A shear panel was added between the rail and sill to prevent floor pan shearing from the sill. The center floor pan tunnel reinforcements were reduced in gage. Figure 30 shows these changes.

Figure 29. Front structure—second modified vehicle.