

Section 3
Results of ESV/RSV Development

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Minicars RSV

The Minicars Research Safety Vehicle

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ABSTRACT

The Research Safety Vehicle (RSV) is a light-weight safety car capable of protecting its front seat occupants in crashes up to 80 km/h (50 mph). It was designed and developed (up to prototype vehicle stage) by Minicars, Inc. of Goleta, California. The RSV gains its crashworthiness from a monocoque structure and advanced air cushion restraints. The car has no frame, but is constructed entirely from thin gauge sheet metal compartments which are foam-filled for energy absorption. The computer-aided design of the structure precisely located the compartments for maximum rigidity (with minimum weight) under normal use, and for energy absorbing crushability during crashes. Soft plastic exterior fascias afford significant protection to pedestrians and reduce damage in low speed accidents. A "high technology" version of the car has a manual transmission which is shifted by computer, a radar-based cruise control (for safe following distances), anti-skid brakes and a collision mitigation system which applies the brakes automatically when a collision is inevitable. There are plans (if capital can be raised) to manufacture a production engineered car by 1985.

INTRODUCTION

In 1974 Minicars, Inc. of Goleta, California conducted an analytical effort to predict and to quantify the societal costs of the automobile in 1985 (Reference 1). The costs included occupant and pedestrian casualties, property damage, maintenance and repairability, emissions, fuel economy, etc. Systems were conceived to deal with and to reduce the costs, and were themselves quantified for eventual consumer price. Combinations of these systems were assessed for overall payoff. Then a combination, which in essence maximized the benefits at the least consumer cost, was selected. That combination was the beginning of the design of the Research Safety Vehicle (RSV).

The following effort (Phase II of the RSV Program) developed the structure and restraint systems of the vehicle and established the compatibility of these systems for integration into a prototype vehicle (Reference 2). A number of important considerations were part of this design effort, including:

- Omnidirectional high-speed impact energy absorption and occupant protection in real world collisions
- Compatibility (a structure which not only protects its own occupants, but also minimizes the consequences of a crash for the occupants of the other car)

- Damageability with 16 km/h (10 mph) "no-damage" front and rear bumpers and soft fenders
- Repairability with a replaceable nose section which absorbs all damage in frontal impacts up to 32 km/h (20 mph)
- Pedestrian impact protection (reducing the levels of injury and the numbers of fatalities by contouring the front end and making its surface appropriately compliant)
- Collision avoidance driver aids (developed through the use of radar and microcomputer electronics).

The Phase III effort of the RSV Program had two parts (Reference 3). The first was the development of the integrated Research Safety Vehicle to the prototype stage (incorporating all of the currently practical and cost effective subsystems). The second was a research activity to demonstrate the applicability of some subsystems to production cars and to demonstrate the performance of other systems which hold promise for the future.

The vehicle effort produced prototypes (Figure 1), built from the ground up, which were designed to maximize safety, yet to maintain relatively high fuel economy, low emissions, public appeal and reasonable cost. But this is not a production car. The objective of the program was to demonstrate the feasibility and practicality of the subsystems, so that they could be integrated by the industry into vehicles the public could buy (Figure 2). It was understood that to mass produce the vehicle in quantities of hundreds of thousands of units per year would require a production engineering effort and a large capital investment.

The research effort produced two additional vehicle prototypes. The High Technology Research Safety Vehicle (Figure 3) incorporates a variety of electronic systems, including radar target detection, anti-skid braking, automatically shifted 5-speed manual transmission, and computer controlled collision mitigation (Reference 4). The Large Research Safety Vehicle (Figure

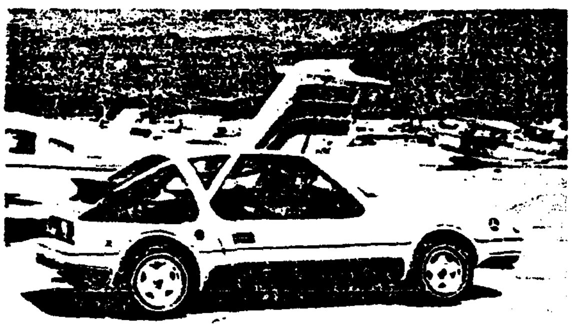

Figure 1. Research safety vehicle.

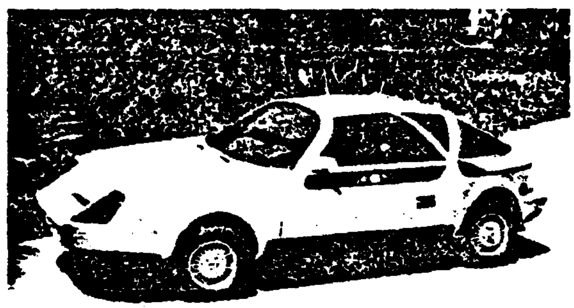

Figure 3. High technology research safety vehicle.

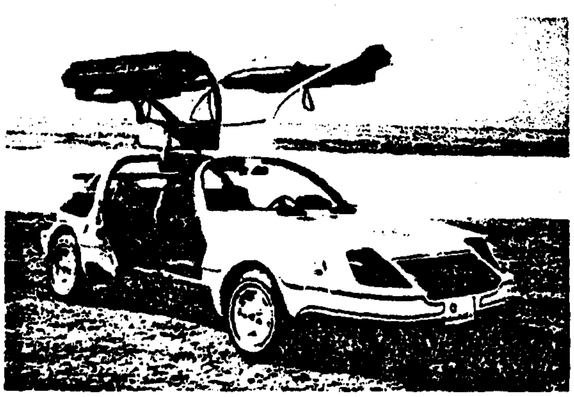

Figure 2. Gull wing doors.

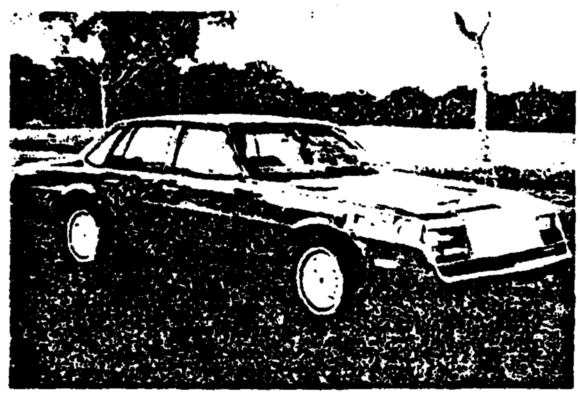

Figure 4. Large research safety vehicle.

4) incorporates the structure/restraint concept in a production car; this vehicle has greater impact energy absorption and protects its occupants up to 64 km/h (40 mph), but still has less weight and better fuel economy than the base production car.

RESULTS OBTAINED—VEHICLE EFFORT

Occupant Protection Crash Tests

Frontal Barrier

Table 1 summarizes the frontal barrier tests which have been conducted on the RSV. The test conditions and injury measures for each test are correspondingly labeled in the tables of Appendix A. With the exception of the Japanese barrier test (discussed later), the results of Table 2 are representative of the final configuration. These results show that there is a substantial margin between the RSV's nominal 80 km/h (50 mph) injury measures and the NHTSA injury criteria.

Car-to-Car Frontal

Table 3 summarizes the significant car-to-car frontal and frontal offset tests. Table 4 shows the results of a Phase IV evaluation test at Dynamic Science involving a head-on impact with a Dodge Challenger at 80 mph. This test is representative of the RSV car-to-car frontal impacts and again shows substantial injury measure margins. The fourth developmental crash test with the Chevrolet Impala (outlined in Table 5) used the same underpowered inflators that the Japanese test used (as will be discussed later) and allowed us to recall and replace the remaining defective inflator units. The development tests showed that it was possible, at least against frame structured vehicles (such as the Impala), to adjust RSV frontal structural stiffness to underride, override or remain aligned. The final configuration will neither

Table 1. RSV frontal barrier impact summary.

Date	Performing agency	Speed (km/h)	Speed (mph)	Driver HIC	Driver Chest Gs	Passenger HIC	Passenger Chest Gs	Remarks
5/12/76	Minicars	81.8	50.8	753	50	722	46	
7/9/76	Minicars	78.9	49.0	474	55	189	30	Right offset
10/7/78	Minicars	80.77	50.17	375	52	497	87	Stiff front structure
2/14/79	Minicars	76.6	47.6	304	45	554	48	
6/10/80	JARI	79.7	49.5	494	51	994	46	Inflator defect

Table 2. Frontal barrier impact (phase III).

Date: 2/14/79
RSV Speed: 76.6 km/h (47.6 mph)

	Driver	Right front passenger
HIC	304	554
Chest Gs (3 msec)	45	48
Left femur, kg (lbs)	568 (1250)	318 (700)
Right femur, kg (lbs)	716 (1575)	405 (890)

Table 3. RSV vehicle-to-vehicle frontal impact summary.

Date	Performing agency	Test mode	Closing speed (km/h)	Closing speed (mph)	RSV injury levels	Other car injury levels	Remarks
12/7/76	Minicars	Left offset RSV front into Volvo	131.8	81.8	Acceptable	---	
8/7/79	Minicars	RSV-Impala offset frontal impact	117.6	73.0	Acceptable	Acceptable	
11/14/79	Minicars	RSV-Impala aligned	101.2	62.8	Unacceptable		RSV underride
12/19/79	Minicars	RSV-Impala aligned	115.6	71.8	Unacceptable	Unacceptable	RSV override
8/18/80	Minicars	RSV-Impala aligned	126.4	78.5	Unacceptable	Unacceptable	Inflator defect
9/10/80	Dynamic Science	RSV-Dodge Challenger aligned	139.4	86.5	Acceptable	Unacceptable	

Table 4. RSV-Dodge Challenger frontal impact (Phase IV quick look results).

Date: 9/10/80
Location: Dynamic Science, Phoenix, Arizona
RSV speed: 69.7 km/h (43.26 mph)
Dodge Challenger speed: 69.7 km/h (43.26 mph)

	RSV left front	RSV right front	Dodge left front	Dodge right front
HIC	690	690	1690	3630
Chest Gs (3 msec)	41	42	92	77
Left femur, kg (lbs)	665 (1462)	483 (1062)	446 (982)	363 (796)
Right femur, kg (lbs)	666 (1465)	434 (955)	417 (917)	652 (1434)

underride nor override the Impala. The results of the individual vehicle-to-vehicle frontal tests are outlined in Appendix B.

Car-to-Car Side

Table 6 summarizes the car-to-car side impact crash tests. In all of these tests the RSV side structure and padding did an effective job of protecting the near side front seat occupant. Although the Part 572 dummy was used, we are convinced that, with padding density modifications, any dummy can be protected in equal weight car-to-car impacts at closing velocities to 64 km/h (40 mph). Fortunately, there are not many rear sear occupants, because the crash dynamics maximize intrusion in that area, and the velocity of dummy interior impact limits rear seat

Table 5. Fourth RSV-Impala frontal impact.

Date: 8/18/80
RSV speed: 63.21 km/h (39.26 mph)
Impala speed: 63.21 km/h (39.26 mph)

	RSV driver	RSV right front passenger	Impala driver	Impala right front passenger
HIC	807	1259	391	763
Chest Gs (3 msec)	45	49	64	77
Left femur, kg (lbs)	455 (1000)	343 (755)	851 (1873)	646 (1422)
Right femur, kg (lbs)	500 (1100)	457 (1006)	1148 (2526)	919 (2022)

Table 6. RSV side impact summary.

Date	Performing agency	Test mode	Speed		Bullet car injury levels	Target car injury levels*	
			(km/h)	(mph)		Front	Rear
11/19/76	Minicars	Volvo into RSV at 270°	63.1/63.1	39.2/39.2	Acceptable	66/40/35	--
6/8/79	Minicars	Impala into RSV at 90°	56.4/56.4	35.0/35.0	--	540/32/32	244/65/50
5/28/80	Renault	Renault into RSV at 270°	50/0	31/0	--	46/50/42	42/47/40
6/17/80	Renault	Renault into RSV at 90°	67.5/0	40.8/0	--	172/50/70	--
6/17/80	JARI	RSV into Datsun 510 at 270°	56.4/56.4	35/35	Acceptable	56/31/76	127/45/72
6/24/80	JARI	Datsun 510 into Datsun 510 at 270°	56.5/55.8	35/34.7	Acceptable	88/55/107	117/80/102
7/4/80	JARI	Datsun 510 into RSV at 270°	56.4/56.4	35/35	Acceptable	23/28/27	70/61/93
7/10/80	JARI	Datsun 510 into RSV at 90°	64.1/64.4	39.8/40	Acceptable	30/56/38	87/84/69

*Nearside occupants only; HIC/Chest Gs/Pelvic Gs.

survival to somewhat lower velocities. Appendix C presents more details of the side impact tests.

Car-to-Car Compatibility

The tests of Tables 7 and 8 were run for compatibility purposes and involved side impacts on a Datsun 510 target car by both an RSV and a Datsun 510: in both tests the target and bullet cars were traveling at 56.4 km/h (35 mph). Table 9 compares the injury measures received in these impacts by the Datsun front and rear near side dummy occupants. Clearly, the forgiving front end design of the RSV has a substantial favorable effect on the observed injury measures.

Table 7. RSV into Datsun 510 left side at 90° (aggressivity test — Phase IV quick look results).

Date: 6/17/80
Location: JARI, Tsukuba, Japan
RSV speed: 56.4 km/h (35 mph)
Datsun 510 speed: 56.4 km/h (35 mph)

	RSV driver	RSV right front passenger	Datsun left front passenger	Datsun left rear passenger
HIC	83	83	56	127
Chest Gs (3 msec)	28	27	31	45
Pelvic Gs (3 msec)	24	21	76	72

Table 8. Datsun 510 into Datsun 510 right side at 90° (Phase IV quick look results).

Date: 6/24/80
Location: JARI, Tsukuba, Japan
Bullet vehicle speed: 56.5 km/h (35 mph)
Target vehicle speed: 55.8 km/h (34.7 mph)

	Target vehicle		Bullet vehicle	
	Left front	Left rear	Left front	Right front
HIC	88	117	98	40
Chest Gs (3 msec)	55	80	23	15
Pelvic Gs (3 msec)	107	102	26	19

Table 9. Compatibility (aggressivity) tests.

Location: JARI, Tsukuba, Japan
RSV and Datsun 510 bullet speed: 56.4 km/h (35 mph)
Datsun 510 target speed: 56.4 km/h (35 mph)

	Datsun passenger			
	Left front		Left rear	
Bullet vehicle	RSV	Datsun	RSV	Datsun
HIC	56	88	127	117
Chest Gs	31	55	45	80
Pelvic Gs	76	107	72	102

Rear Impact

The only rear impact conducted in the program thus far was in Phase II, as shown in Table 10. The injury measures were acceptable in the 40 mph Volvo impact.

Rollover

The only rollover test was also conducted in Phase II; this test clearly demonstrated the capability of the structure and padding to protect both front and rear seat occupants without seat belts, as shown in Table 11.

Fuel Economy and Emissions

Table 12 shows the results of the RSV fuel economy and emissions testing at Western Washington University. These tests turned out quite well, even though not conducted strictly in accordance with EPA procedures (which would be at 4,000 and 50,000 miles).

Collision Avoidance Capabilities

Although the focus of the RSV program was on crashworthiness, the collision avoidance capabilities of the vehicle were not ignored. Table 13 summarizes the tests conducted at JARI in Japan and at Daimler-Benz in West Germany. In both sets of tests the RSV met the IESV goals, except for lateral deviation on irregular pavement and hill holding with the parking brake. Only at JARI did the stopping distance (with front brake system failure) and the returnability (at 40 km/h in a clockwise direction) exceed the specifications. There is some question about the adequacy of Minicars' front end set-up procedures, since both cars exhibited free play in the steering mechanism. Unfortunately, there was insufficient time prior to the conference to investigate and retest the car.

Pedestrian Impact Mitigation

Pedestrian impact tests were conducted at the Battelle Institute, Columbus, Ohio. Table 14 shows the difference in performance achieved with the front fascia positioned directly on the foam bumper, as in the nominal configuration, and that achieved with the fascia moved 5 inches forward of the bumper. Clearly, the knee impact accelerations and other injury measures are significantly reduced. Our conclusion is that providing about 3 inches of (low force) deformation space between the fascia and the bumper will reduce the already favorable pedestrian impact

Table 10. Volvo into stationary RSV rear (Phase II).

Date: 7/29/76
Volvo speed: 63.9 km/h (39.7 mph)

	RSV passenger	
	Right front	Right rear
HIC	185	104
Chest Gs (3 msec)	50	40
Pelvic Gs (3 msec)	50	75

Table 11. Rollover test (Phase II).

Date: 12/17/76
Dolly: Inclined per FMVSS 208
Dolly speed: 49.6 km/h (30.8 mph) (Three complete rolls)

	Driver	Left rear passenger
HIC	100	100
Chest Gs (3 msec)	7	6
Pelvic Gs (3 msec)	10	8

Table 12. Fuel economy and emissions tests.

Tests were performed by Western Washington University using EPA dynamometer test procedures on a low mileage RSV with a 1980, 1.5 liter Honda engine and Michelin tires:

Test weight	1307 kg	(2875 lbs)
Road load	11.15 hp	
Urban fuel economy	12.3 km/l	(28.0 mpg)
Highway fuel economy	17.5 km/l	(41.2 mpg)
Combined fuel economy	14.2 km/l	(33.4 mpg)

Emissions assuming that these low mileage emissions are representative of 50,000 mile performance:

Hydrocarbons	0.40 g/mi
Carbon monoxide	2.53 g/mi
Nitrous oxide	0.71 g/mi

injury measures, without significantly affecting any other performance aspect of the vehicle.

Damageability Tests

Low-speed damageability tests were conducted at Dynamic Science in August. As indicated in Table 15, the tests confirmed the design intention to minimize impact damage in circumstances in which a conventional car (such as the Citation) would incur substantial costs of repair. The author has personally taken a baseball bat to the RSV's soft fenders without damage—although, unfortunately, no comparable demonstration was made with the Citation.

Accommodations

Figure 5 shows the front seat accommod tions of the RSV. The interior volume (calc lated by EPA criteria) is equivalent to that a compact car, and the ease of entry and ex seating comfort and driver instrumentati are rated "good" in subjective judgmen Obviously, each car manufacturer judg interior accommodations by his own criteri so it is only our intention to illustrate that t safety features incorporated in the car ne not interfere with or preclude an acceptat interior configuration. Note, in particular, t

Table 13. Collision avoidance tests (Phase IV quick look results).

The following tests were performed by JARI in Japan during April and May, 1980, and by Daimler-Benz in West Germany during June and July, 1980:

- Steady state yaw response
- Transient yaw response
- Returnability
- Lateral acceleration
- Control at breakaway
- Crosswind sensitivity
- Steering control sensitivity
- Pavement irregularity
- Overturning immunity
- Brake effectiveness
- Stopping distance
- Parking brake

In both sets of tests the RSV met the IESV goals, except:

- Pavement irregularity lateral deviation
  Reason—free play in the steering
- Hill holding—parking brake
  Reason—added weight
- Stopping distance front system failure mode*
  Reason—improper bleeding
- Returnability at 40 km/h (25 mph) clockwise direction*
  Reason—free play in the steering system

*JARI only.

Table 14. Pedestrian impact tests* (Phase III).

Velocity impact (mph)	Fascia position	Peak resultant acceleration at time after impact										Head severity index
		Head		Chest		Pelvis		Knee		Foot		
		(Gs)	(msec)	(Gs)	(msec)	(Gs)	(msec)	(gs)	(msec)	(Gs)	(msec)	
20.1	Normal	94	138	25	126	29	16	80	10	200	62	661
25.0	Normal	133	116	34	129	48	24	112	8	330	52	1307
20.0	5″ forward	63	159	29	160	33	69	42	31	39	89	258
25.0	5″ forward	75	130	22	78	58	46	50	24	260	56	838

*Performed by the Battelle Institute.

Table 15. Low-speed damageability tests (Phase III).

Date: August 1980
Performed by: Dynamic Science
Vehicles: RSV and Chevrolet Citation

Test mode	Impact speed (km/h)	(mph)	Bullet vehicle damage	Target vehicle damage
RSV front into RSV rear	20.77	(12.9)	No visible damage	Cosmetic damage
RSV front into RSV rear	24.96	(15.5)	No visible damage	10 cm crack in taillight fiberglass panel
RSV front into Citation rear	24.96	(15.5)	No visible damage	Significant pressure buckles forward of and above each wheel opening ($599)
RSV front into Citation left side	8.37	(5.2)	No visible damage	Maximum door skin depression ($351)
RSV front into RSV side	8.21	(5.1)	No visible damage	Two small impressions were left on the outer skin of the door
RSV front into barrier	13.36	(8.3)	No visible damage	None
RSV front into barrier	28.18	(17.5)	Noticeable permanent deformation across entire bumper face and across bolt-on structural section	None

high mounted instrumentation, the transparent headrest, the lack of front seat belts and the rear seat leg room.

RESULTS OBTAINED—RESEARCH EFFORT

High Technology RSV

The High Technology RSV incorporates the electronic control features listed in Table 16. Since it is a research vehicle (involving first and second generation development electronics), no extensive evaluation tests were conducted. The development testing did indicate that collision mitigation braking can reduce the velocity of the vehicle by 25 to 65 km/h (15 to 40 mph). This braking is triggered by a computer which processes the radar system signal. The computer/radar combination virtually precludes highway false alarms. The car-following cruise control works substantially better than a human driver in controlling engine power to maintain steady following distances. The anti-skid braking system works well on a variety of skid-producing surfaces. The automated electronically controlled 5-speed manual transmission provides excellent fuel economy with the smoothness of a good manual shift driver. The electronic display shown in Figure 6 is likely to be the forerunner of more production-oriented displays of a comparable level of sophistication.

Table 16. Electronic control features of the high technology RSV.

Collision mitigation braking	—	Reduces impact speed 15 to 40 mph
Car-following cruise control	—	Maintains distance without hunting
Anti-skid braking	—	Holds lane on wet, gravel, ice, irregular road; operates on 4-wheel differences
Automated manual transmission	—	Electronic shifting utilizes 5-speed manual selection for fuel economy
Electronic display	—	32-character operating analog, digital status, diagnostic message modes

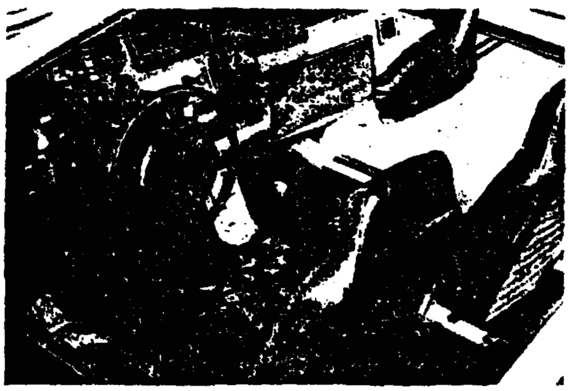

Figure 5. Front seat accommodations.

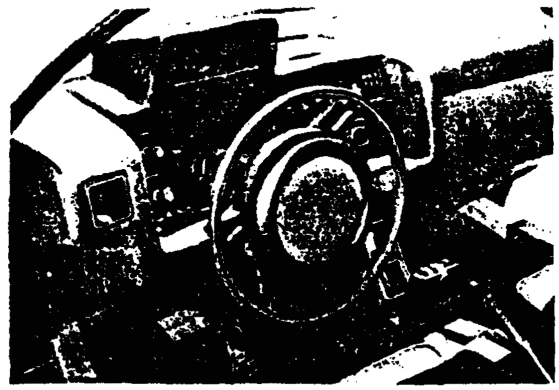

Figure 6. Electronic display.

Large Research Safety Vehicle

Crashworthiness

The Large Research Safety Vehicle has now completed a number of crashworthiness tests, as shown in Table 17. We have demonstrated low injury measures (relative to the NHTSA injury criteria) for all three front seat passenger positions and in both frontal and angled barrier tests to 65 km/h (40 mph). Although not at the same speed, a marked improvement in side impact protection compared to the original Impala padding was observed when RSV type padding was added. (The last two tests listed in Table 17 compare the results.) Summaries of the individual tests are presented in Appendix D.

Fuel Economy and Emissions

The fuel economy and emissions performance tests conducted by D&M Engineering are outlined in Table 18. The results indicate that a full size car can be designed (through weight reduction and available technology) to exhibit significantly higher crashworthiness, and at the same time to achieve much improved fuel economy and reduced emissions.

PROGRAM CONCLUSIONS

Through the insight of the management of the National Highway Traffic Safety Administration, and the able direction of their Contract Technical Manager, Mr. Jerome Kossar, there are many things about the car that are just right. There have been, of course, some disappointments, and some concepts which, while they work well in tests, need real world evaluation.

A major problem has been the weight growth of the car (Table 19). We had hoped that, in the one iteration of the design from the Phase II subsystem efforts to the Phase III integrated car, we could maintain the weight budgets without a complete redesign. It turned out that, in order to accommodate all of the requirements for all of the subsystems simultaneously, the weight had to increase about 15 percent more than expected. Investigation has convinced us that the weight growth can be removed with iteration. Nevertheless, the car as tested (at 2578 pounds) is ap-

Table 17. LRSV impact tests.

Date	Mode	Speed		Occupant injury measures							
				Driver			Middle passenger		Right front passenger		
		(km/h)	(mph)	HIC	Chest Gs	Pelvic Gs	HIC	Chest Gs	HIC	Chest Gs	Pelvic Gs
5/9/79	Frontal barrier	62.8	37	174	37		169	30	178	30	
7/20/79	30° barrier	54.4	40	248	32		74	25	130	30	
10/4/79	90° side bogey Impala padding	48.3	30	627*	150*	105*			182	90	100*
2/7/80	270° side bogey RSV type padding	41.2	25.6	132	55	55					

*Right rear passenger.

Table 18. LRSV fuel economy and emissions tests.

Tests by D&M Engineering using EPA dynamometer test procedures on a low mileage LRSV with a 1978, 1.9 modified B19 Volvo engine.

Test weight	1477 kg	(3250 lbs)
Road load	10.8 hp	
Urban fuel economy	9.75 km/l	(22.9 mpg)
Highway fuel economy	15.4 km/l	(36.2 mpg)
Combined fuel economy	11.7 km/l	(27.5 mpg)

Emissions assuming that these low mileage emissions are representative of 50,000 mile performance:

Hydrocarbons	0.19 g/mi
Carbon monoxide	2.38 g/mi
Nitrous oxide	0.57 g/mi

proximately 272 pounds over our target weight. This weight growth is not overly surprising—nor is there any reason to doubt the ability to eliminate it in production.

Minicars has been able to show with the LRSV that the next generation of full size six-passenger cars can weigh 20 percent less than the 1977 Impala (Table 20), and still protect their occupants to 65 km/h (40 mph). At its current weight, 80 km/h (50 mph), occupant protection is possible. Later in this Conference, Volkswagen will conduct a 55 to 65 km/h (35 to 40 mph) crash test of a Minicars prepared front seat airbag Citation. This vehicle weighs 180 kg (400 pounds) less than the LRSV. In several previous conferences the opinion has been expressed that improved safety involves substantial weight and cost penalties. Yet we have proven that performance can be increased while weight is being significantly reduced.

Another disappointment was that the injury measures in the first Phase IV evaluation tests (conducted in Japan) were substantially higher than those that had been obtained during development a year earlier. A Phase III two-car head-on frontal development test with full instrumentation was conducted soon thereafter, with similarly disappointing results.

The instrumentation led us to suspect, in our first "defects" investigation, that the passenger restraint was not performing correctly. We then conducted some component tests and found (as shown in Figure 7) that the inflators used in the two tests (and installed in all vehicles for Phase IV evaluation) were significantly different from the earlier development test units. The most recently delivered inflators filled the bags significantly slower than did the earlier development units (perhaps because Thiokol had used a different

Table 19. RSV weight by system.

System	Phase II estimated weight (lbs)	Final Phase III prototype weight (lbs)	Difference (lbs)	Reasons for major differences
Body-in-white (including foam)	579	632	+53	Bolt-on nose, side sills, rear structure, etc., redesigned for increased stiffness; thicker gauge mild steel parts substituted for HSLA steel parts.
Powertrain/rear suspension (including engine cradle & accessories)	609	532	−77	Poor initial estimate, engine cradle redesigned.
Wheels & tires	166	194	+28	Specified heavier run-flat wheels and tires.
Fenders, fascias, hood surround, rear air scoops & body panel & attaching hardware	56	135	+79	Poor initial estimate, in-house fabrication techniques resulted in unnecessarily thick FRP parts, wheel houses added.
Two doors (including glazing)	142	250	+108	Latching and locking mechanisms moved from body-in-white to doors, added structure to increase strength and stiffness.
Front suspension & steering	102	102	0	
Steering wheel & column, driver ACRS	43	44	+1	
Electrical system (including battery)	43	43	0	
Brake system (includes assembly & brake lines; does not include disks, calipers or pads)	23	41	+18	Vacuum boost system added.
Cooling system	23	39	+16	Aluminum tubing substituted for plastic tubing.
Rear hatch (including glazing)	25	34	+9	
Hood	11	32	+21	Redesigned for increased rigidity and pedestrian protection.
Fuel cell, filler & emissions	27	31	+4	
Bumpers (excluding fascias)	18	30	+12	Rubrics added.
Driver seat	29	28	−1	
Passenger seat	29	28	−1	
Rear seat	12	21	+9	
Passenger ACRS	25	21	−4	
Heater, defroster & ventilation	20	18	−2	
Floor covering	12	18	+6	
Interior padding and trim (excluding doors & dash)	25	15	−10	
Dash	8	12	+4	
Weather sealing	6	11	+5	
Lighting	11	11	0	
Rear passenger restraints	16	10	−6	
Gear shift	3	10	+7	
Windshield wiper & washer	8	10	+2	
Instrument panel	4	8	+4	
Parking brake	6	7	+1	
Front bulkhead	5	7	+2	

Table 19. (Continued)

System	Phase II estimated weight (lbs)	Final Phase III prototype weight (lbs)	Difference (lbs)	Reasons for major differences
Engine cover	4	6	+2	
Accessories	8	5	−3	
Center spine cover	10	4	−6	
Indirect vision	1	3	+2	
Door latches, locks & controls	6	—	—	See Doors.
Paint, body putty, deadeners	74	50	−24	Initial estimate also included allowances for miscellaneous items.
Fluids	87	87	0	
Curb weight	2306	2578	+272	May not sum exactly due to rounding.

Table 20. LRSV weight reduction.

Base sedan curb weight*	3869 pounds
LRSV curb weight	2960 pounds
Total weight difference	909 pounds

Weight savings by systems and components	Weight change (pounds)
Engine transmission, differential & accessories	−290
Body-in-white, structure, door & glass	−157
Steering front suspension and brakes	−109
Rear suspension and brakes	− 79
Front fenders and rear deck	− 55
Front and rear bumpers	− 54
Hood	− 51
Other systems and components	−114
	−909

*Base sedan weight taken from MVMA Specifications.

lot of production grain). This led to a revision of our inflator specifications—and to our first, but completely successful, "recall" campaign.

There are also a variety of other problems which were not considered important enough to be completely resolved for prototype use, such as adequately counterbalancing and sealing the door. For performance tests these factors are not important, although the gull-wing doors of the show car have been effectively sealed and counterbalanced through most of the range of motion. Further, it isn't clear that a gull-wing door of this configuration is appropriate to a production vehicle.

Similarly, the A-posts were not designed to incorporate a recess for the glass windshield (as is found in stamped production posts), so there is some occlusion of vision in the frontal area. There is no doubt the change can be made, but

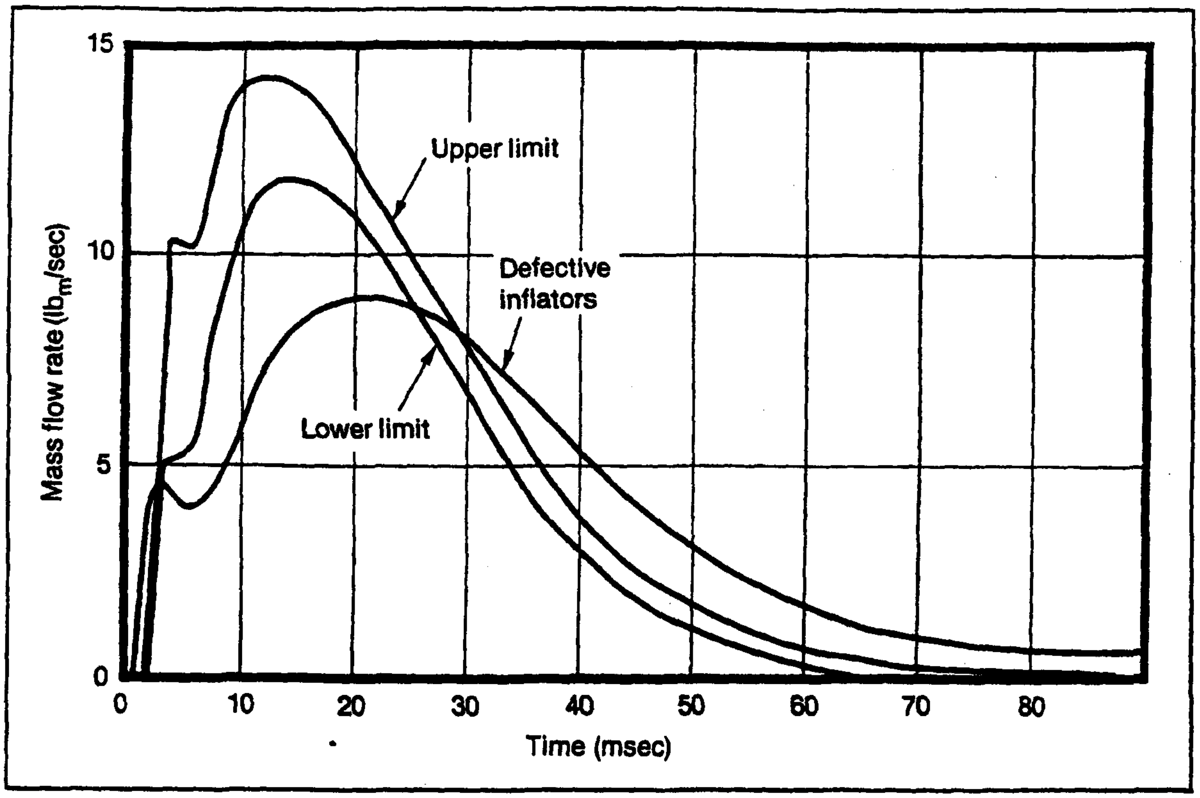

Figure 7. Inflator characteristics.

it presently seems inappropriate to invest the necessary funds in dies to produce the right configuration.

When the car grew in weight, changes should have been made to the suspension, steering, braking, engine and transmission systems. To adequately optimize the results, these changes would have added another 50 to 100 pounds—since those systems were designed for a target weight vehicle of about 2200 pounds. On the other hand, when the car was tested at 2578 pounds, only a few items required adjustment and modification. In most cases a modification was sufficient to make the vehicle perform as close to the program goals as possible without the iteration of design necessary to reduce the weight of the non-running gear. In only a few tests, such as pavement irregularity and hill holding, did the vehicle not achieve the performance goals we had hoped for. We believe that, with an additional design iteration and a production engineering effort, a commercial version will weigh 2200 pounds, and will achieve these goals.

Lastly, about eighteen months ago Minicars began to look into the feasibility of producing and marketing the RSV. Until that time, we viewed the project as a research and development effort adaptable to production. In Phase II the Budd Company had prepared a producible design in sufficient detail to estimate the investment costs at several hundred million dollars and the consumer price at about $7000 (1980 dollars) per vehicle. So we knew the car could be made (in hundreds of thousands per year) to sell at a reasonable premium in price and with an investment comparable to that of a conventional car. But then there was the question of whether people would buy in that quantity.

Numerous studies conducted by government, industry and public interest groups document strong positive consumer statements on automotive safety. A Harris poll, a Peter Hart Research Associates survey and various studies by General Motors (GM) verify the demand for safety. One 1979 GM study showed that 70 percent of those surveyed preferred airbags over automatic belts, even at a substantial price increase. The NHTSA commissioned three separate studies to assess market reaction to the RSV. All were extremely favorable.

The inevitable question, then, is "Why doesn't one of the auto manufacturers plan to produce this vehicle?" Obviously, the RSV concept involves more manufacturing, marketing and financial risk than a conventional car. The industry's present evolutionary improvement approach keeps perceived quality and value high, gradually educates the consumer and doesn't obsolete plant and equipment too fast; so where is the payoff for a manufacturer to change to an RSV concept?

If an auto manufacturer won't invest the necessary hundreds of millions of dollars, who would? One possibility is to manufacture the car in specialty car quantities. With 20 million dollars in private equity capital, federal loan guarantees of 40 to 60 million dollars are available under the right circumstances.

Pretty clearly, these financial considerations set the bounds for a new venture. Careful analysis has suggested that, in rented facilities in an area of substantial unemployment and low cost labor, with a minimum of pressed parts, and with engines and running gear which are already in production, 2,000 people could produce 20,000 to 30.000 cars per year (primarily with flat pattern fabrication tools and equipment, and hand-operated assembly jigs and fixtures).

Fortuitously, the body structure has already been designed for press brake fabrication. But how much would the car cost to make if fabricated in these quantities? This was roughly estimated three different ways. First, we commissioned Rath & Strong, who has computerized composite components price and weight lists, as well as adjustment algorithms for quantity, materials, labor cost, etc. Second, we visited, discussed and estimated the cost in conjunction with two specialty car manufacturers who actually make 25,000 to 30,000 cars per year. And, third, we made our own estimates from a careful analysis of the detailed manufacturing procedure. Our early estimate, being more specific, was $10,000 (1980 dollars) per unit.

The next question was, "Would anybody pay $10,000 for a car like this?" As a researcher, I have my own opinion about the validity of consumer surveys dealing with unavailable products, so we commissioned A.T. Kearney, a management consulting firm, to interview auto dealers and see what they thought. Their conclusion was that each dealer could sell ten cars per month in a reasonably sized territory and that a buildup to 250 dealers across the country was about right. The project was then completely bounded—except to find the players.

We were fortunate to find in Regie Nationale des Usines Renault, the Renault Motors Division, an excellent supplier of running gear and engine components, and in Societe anonyme des Usines Chausson (30 percent owned by Renault), a complete auto design, development and manufacturing company which could do the production engineering, design of tools, jigs and fixtures, selection of equipment and plant layout. Because of Renault's association with American Motors, it was originally thought that the vehicle could be sold by the combined dealer organization. But the problems of combining the two dealer networks precluded obtaining a marketing commitment for another year or two. On the other hand, Rolls Royce Motors International had just acquired the marketing rights to Lotus. This led naturally to the next step: an adjustment of the plan to include two versions of the car—a very limited hand-crafted luxury version first. followed in a couple of years by a larger quantity, more reasonably priced vehicle, financed as an extension of the first.

Our investment banking consultants, A. David Silver and Company in New York, liked the idea, since, when the details were worked out, it became clear that only about $10 million in equity and $30 million in loans were required for Phase I—which would be profitable even if the project did not proceed into Phase II. A Private Placement Memoranda was then prepared and released. Table 21 summarizes the use of investment capital showing about $40 million in Phase I and $45 million in Phase II.

A company, called "Response Motors," has been formed to produce and market commercial versions of the car (Reference 5). The Luxury version is shown in Figure 8. It would be elongated some 10 inches and configured with a flatter roof and a Lunke sliding door system. but it would still incorporate the RSV foam-filled sheet metal structure, dual-chambered airbags and some of the special research electronics features described above.

Table 21. Projected use of funds—investment costs.

	Phase I			Phase II		Total
	1981	1982	1983	1984	1985	
Plant & equipment:						
Plant remodeling	$	$ 1,200	$	$ 3,000	$ 3,000	$ 7,200
Machinery & equipment	1,000	2,300	3,700	4,500	5,641	17,141
Tools & fixtures		300	1,100	1,200	1,552	4,752
Special tooling	3,000	3,200	3,700	7,000	10,020	28,020
Transportation equipment		500		630	461	1,591
Production design & engineering	3,000	2,000		1,000		8,000
Contingency (5%)	460	1,352	710	1,020	1,040	4,582
Total plant & equipment	7,460	11,452	12,310	18,350	21,714	71,286
Preoperating expenses:						
Investment studies	710		500			1,210
Pre-production expenses	1,500	1,500	4,214	3,000		10,214
Total preoperating expenses	2,210	1,500	4,714	3,000		11,424
Total use of investment funds	$9,671	$12,952	$17,024	$21,350	$21,714	$82,711
	Approximately $40 million			Approximately $45 million		

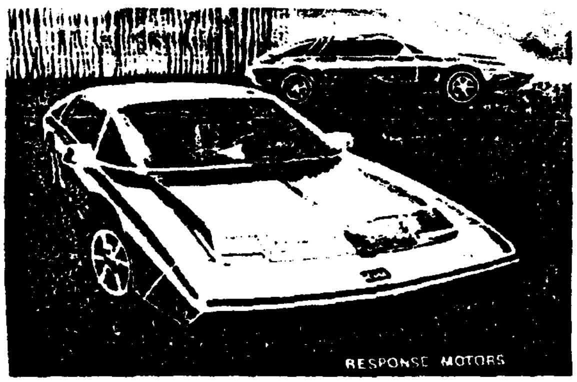

Figure 8. The luxury RSV.

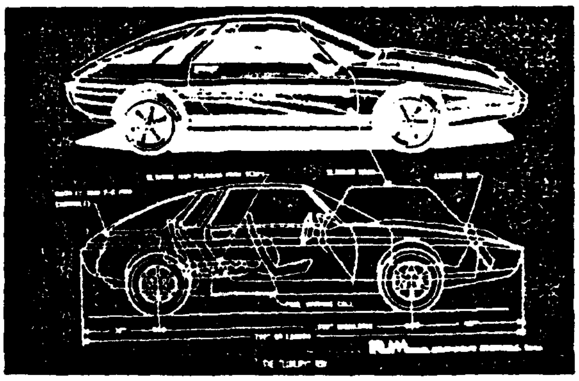

Figure 9. Features of the luxury RSV.

The luggage capacity of the luxury vehicle is almost doubled by raising the hood and making the center floor of the luggage compartment substantially thinner (and lower) than the foam-filled section employed in the existing configuration (Figure 9). Reducing this section is the result of the analysis of a variety of frontal impact tests, including underride, override, offset and head-on crash modes.

This analysis indicated that, when impacting both frame and integrated structure vehicles, impact energy is primarily absorbed in the RSV by the foam-filled wheel well panel, the thick outer periphery of the luggage compartment, and the ncer strength of the luggage compartment floor and the upper fender boxes. The analysis also leads us to believe that, by sacrificing compatibility, a front engine configuration is perfectly possible, with little degradation of occupant protection and pedestrian impact capability.

The standard version, which would be produced (starting in 1985) in quantities of up to 30,000 per year, is shown in Figure 10. It would have conventional opening doors and a Renault 1.6 liter engine with a 5-speed manual transmission, and it would be expected to weigh about 2200 pounds.

Both the luxury and the standard cars would use the RSV prototype structural concept with little change (and would have 60 percent parts commonality between them). The use of brake formed parts will save many millions of investment dollars for presses and dies and is ideal for limited production runs by semi-skilled workers.

The exterior of both vehicles (which makes little or no structural contribution) is a polyurethane plastic which has a relatively high flex-modulus to reduce minor damage and to style the energy absorbing structure (Figure 11).

Table 22, a summary of the pertinent financial information, indicates that, in reasonable quantities and at sellable prices, the company can be expected to make a substantial return for investors.

At this point, I have no way of knowing whether we will be successful in raising the necessary equity capital, or of quaranteeing that consumer demand for a vehicle providing a substantially higher level of safety will be as high as was

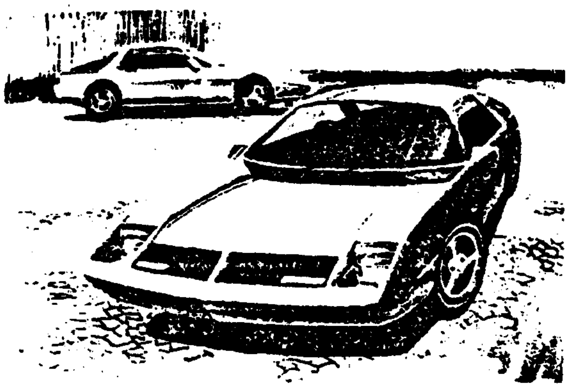

Figure 10. The standard RSV.

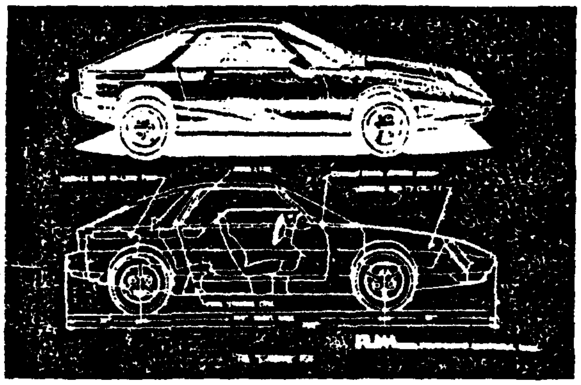

Figure 11. Dimensions of the standard RSV.

Table 22. Manufacturing plan.

	1983	1984	1985	1986	1987
Number of cars produced:					
Luxury RSV	1,000	2,000	2,000	2,000	2,000
Standard RSV			8,000	16,000	24,000
Total production	1,000	2,000	10,000	18,000	26,000
Factory sales price per car:					
Luxury RSV	$20,500	$20,500	$ 20,500	$ 20,500	$ 20,500
Standard RSV			10,250	10,250	10,250
Sales (in thousands)	$20,500	$41,000	$123,000	$205,000	$287,000
Pre-tax profit (loss)	(2,759)	1,831	15,754	37,789	63,356
Income tax			500	1,700	2,851
Net income (loss)	$ 2,759)	$ 1,831	$ 15,250	$ 36,089	$ 60,505

expected. I believe those answers are important to the future planning of government and industry, and I solicit your support to assess the level of consumer demand for high performance auto safety in the real world.

With a few exceptions, Minicars is reasonably satisfied with our efforts and the results obtained. Our impression is that the Congress and the public of the United States are interested and impressed with the program's results, but somewhat disappointed with the rate and timing of the industry's incorporation of the technology. Through the project, the NHTSA foresaw in 1975 America's need for lightweight, safe, fuel economical vehicles, but was unable to convince the industry to produce such cars. The huge investments now being committed to retool automotive production do include slightly improved occupant protection, damageability and repairability, etc., but focus primarily on fuel economy. I would hope that public information derived from programs like this would increase consumer demand—and thereby create a sizeable market for high level safety performance. Otherwise, the highway carnage will have to get bad enough (or some other factor significant enough) to reflect itself in an economic marketplace reaction before RSV-ty safety will be implemented by the manufacture

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Appendix A

RSV Barrier Tests

Table A-1. Frontal barrier impact (Phase II).

Date: 5/12/76
RSV speed: 81.79 km/h (50.8 mph)

	Driver	Right front passenger
HIC	753	722
Chest Gs (3 msec)	50	46
Left femur, kg (lbs)	668 (1470)	1456 (3200)
Right femur, kg (lbs)	591 (1300)	818 (1800)

Table A-2. Right offset frontal barrier impac (Phase II).

Date: 7/9/76
RSV speed: 78.9 km/h (49.0 mph)

	Driver	Right front passenger
HIC	474	189
Chest Gs (3 msec)	55	30
Left femur, kg (lbs)	591 (1300)	445 (980)
Right femur, kg (lbs)	545 (1200)	314 (690)

Table A-3. Frontal barrier impact (Phase III).

Date: 10/7/78
RSV speed: 80.77 km/h (50.17 mph)

	Driver	Right front passenger
HIC	375	497
Chest Gs (3 msec)	52	87
Left femur, kg (lbs)	N/A	523 (1150)
Right femur, kg (lbs)	545 (1200)	886 (1950)

Table A-4. Frontal barrier impact (Phase IV quick look results).

Date: 6/10/80
RSV speed: 79.7 km/h (49.5 mph)

	Driver	Right front passenger
HIC	494	994
Chest Gs (3 msec)	51	46
Left femur, kg (lbs)	497 (1085)	581 (1278)
Right femur, kg (lbs)	607 (1335)	525 (1155)

Appendix B

RSV Vehicle-to-Vehicle Frontal Tests*

Table B-1. Left offset RSV-Volvo frontal impact (Phase II).

Date: 12/7/76
RSV speed: 65.9 km/h (40.9 mph)
Volvo speed: 65.9 km/h (40.9 mph)

	RSV Driver	RSV Right front passenger
HIC	230	215
Chest Gs (3 msec)	42	59
Left femur, kg (lbs)	1364 (3000)	545 (1200)
Right femur, kg (lbs)	636 (1300)	818 (1800)

Table B-2. First RSV-Impala frontal impact.

Date: 8/7/79
RSV speed: 58.8 km/h (36.5 mph)
Impala speed: 58.8 km/h (36.5 mph)

	RSV driver	RSV right front passenger	Impala driver
HIC	183	261	963
Chest Gs (3 msec)	36	29	40
Left femur, kg (lbs)	591 (1300)	364 (800)	136 (300)
Right femur, kg (lbs)	727 (1600)	273 (600)	500 (1100)

*Research Safety Vehicle phase III results, unless otherwise noted.

Table B-3. Second RSV-Impala frontal impact (RSV underride).

Date: 11/14/76
RSV speed: 57.2 km/h (35.5 mph)
Impala speed: 44.0 km/h (27.3 mph)

	RSV driver	Impala driver
HIC	514	342
Chest Gs (3 msec)	55	70
Left femur, kg (lbs)	519 (1300)	455 (1000)
Right femur, kg (lbs)	727 (1600)	409 (900)

Table B-4. Third RSV-Impala frontal impact (RSV override).

Date: 12/19/79
RSV speed: 57.8 km/h (35.9 mph)
Impala speed: 57.8 km/h (35.9 mph)

	RSV driver	RSV right front passenger	Impala driver	Impala right front passenger
HIC	813	2243	484	390
Chest Gs (3 msec)	74	70	21	30
Left femur, kg (lbs)	409 (900)	273 (600)	136 (300)	227 (500)
Right femur, kg (lbs)	409 (900)	364 (800)	91 (200)	182 (400)

Appendix C

RSV Side Impact Tests

Table C-1. Volvo into RSV left side at 90° (Phase II).

Date: 11/19/76
RSV speed: 63.1 km/h (39.2 mph)
Volvo speed: 63.1 km/h (39.2 mph)

	RSV driver	RSV right front passenger
HIC	66	39
Chest Gs (3 msec)	40	40
Pelvic Gs (3 msec)	35	26

Table C-2. Impala into RSV right side at 90 (Phase III).

Date: 6/8/79
RSV speed: 56.4 km/h (35.0 mph)
Impala speed: 56.4 km/h (35.0 mph)

	RSV right front passenger	RSV right rear passenger
HIC	540	244
Chest Gs (3 msec)	32	65
Pelvic Gs (3 msec)	32	50

Table C-3. Renault 20 into RSV left side at 90° (Phase IV quick look results).

Date: 5/28/80
Location: Lardy, France
RSV speed: 0
Renault 20 speed: 50 km/h (31 mph)

	RSV driver	RSV right front passenger	RSV left rear passenger
HIC	46	57	42
Chest Gs (3 msec)	50	43	47
Pelvic Gs (3 msec)	42	15	40

Table C-4. Renault 20 into RSV right side at 90° (Phase IV quick look results).

Date: 6/17/80
Location: Lardy, France
RSV speed: 0
Renault 20 speed: 65.7 km/h (40.8 mph)

	RSV driver	RSV right front passenger	RSV left rear passenger
HIC	175	172	310
Chest Gs (3 msec)	80	50	80
Pelvic Gs (3 msec)	20	70	80

Table C-5. Datsun 510 into RSV left side at 90° (Phase IV quick look results).

Date: 7/4/80
Location: Tsukuba, Japan
RSV speed: 56.4 km/h (35 mph)
Datsun 510 speed: 56.4 km/h (35 mph)

	RSV left front	RSV left rear	Datsun left front	Datsun right front
HIC	23	70	92	89
Chest Gs (3 msec)	28	61	19	16
Pelvic Gs (3 msec)	27	93	47	24

Table C-6. Datsun 510 into RSV right side at 90° (Phase IV quick look results).

Date: 7/10/80
Location: Tsukuba, Japan
RSV speed: 64.4 km/h (40 mph)
Datsun 510 speed: 64.1 km/h (39.8 mph)

	RSV right front	RSV right rear	Datsun left front	Datsun right front
HIC	30	87	187	191
Chest Gs (3 msec)	56	84	24	23
Pelvic Gs (3 msec)	38	69	29	27

Appendix D

Large RSV Impact Tests*

Table D-1. LRSV frontal barrier impact.

Date: 5/9/79
LRSV speed: 62.8 km/h (39.0 mph)

	Driver	Middle front passenger	Right front passenger
HIC	174	169	178
Chest Gs (3 msec)	37	30	30
Left femur, kg (lbs)	523 (1150)	364 (800)	364 (800)
Right femur, kg (lbs)	500 (1100)	500 (1100)	455 (1000)

Table D-2. LRSV 30° oblique barrier impact.

Date: 7/20/79
LRSV speed: 54.4 km/h (40 mph)

	Driver	Middle front passenger	Right front passenger
HIC	248	74	130
Chest Gs (3 msec)	32	25	35
Left femur, kg (lbs)	591 (1300)	273 (600)	568 (1250)
Right femur, kg (lbs)	455 (1000)	545 (1200)	273 (600)

Table D-3. SAE 1818 kg (4000 lb) Bogey into LRSV right side at 90°.

Date: 10/4/79
Bogey speed: 48.3 km/h (30 mph)

	Right front passenger	Right rear passenger
HIC	182	627
Chest Gs (3 msec)	90	150
Pelvic Gs (3 msec)	100	105

Table D-4. SAE 1818 kg (4000 lb) Bogey into LRSV left side at 90°.

Date: 2/7/80
Bogey speed: 41.2 km/h (25.6 mph)

	Driver
HIC	132
Chest Gs (3 msec)	55
Pelvic Gs (3 msec)	55

*Conducted under phase III of the Research Safety Vehicle program.

THE MINICARS RESEARCH SAFETY VEHICLE

D. Friedman
Minicars, Inc.

October 1980

THE MINICARS RESEARCH SAFETY VEHICLE

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ABSTRACT

The Research Safety Vehicle (RSV) is a lightweight safety car capable of protecting its front seat occupants in crashes up to 80 km/h (50 mph). It was designed and developed (up to prototype vehicle stage) by Minicars, Inc. of Goleta, California. The RSV gains its crashworthiness from a monocoque structure and advanced air cushion restraints. The car has no frame, but is constructed entirely from thin gauge sheet metal compartments which are foam-filled for energy absorption. The computer-aided design of the structure precisely located the compartments for maximum rigidity (with minimum weight) under normal use, and for energy absorbing crushability during crashes. Soft plastic exterior fascias afford significant protection to pedestrians and reduce damage in low speed accidents. A "high technology" version of the car has a manual transmission which is shifted by computer, a radar-based cruise control (for safe following distances), anti-skid brakes and a collision mitigation system which applies the brakes automatically when a collision is inevitable. There are plans (if capital can be raised) to manufacture a production engineered car by 1985.

INTRODUCTION

In 1974 Minicars, Inc. of Goleta, California conducted an analytical effort to predict and to quantify the societal costs of the automobile in 1985 (Reference 1). The costs included occupant and pedestrian casualties, property damage, maintenance and repairability, emissions, fuel economy, etc. Systems were conceived to deal with and to reduce the costs, and were themselves quantified for eventual consumer price. Combinations of these systems were assessed for overall payoff. Then a combination, which in essence maximized the benefits at the least consumer cost, was selected. That combination was the beginning of the design of the Research Safety Vehicle (RSV).

The following effort (Phase II of the RSV Program) developed the structure and restraint systems of the vehicle and established the compatibility of these systems for integration into a prototype vehicle (Reference 2). A number of important considerations were part of this design effort, including:

- Omnidirectional high-speed impact energy absorption and occupant protection in real world collisions
- Compatibility (a structure which not only protects its own occupants, but also minimizes the consequences of a crash for the occupants of the other car)
- Damageability with 16 km/h (10 mph) "no-damage" front and rear bumpers and soft fenders

- Repairability with a replaceable nose section which absorbs all damage in frontal impacts up to 32 km/h (20 mph)
- Pedestrian impact protection (reducing the levels of injury and the numbers of fatalities by contouring the front end and making its surface appropriately compliant)
- Collision avoidance driver aids (developed through the use of radar and microcomputer electronics).

The Phase III effort of the RSV Program had two parts (Reference 3). The first was the development of the integrated Research Safety Vehicle to the prototype stage (incorporating all of the currently practical and cost effective subsystems). The second was a research activity to demonstrate the applicability of some subsystems to production cars and to demonstrate the performance of other systems which hold promise for the future.

The vehicle effort produced prototypes (Figure 1), built from the ground up, which were designed to maximize safety, yet to maintain relatively high fuel economy, low emissions, public appeal and reasonable cost. But this is not a production car. The objective of the program was to demonstrate the feasibility and practicality of the subsystems, so that they could be integrated by the industry into vehicles the public could buy (Figure 2). It was understood that to mass produce the vehicle in quantities of hundreds of thousands of units per year would require a production engineering effort and a large capital investment.

The research effort produced two additional vehicle prototypes. The High Technology Research Safety Vehicle (Figure 3) incorporates a variety of electronic systems, including radar target detection, anti-skid braking, automatically shifted 5-speed manual transmission, and computer controlled collision mitigation (Reference 4). The Large Research Safety Vehicle (Figure 4) incorporates the structure/restraint concept in a production car; this vehicle has greater impact energy absorption and protects its occupants up to 64 km/h (40 mph), but still has less weight and better fuel economy than the base production car.

RESULTS OBTAINED - VEHICLE EFFORT

Occupant Protection Crash Tests

Frontal Barrier. Table 1 summarizes the frontal barrier tests which have been conducted on the RSV. The test conditions and injury measures for each test are correspondingly labeled in the tables of Appendix A. With the exception of the Japanese barrier test (discussed later), the results of Table 2 are representative of the final configuration. These results show that there is a substantial margin between the RSV's nominal 80 km/h (50 mph) injury measures and the NHTSA injury criteria.

Car-to-Car Frontal. Table 3 summarizes the significant car-to-car frontal and frontal offset tests. Table 4 shows the results of a Phase IV evaluation test at Dynamic Science involving a head-on impact with a Dodge Challenger at

Figure 1. Research Safety Vehicle

Figure 2. Gull Wing Doors

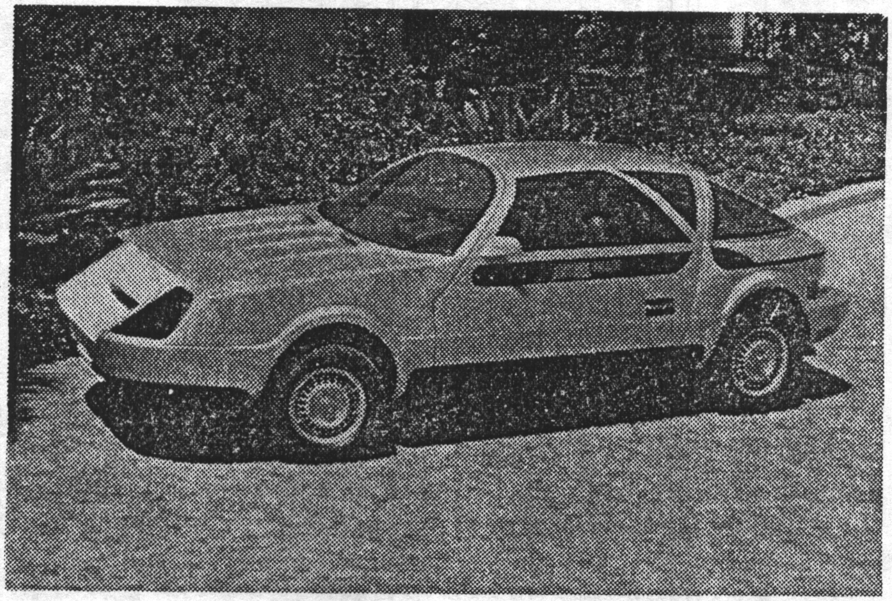

Figure 3. High Technology Research Safety Vehicle

Figure 4. Large Research Safety Vehicle

Table 1
RSV Frontal Barrier Impact Summary

Date	Performing Agency	Speed		Driver		Passenger		Remarks
		(km/h)	(mph)	HIC	Chest Gs	HIC	Chest Gs	
5/12/76	Minicars	81.8	50.8	753	50	722	46	
7/9/76	Minicars	78.9	49.0	474	55	189	30	Right offset
10/7/78	Minicars	80.77	50.17	375	52	497	87	Stiff front Structure
2/14/79	Minicars	76.6	47.6	304	45	554	48	
6/10/80	JARI	79.7	49.5	494	51	994	46	Inflator defect

Table 2
Frontal Barrier Impact (Phase III)

Date: 2/14/79
RSV Speed: 76.6 km/h (47.6 mph)

	Driver	Right Front Passenger
HIC	304	554
Chest Gs (3 msec)	45	48
Left femur, kg (lbs)	568 (1250)	318 (700)
Right femur, kg (lbs)	716 (1575)	405 (890)

Table 3

RSV Vehicle-to-Vehicle Frontal Impact Summary

Date	Performing Agency	Test Mode	Closing Speed (km/h)	(mph)	RSV Injury Levels	Other Car Injury Levels	Remarks
12/7/76	Minicars	Left offset RSV Front into Volvo	131.8	81.8	Acceptable	---	
8/7/79	Minicars	RSV-Impala offset Frontal Impact	117.6	73.0	Acceptable	Acceptable	
11/14/79	Minicars	RSV-Impala aligned	101.2	62.8	Unacceptable		RSV underride
12/19/79	Minicars	RSV-Impala aligned	115.6	71.8	Unacceptable	Unacceptable	RSV override
8/18/80	Minicars	RSV-Impala aligned	126.4	78.5	Unacceptable	Unacceptable	Inflator defect
9/10/80	Dynamic Science	RSV-Dodge Challenger aligned	139.4	86.5	Acceptable	Unacceptable	

Table 4

RSV-Dodge Challenger Frontal Impact
(Phase IV Quick Look Results)

Date: 9/10/80

Location: Dynamic Science, Phoenix, Arizona

RSV Speed: 69.7 km/h (43.26 mph)

Dodge Challenger Speed: 69.7 km/h (43.26 mph)

	RSV Left Front	RSV Right Front	Dodge Left Front	Dodge Right Front
HIC	690	690	1690	3630
Chest Gs (3 msec)	41	42	92	77
Left femur, kg (lbs)	665 (1462)	483 (1062)	446 (982)	362 (796)
Right femur, kg (lbs)	666 (1465)	434 (955)	417 (917)	652 (1434)

80 mph. This test is representative of the RSV car-to-car frontal impacts and again shows substantial injury measure margins. The fourth developmental crash test with the Chevrolet Impala (outlined in Table 5) used the same underpowered inflators that the Japanese test used (as will be discussed later) and allowed us to recall and replace the remaining defective inflator units. The development tests showed that it was possible, at least against frame structured vehicles (such as the Impala), to adjust RSV frontal structural stiffness to underride, override or remain aligned. The final configuration will neither underride nor override the Impala. The results of the individual vehicle-to-vehicle frontal tests are outlined in Appendix B.

Car-to-Car Side. Table 6 summarizes the car-to-car side impact crash tests. In all of these tests the RSV side structure and padding did an effective job of protecting the near side front seat occupant. Although the Part 572 dummy was used, we are convinced that, with padding density modifications, any dummy can be protected in equal weight car-to-car impacts at closing velocities to 64 km/h (40 mph). Fortunately, there are not many rear seat occupants, because the crash dynamics maximize intrusion in that area, and the velocity of dummy interior impact limits rear seat survival to somewhat lower velocities. Appendix C presents more details of the side impact tests.

Car-to-Car Compatibility. The tests of Tables 7 and 8 were run for compatibility purposes and involved side impacts on a Datsun 510 target car by both an RSV and a Datsun 510; in both tests the target and bullet cars were traveling at 56.4 km/h (35 mph). Table 9 compares the injury measures received in these impacts by the Datsun front and rear near side dummy occupants. Clearly, the forgiving front end design of the RSV has a substantial favorable effect on the observed injury measures.

Rear Impact. The only rear impact conducted in the program thus far was in Phase II, as shown in Table 10. The injury measures were acceptable in the 40 mph Volvo impact.

Rollover. The only rollover test was also conducted in Phase II; this test clearly demonstrated the capability of the structure and padding to protect both front and rear seat occupants without seat belts, as shown in Table 11.

Fuel Economy and Emissions

Table 12 shows the results of the RSV fuel economy and emissions testing at Western Washington University. These tests turned out quite well, even though not conducted strictly in accordance with EPA procedures (which would be at 4,000 and 50,000 miles).

Collision Avoidance Capabilities

Although the focus of the RSV program was on crashworthiness, the collision avoidance capabilities of the vehicle were not ignored. Table 13 summarizes the tests conducted at JARI in Japan and at Daimler-Benz in West Germany. In both sets of tests the RSV met the IESV goals, except for lateral deviation on irregular pavement and hill holding with the parking brake. Only at JARI did the

Table 5

Fourth RSV-Impala Frontal Impact

Date: 8/18/80
RSV Speed: 63.21 km/h (39.26 mph)
Impala Speed: 63.21 km/h (39.26 mph)

	RSV Driver	RSV Right Front Passenger	Impala Driver	Impala Right Front Passenger
HIC	807	1259	391	763
Chest Gs (3 msec)	45	49	64	77
Left femur, kg (lbs)	455 (1000)	343 (755)	851 (1873)	646 (1422)
Right femur, kg (lbs)	500 (1100)	457 (1006)	1148 (2526)	919 (2022)

Table 6

RSV Side Impact Summary

Date	Performing Agency	Test Mode	Speed		Bullet Car Injury Levels	Target Car Injury Levels*	
			(km/h)	(mph)		Front	Rear
11/19/76	Minicars	Volvo into RSV at 270°	63.1/63.1	39.2/39.2	Acceptable	66/40/35	--
6/8/79	Minicars	Impala into RSV at 90°	56.4/56.4	35.0/35.0	--	540/32/32	244/65/50
5/28/80	Renault	Renault into RSV at 270°	50/0	31/0	--	46/50/42	42/47/40
6/17/80	Renault	Renault into RSV at 90°	67.5/0	40.8/0	--	172/50/70	--
6/17/80	JARI	RSV into Datsun 510 at 270°	56.4/56.4	35/35	Acceptable	56/31/76	127/45/72
6/24/80	JARI	Datsun 510 into Datsun 510 at 270°	56.5/55.8	35/34.7	Acceptable	88/55/107	117/80/102
7/4/80	JARI	Datsun 510 into RSV at 270°	56.4/56.4	35/35	Acceptable	23/28/27	70/61/93
7/10/80	JARI	Datsun 510 into RSV at 90°	64.1/64.4	39.8/40	Acceptable	30/56/38	87/84/69

*Nearside occupants only; HIC/Chest Gs/Pelvic Gs.

Table 7

RSV Into Datsun 510 Left Side at 90^{o}
(Aggressivity Test - Phase IV Quick Look Results)

Date: 6/17/80

Location: JARI, Tsukuba, Japan

RSV Speed: 56.4 km/h (35 mph)

Datsun 510 Speed: 56.4 km/h (35 mph)

	RSV Driver	RSV Right Front Passenger	Datsun Left Front Passenger	Datsun Left Rear Passenger
HIC	83	83	56	127
Chest Gs (3 msec)	28	27	31	45
Pelvic Gs (3 msec)	24	21	76	72

Table 8

Datsun 510 Into Datsun 510 Right Side at 90^{o}
(Phase IV Quick Look Results)

Date: 6/24/80

Location: JARI, Tsukuba, Japan

Bullet Vehicle Speed: 56.5 km/h (35 mph)

Target Vehicle Speed: 55.8 km/h (34.7 mph)

	Target Vehicle		Bullet Vehicle	
	Left Front	Left Rear	Left Front	Right Front
HIC	88	117	98	40
Chest Gs (3 msec)	55	80	23	15
Pelvic Gs (3 msec)	107	102	26	19

Table 9

Compatability (Aggressivity) Tests

Location: JARI, Tsukuba, Japan

RSV and Datsun 510 Bullet Speed: 56.4 km/h (35 mph)

Datsun 510 Target Speed: 56.4 km/h (35 mph)

	Datsun Passenger			
	Left Front		Left Rear	
Bullet Vehicle	RSV	Datsun	RSV	Datsun
HIC	56	88	127	117
Chest Gs	31	55	45	80
Pelvic Gs	76	107	72	102

Table 10

Volvo into Stationary RSV Rear (Phase II)

Date: 7/29/76

Volvo Speed: 63.9 km/h (39.7 mph)

	RSV Passenger	
	Right Front	Right Rear
HIC	185	104
Chest Gs (3 msec)	50	40
Pelvic Gs (3 msec)	50	75

Table 11

Rollover Test (Phase II)

Date: 12/17/76

Dolly: Inclined per FMVSS 208

Dolly Speed: 49.6 km/h (30.8 mph) (Three complete rolls)

	Driver	Left Rear Passenger
HIC	100	100
Chest Gs (3 msec)	7	6
Pelvic Gs (3 msec)	10	8

Table 12

Fuel Economy and Emissions Tests

Tests were performed by Western Washington University using EPA dynamometer test procedures on a low mileage RSV with a 1980, 1.5 liter Honda engine and Michelin tires:

Test Weight	1307 kg	(2875 lbs)
Road Load	11.15 hp	
Urban Fuel Economy	12.3 km/l	(28.0 mpg)
Highway Fuel Economy	17.5 km/l	(41.2 mpg)
Combined Fuel Economy	14.2 km/l	(33.4 mpg)

Emissions assuming that these low mileage emissions are representative of 50,000 mile performance:

Hydrocarbons	0.40 g/mi
Carbon monoxide	2.53 g/mi
Nitrous oxide	0.71 g/mi

Table 13

Collision Avoidance Tests
(Phase IV Quick Look Results)

The following tests were performed by JARI in Japan during April and May, 1980 and by Daimler-Benz in West Germany during June and July, 1980:

- Steady State Yaw Response
- Transient Yaw Response
- Returnability
- Lateral Acceleration
- Control at Breakaway
- Crosswind Sensitivity
- Steering Control Sensitivity
- Pavement Irregularity
- Overturning Immunity
- Brake Effectiveness
- Stopping Distance
- Parking Brake

In both sets of tests the RSV met the IESV goals, except:

- Pavement Irregularity Lateral Deviation
  Reason - Free Play in the Steering System
- Stopping Distance Front System Failure Mode*
  Reason - Improper Bleeding
- Hill Holding - Parking Brake
  Reason - Added Weight
- Returnability at 40 km/h (25 mph) Clockwise Direction*
  Reason - Free Play in the Steering System

*JARI only.

stopping distance (with front brake system failure) and the returnability (at 40 km/h in a clockwise direction) exceed the specifications. There is some question about the adequacy of Minicars' front end set-up procedures, since both cars exhibited free play in the steering mechanism. Unfortunately, there was insufficient time prior to the conference to investigate and retest the car.

Pedestrian Impact Mitigation

Pedestrian impact tests were conducted at the Battelle Institute, Columbus, Ohio. Table 14 shows the difference in performance achieved with the front fascia positioned directly on the foam bumper, as in the nominal configuration, and that achieved with the fascia moved 5 inches forward of the bumper. Clearly, the knee impact accelerations and other injury measures are significantly reduced. Our conclusion is that providing about 3 inches of (low force) deformation space between the fascia and the bumper will reduce the already favorable pedestrian impact injury measures, without significantly affecting any other performance aspect of the vehicle.

Damageability Tests

Low-speed damageability tests were conducted at Dynamic Science in August. As indicated in Table 15, the tests confirmed the design intention to minimize impact damage in circumstances in which a conventional car (such as the Citation) would incur substantial costs of repair. The author has personally taken a baseball bat to the RSV's soft fenders without damage — although, unfortunately, no comparable demonstration was made with the Citation.

Table 14

Pedestrian Impact Tests* (Phase III)

Velocity at Impact (mph)	Fascia Position	Peak Resultant Acceleration at Time After Impact										Head Severity Index
		Head		Chest		Pelvis		Knee		Foot		
		(Gs)	(msec)	(Gs)	(msec)	(Gs)	(msec)	(Gs)	(msec)	(Gs)	(msec)	
20.1	Normal	94	138	25	126	29	16	80	10	200	62	661
25.0	Normal	133	116	34	129	48	24	112	8	330	52	1307
20.0	5" Forward	63	159	29	160	33	69	42	31	39	89	258
25.0	5" Forward	75	130	22	78	58	46	50	24	260	56	838

*Performed by the Battelle Institute.

Table 15

Low-Speed Damageability Tests (Phase III)

Date: August 1980

Performed by: Dynamic Science

Vehicles: RSV and Chevrolet Citation

Test Mode	Impact Speed		Bullet Vehicle Damage	Target Vehicle Damage
	(km/h)	(mph)		
RSV front into RSV rear	20.77	(12.9)	No visible damage	Cosmetic damage
RSV front into RSV rear	24.96	(15.5)	No visible damage	10 cm crack in tail-light fiberglass panel
RSV front into Citation rear	24.96	(15.5)	No visible damage	Significant pressure buckles forward of and above each wheel opening ($599)
RSV front into Citation left side	8.37	(5.2)	No visible damage	Maximum door skin depression ($351)
RSV front into RSV side	8.21	(5.1)	No visible damage	Two small impressions were left on the outer skin of the door
RSV front into barrier	13.36	(8.3)	No visible damage	None
RSV front into barrier	28.18	(17.5)	Noticeable permanent deformation across entire bumper face and across bolt-on structural section	None

Accommodations

Figure 5 shows the front seat accommodations of the RSV. The interior volume (calculated by EPA criteria) is equivalent to that of a compact car, and the ease of entry and exit, seating comfort and driver instrumentation are rated "good" in subjective judgments. Obviously, each car manufacturer judges interior accommodations by his own criteria, so it is only our intention to illustrate that the safety features incorporated in the car need not interfere with or preclude an acceptable interior configuration. Note, in particular, the high mounted instrumentation, the transparent headrest, the lack of front seat belts and the rear seat leg room.

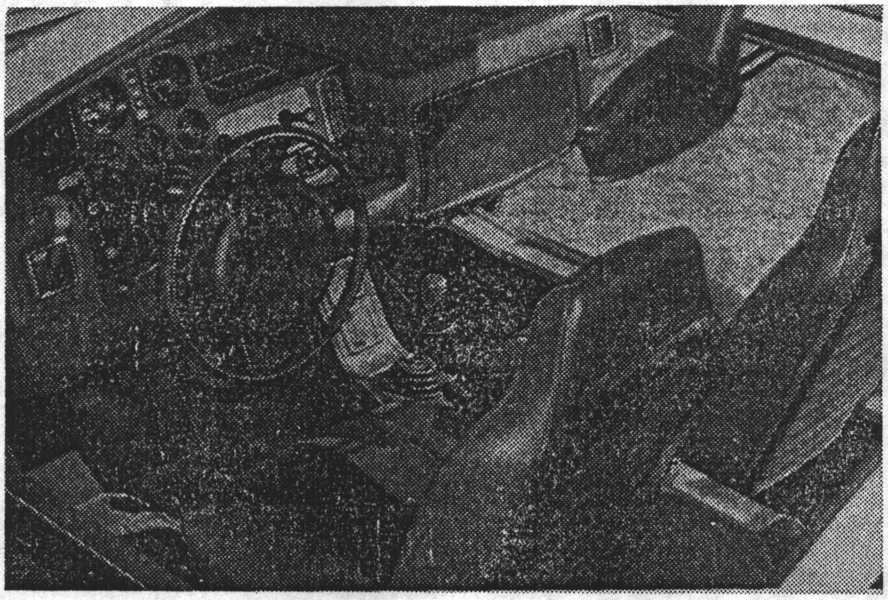

Figure 5. Front Seat Accommodations

RESULTS OBTAINED – RESEARCH EFFORT

High Technology RSV

The High Technology RSV incorporates the electronic control features listed in Table 16. Since it is a research vehicle (involving first and second generation development electronics), no extensive evaluation tests were conducted. The development testing did indicate that collision mitigation braking can reduce the velocity of the vehicle by 25 to 65 km/h (15 to 40 mph). This braking is triggered by a computer which processes the radar system signal. The computer/radar combination virtually precludes highway false alarms. The car-following cruise control works substantially better than a human driver in controlling engine power to maintain steady following distances. The anti-skid braking system works well on a variety of skid-producing surfaces. The automated electronically controlled 5-speed manual transmission provides excellent fuel economy with the smoothness of a good manual shift driver. The electronic display shown in Figure 6 is likely to be the forerunner of more production-oriented displays of a comparable level of sophistication.

Table 16

Electronic Control Features of the High Technology RSV

Collision Mitigation Braking	-	Reduces impact speed 15 to 40 mph
Car-Following Cruise Control	-	Maintains distance without hunting
Anti-Skid Braking	-	Holds lane on wet, gravel, ice, irregular road; operates on 4-wheel differences
Automated Manual Transmission	-	Electronic shifting utilizes 5-speed manual selection for fuel economy
Electronic Display	-	32-character operating analog, digital status, diagnostic message modes

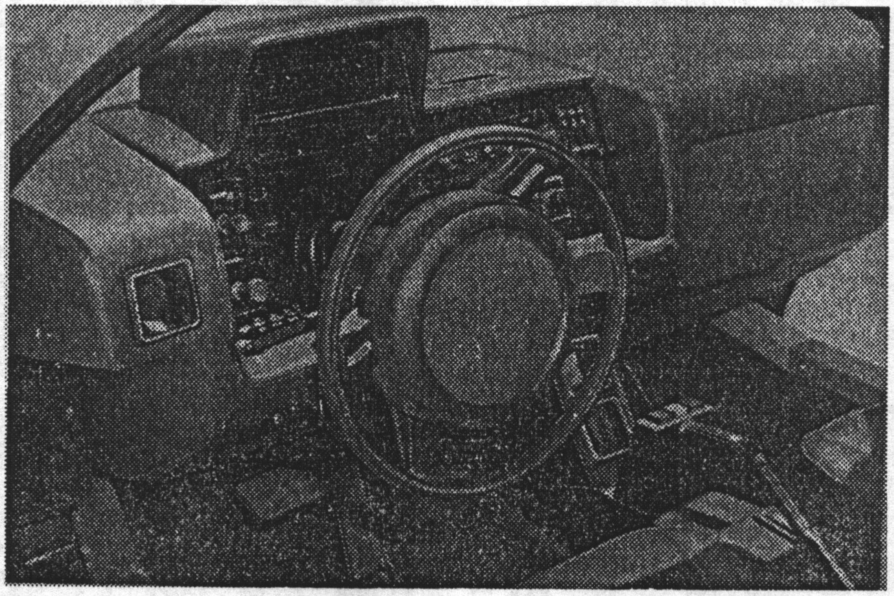

Figure 6. Electronic Display

Large Research Safety Vehicle

Crashworthiness. The Large Research Safety Vehicle has now completed a number of crashworthiness tests, as shown in Table 17. We have demonstrated low injury measures (relative to the NHTSA injury criteria) for all three front seat passenger positions and in both frontal and angled barrier tests to 65 km/h (40 mph). Although not at the same speed, a marked improvement in side impact protection (compared to the original Impala padding) was observed when RSV type padding was added. (The last two tests listed in Table 17 compare the results.)Summaries of the individual tests are presented in Appendix D:

Fuel Economy and Emissions. The fuel economy and emissions performance tests conducted by D&M Engineering are outlined in Table 18. The results indicate that a full size car can be designed (through weight reduction and available technology) to exhibit significantly higher crashworthiness, and at the same time to achieve much improved fuel economy and reduced emissions.

PROGRAM CONCLUSIONS

Through the insight of the management of the National Highway Traffic Safety Administration, and the able direction of their Contract Technical Manager, Mr. Jerome Kossar, there are many things about the car that are just right. There have been, of course, some disappointments, and some concepts which, while they work well in tests, need real world evaluation.

A major problem has been the weight growth of the car (Table 19). We had hoped that, in the one iteration of the design from the Phase II subsystem efforts to the Phase III integrated car, we could maintain the weight budgets wihout a complete redesign. It turned out that, in order to accommodate all of the requirements for all of the subsystems simultaneously, the weight had to increase about 15 percent more than expected. Investigation has convinced us that the weight growth can be removed with iteration. Nevertheless, the car as tested (at 2578 pounds) is approximately 272 pounds over our target weight. This weight growth is not overly surprising - nor is there any reason to doubt the ability to eliminate it in production.

Minicars has been able to show with the LRSV that the next generation of full size six-passenger cars can weigh 20 percent less than the 1977 Impala (Table 20, and still protect their occupants to 65 km/h (40 mph). At its current weight, 80 km/h (50 mph), occupant protection is possible. Later in this Conference, Volkswagen will conduct a 55 to 65 km/h (35 to 40 mph) crash test of a Minicars prepared front seat airbag Citation. This vehicle weighs 180 kg (400 pounds) less than the LRSV. In several previous conferences the opinion has been expressed that improved safety involves substantial weight and cost penalties. Yet we have proven that performance can be increased while weight is being significantly reduced.

Another disappointment was that the injury measures in the first Phase IV evaluation tests (conducted in Japan) were substantially higher than those that had been obtained during development a year earlier. A Phase III two-car head-on frontal development test with full instrumentation was conducted soon thereafter, with similarly disappointing results.

Table 17

LRSV Impact Tests

Date	Mode	Speed		Occupant Injury Measures							
				Driver			Middle Passenger		Right Front Passenger		
		(km/h)	(mph)	HIC	Chest Gs	Pelvic Gs	HIC	Chest Gs	HIC	Chest Gs	Pelvic Gs
5/9/79	Frontal barrier	62.8	37	174	37		169	30	178	30	
7/20/79	30° barrier	54.4	40	248	32		74	25	130	30	
10/4/79	90° side bogey Impala padding	48.3	30	627*	150*	105*			182	90	100*
2/7/80	270° side bogey RSV type padding	41.2	25.6	132	55	55					

*Right rear passenger.

Table 18

LRSV Fuel Economy and Emissions Tests

Tests by D&M Engineering using EPA dynamometer test procedures on a low mileage LRSV with a 1978, 1.9 modified B19 Volvo engine

Test Weight	1477 kg	(3250 lbs)
Road Load	10.8 hp	
Urban Fuel Economy	9.75km/l	(22.9 mpg)
Highway Fuel Economy	15.4 km/l	(36.2 mpg)
Combined Fuel Economy	11.7 km/l	(27.5 mpg)

Emissions assuming that these low mileage emissions are representative of 50,000 mile performance:

Hydrocarbons	0.19 g/mi
Carbon monoxide	2.38 g/mi
Nitrous oxide	0.57 g/mi

Table 19

RSV Weight by System

System	Phase II Estimated Weight (lbs)	Final Phase III Prototype Weight (lbs)	Difference (lbs)	Reasons for Major Differences
Body-in-white (including foam)	579	632	+53	Bolt-on nose, side sills, rear structure, etc., redesigned for increased stiffness; thicker gauge mild steel parts substituted for HSLA steel parts.
Powertrain/rear suspension (including engine cradle & accessories)	609	532	-77	Poor initial estimate, engine cradle redesigned.
Wheels & tires	166	194	+28	Specified heavier run-flat wheels and tires.
Fenders, fascias, hood surround, rear air scoops & body panel & attaching hardware	56	135	+79	Poor initial estimate, in-house fabrication techniques resulted in unncessarily thick FRP parts, wheel houses added.
Two doors (including glazing)	142	250	+108	Latching and locking mechanisms moved from body-in-white to doors, added structure to increase strength and stiffness.
Front suspension & steering	102	102	0	
Steering wheel & column, driver ACRS	43	44	+1	
Electrical system (including battery)	43	43	0	
Brake system (includes assembly & brake lines; does not include disks, calipers or pads)	23	41	+18	Vacuum boost system added.
Cooling system	23	39	+16	Aluminum tubing substituted for plastic tubing.
Rear hatch (including glazing)	25	34	+9	
Hood	11	32	+21	Redesigned for increased rigidity and pedestrian protection.
Fuel cell, filler & emissions	27	31	+4	
Bumpers (excluding fascias)	18	30	+12	Rubrics added.
Driver seat	29	28	-1	
Passenger seat	29	28	-1	
Rear seat	12	21	+9	
Passenger ACRS	25	21	-4	
Heater, defroster & ventilation	20	18	-2	
Floor covering	12	18	+6	
Interior padding and trim (excluding doors & dash)	25	15	-10	
Dash	8	12	+4	
Weather sealing	6	11	+5	
Lighting	11	11	0	
Rear passenger restraints	16	10	-6	
Gear shift	3	10	+7	
Windshield wiper & washer	8	10	+2	
Instrument panel	4	8	+4	
Parking brake	6	7	+1	
Front bulkhead	5	7	+2	
Engine cover	4	6	+2	
Accessories	8	5	-3	
Center spine cover	10	4	-6	
Indirect vision	1	3	+2	
Door latches, locks & controls	6	--	--	See Doors.
Paint, body putty, deadeners	74	50	-24	Initial estimate also included allowances for miscellaneous items.
Fluids	87	87	0	
Curb weight	2306	2578	+272	May not sum exactly due to rounding.

Table 20

LRSV Weight Reduction

Base Sedan Curb Weight*	3869 pounds
LRSV Curb Weight	2960 pounds
Total Weight Difference	909 pounds

Weight Savings by Systems and Components	Weight Change (pounds)
Engine transmission, differential & accessories	-290
Body-in-white, structure, door & glass	-157
Steering front suspension and brakes	-109
Rear suspension and brakes	- 79
Front fenders and rear deck	- 55
Front and rear bumpers	- 54
Hood	- 51
Other systems and components	-114
	-909

*Base sedan weight taken from MVMA Specifications.

The instrumentation led us to suspect, in our first "defects" investigation, that the passenger restraint was not performing correctly. We then conducted some component tests and found (as shown in Figure 7) that the inflators used in the two tests (and installed in all vehicles for Phase IV evaluation) were significantly different from the earlier development test units. The most recently delivered inflators filled the bags significantly slower than did the earlier development units (perhaps because Thiokol had used a different lot of production grain). This led to a revision of our inflator specifications — and to our first, but completely successful, "recall" campaign.

There are also a variety of other problems which were not considered important enough to be completely resolved for prototype use, such as adequately counterbalancing and sealing the door. For performance tests these factors are not important, although the gull-wing doors of the show car have been effectively sealed and counterbalanced through most of the range of motion. Further, it isn't clear that a gull-wing door of this configuration is appropriate to a production vehicle.

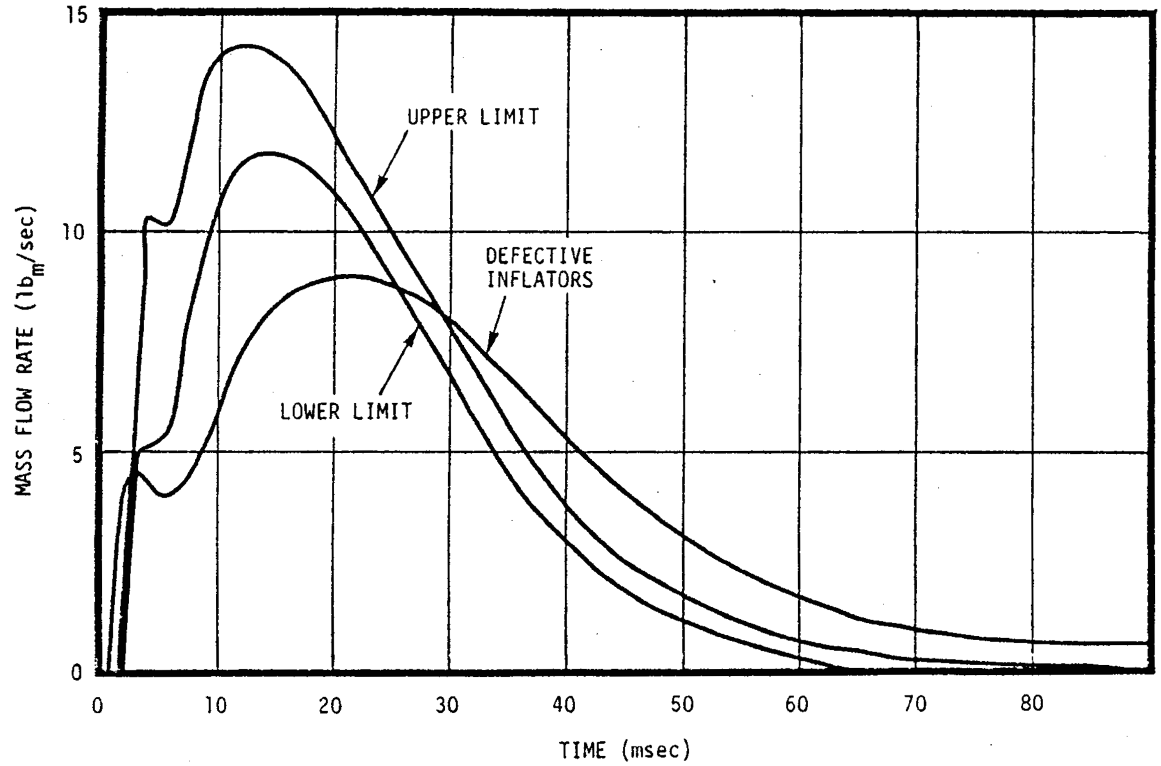

Figure 7. Inflator Characteristics

Similarly, the A-posts were not designed to incorporate a recess for the glass windshield (as is found in stamped production posts), so there is some occlusion of vision in the frontal area. There is no doubt the change can be made, but it presently seems inappropriate to invest the necessary funds in dies to produce the right configuration.

When the car grew in weight, changes should have been made to the suspension, steering, braking, engine and transmission systems. To adequately optimize the results, these changes would have added another 50 to 100 pounds – since those systems were designed for a target weight vehicle of about 2200 pounds. On the other hand, when the car was tested at 2578 pounds, only a few items required adjustment and modification. In most cases a modification was sufficient to make the vehicle perform as close to the program goals as possible without the iteration of design necessary to reduce the weight of the non-running gear. In only a few tests, such as pavement irregularity and hill holding, did the vehicle not achieve the performance goals we had hoped for. We believe that, with an additional design iteration and a production engineering effort, a commercial version will weigh 2200 pounds, and will achieve these goals.

Lastly, about eighteen months ago Minicars began to look into the feasibility of producing and marketing the RSV. Until that time, we viewed the project as a research and development effort adaptable to production. In Phase II the Budd Company had prepared a producible design in sufficient detail to estimate the investment costs at several hundred million dollars and the consumer price at about $7000 (1980 dollars) per vehicle. So we knew the car could be made (in hundreds of thousands per year) to sell at a reasonable premium in price and with an investment comparable to that of a conventional car. But then there was the question of whether people would buy in that quantity.

Numerous studies conducted by government, industry and public interest groups document strong positive consumer statements on automotive safety. A Harris poll, a Peter Hart Research Associates survey and various studies by General Motors (GM) verify the demand for safety. One 1979 GM study showed that 70 percent of those surveyed preferred airbags over automatic belts, even at a substantial price increase. The NHTSA commissioned three separate studies to assess market reaction to the RSV. All were extremely favorable.

The inevitable question, then, is "Why doesn't one of the auto manufacturers plan to produce this vehicle?" Obviously, the RSV concept involves more manufacturing, marketing and financial risk than a conventional car. The industry's present evolutionary improvement approach keeps perceived quality and value high, gradually educates the consumer and doesn't obsolete plant and equipment too fast; so where is the payoff for a manufacturer to change to an RSV concept?

If an auto manufacturer won't invest the necessary hundreds of millions of dollars, who would? One possibility is to manufacture the car in specialty car quantities. With 20 million dollars in private equity capital, federal loan guarantees of 40 to 60 million dollars are available under the right circumstances.

Pretty clearly, these financial considerations set the bounds for a new venture. Careful analysis has suggested that, in rented facilities in an area of substantial unemployment and low cost labor, with a minimum of pressed parts, and with engines and running gear which are already in production, 2,000 people could produce 20,000 to 30,000 cars per year (primarily with flat pattern fabrication tools and equipment, and hand-operated assembly jigs and fixtures).

Fortuitously, the body structure has already been designed for press brake fabrication. But how much would the car cost to make if fabricated in these quantities? This was roughly estimated three different ways. First, we commissioned Rath & Strong, who has computerized composite components price and weight lists, as well as adjustment algorithms for quantity, materials, labor cost, etc. Second, we visited, discussed and estimated the cost in conjunction with two specialty car manufacturers who actually make 25,000 to 30,000 cars per year. And, third, we made our own estimates from a careful analysis of the detailed manufacturing procedure. Our early estimate, being more specific, was $10,000 (1980 dollars) per unit.

The next question was, "Would anybody pay $10,000 for a car like this?" As a researcher, I have my own opinion about the validity of consumer surveys dealing with unavailable products, so we commissioned A.T. Kearney, a management consulting firm, to interview auto dealers and see what they thought. Their conclusion was that each dealer could sell ten cars per month in a reasonably sized territory and that a buildup to 250 dealers across the country was about right. The project was then completely bounded – except to find the players.

We were fortunate to find in Regie Nationale des Usines Renault, the Renault Motors Division, an excellent supplier of running gear and engine components, and in Societe anonyme des Usines Chausson (30 percent owned by Renault), a complete auto design, development and manufacturing company which could do the production engineering, design of tools, jigs and fixtures, selection of equipment and plant layout. Because of Renault's association with American Motors, it was originally thought that the vehicle could be sold by the combined dealer organization. But the problems of combining the two dealer networks precluded obtaining a marketing commitment for another year or two. On the other hand, Rolls Royce Motors International had just acquired the marketing rights to Lotus. This led naturally to the next step: an adjustment of the plan to include two versions of the car - a very limited hand-crafted luxury version first, followed in a couple of years by a larger quantity, more reasonably priced vehicle, financed as an extension of the first.

Our investment banking consultants, A. David Silver and Company in New York, liked the idea, since, when the details were worked out, it became clear that only about $10 million in equity and $30 million in loans were required for Phase I - which would be profitable even if the project did not proceed into Phase II. A Private Placement Memoranda was then prepared and released. Table 21 summarizes the use of investment capital showing about $40 million in Phase I and $45 million in Phase II.

Table 21

Projected Use of Funds - Investment Costs

	Phase I			Phase II		
	1981	1982	1983	1984	1985	Total
Plant & equipment:						
Plant remodeling	$	$ 1,200	$	$ 3,000	$ 3,000	$ 7,200
Machinery & Equipment	1,000	2,300	3,700	4,500	5,641	17,141
Tools & fixtures		300	1,100	1,200	1,552	4,752
Special tooling	3,000	3,200	3,700	7,000	10,020	28,020
Transportation equipment		500		630	461	1,591
Production design & engineering	3,000	2,000		1,000		8,000
Contingency (5%)	460	1,352	710	1,020	1,040	4,582
Total plant & equipment	7,460	11,452	12,310	18,350	21,714	71,286
Preoperating expenses:						
Investment studies	710		500			1,210
Pre-production expenses	1,500	1,500	4,214	3,000		10,214
Total preoperating expenses	2,210	1,500	4,714	3,000		11,424
Total use of investment funds	$ 9,671	$12,952	$17,024	$21,350	$21,714	$82,711
	Approximately $40 million			Approximately $45 million		

A company, called "Response Motors," has been formed to produce and market commercial versions of the car (Reference 5). The Luxury version is shown in Figure 8. It would be elongated some 10 inches and configured with a flatter roof and a Lunke sliding door system, but it would still incorporate the RSV foam-filled sheet metal structure, dual-chambered airbags and some of the special research electronics features described above.

The luggage capacity of the luxury vehicle is almost doubled by raising the hood and making the center floor of the luggage compartment substantially thinner (and lower) than the foam-filled section employed in the existing configuration (Figure 9). Reducing this section is the result of the analysis of a variety of frontal impact tests, including underride, override, offset and head-on crash modes.

This analysis indicated that, when impacting both frame and integrated structure vehicles, impact energy is primarily absorbed in the RSV by the foam-filled wheel well panel, the thick outer periphery of the luggage compartment, and the sheer strength of the luggage compartment floor and the upper fender boxes. The analysis also leads us to believe that, by sacrificing compatibility, a front engine configuration is perfectly possible, with little degradation of occupant protection and pedestrian impact capability.

The standard version, which would be produced (starting in 1985) in quantities of up to 30,000 per year, is shown in Figure 10. It would have conventional opening doors and a Renault 1.6 liter engine with a 5-speed manual transmission, and it would be expected to weigh about 2200 pounds.

Both the luxury and the standard cars would use the RSV prototype structural concept with little change (and would have 60 percent parts commonality between them). The use of brake formed parts will save many millions of investment dollars for presses and dies and is ideal for limited production runs by semi-skilled workers.

The exterior of both vehicles (which makes little or no structural contribution) is a polyurethane plastic which has a relatively high flex-modulus to reduce minor damage and to style the energy absorbing structure (Figure 11).

Table 22, a summary of the pertinent financial information, indicates that, in reasonable quantities and at sellable prices, the company can be expected to make a substantial return for investors.

At this point, I have no way of knowing whether we will be successful in raising the necessary equity capital, or of guaranteeing that consumer demand for a vehicle providing a substantially higher level of safety will be as high as was expected. I believe those answers are important to the future planning of government and industry, and I solicit your support to assess the level of consumer demand for high performance auto safety in the real world.

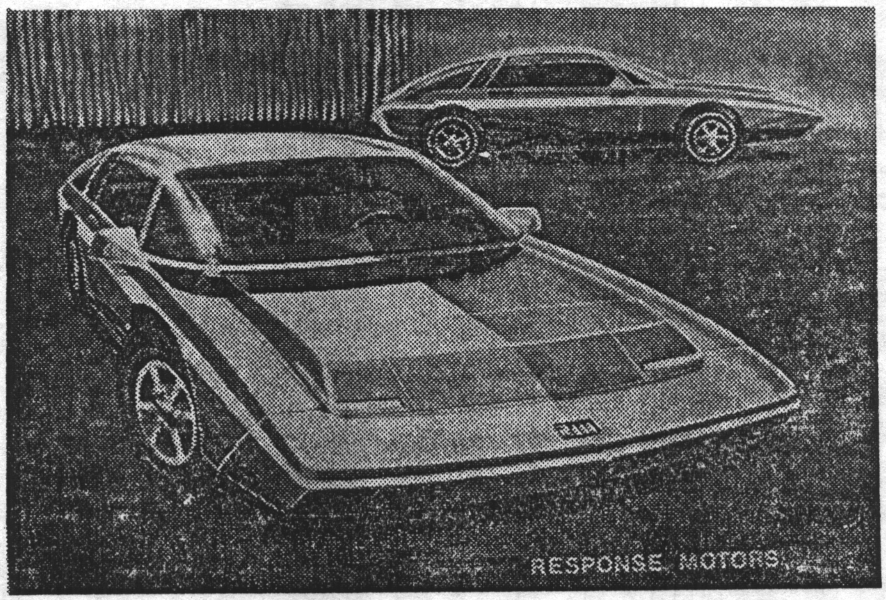

Figure 8. The Luxury RSV

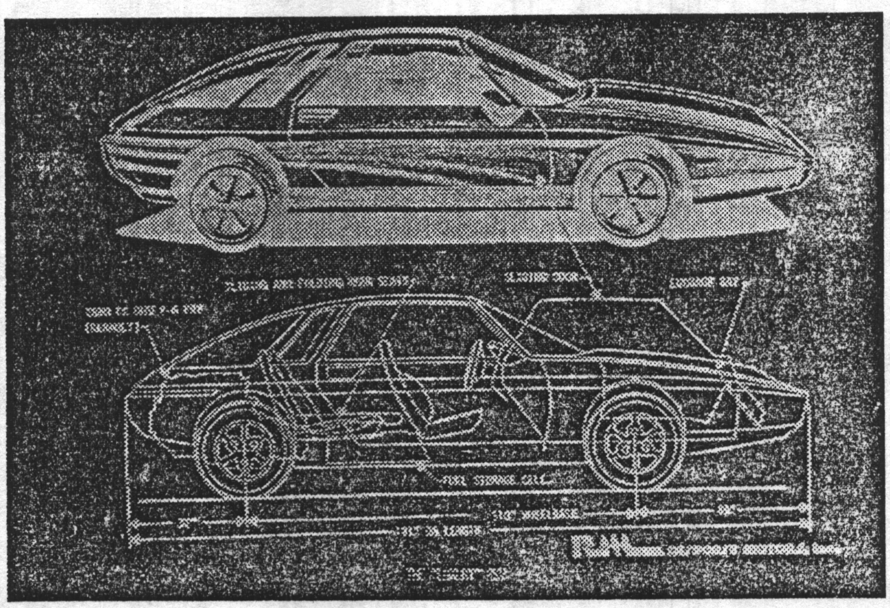

Figure 9. Features of the Luxury RSV

Figure 10. The Standard RSV

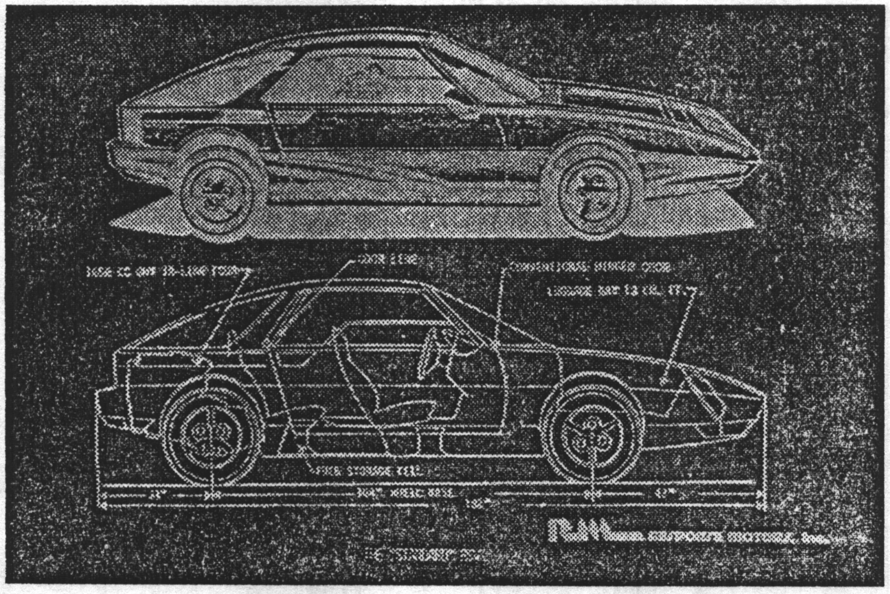

Figure 11. Dimensions of the Standard RSV

Table 22

Manufacturing Plan

	1983	1984	1985	1986	1987
Number of cars produced:					
Luxury RSV	1,000	2,000	2,000	2,000	2,000
Standard RSV			8,000	16,000	24,000
Total production	1,000	2,000	10,000	18,000	26,000
Factory sales price per car:					
Luxury RSV	$ 20,500	$ 20,500	$ 20,500	$ 20,500	$ 20,500
Standard RSV			10,250	10,250	10,250
Sales (in thousands)	$ 20,500	$ 41,000	$123,000	$205,000	$287,000
Pre-tax profit (loss)	(2,759)	1,831	15,754	37,789	63,356
Income tax			500	1,700	2,851
Net income (loss)	$ (2,759)	$ 1,831	$ 15,250	$ 36,089	$ 60,505

* * * * * * *

With a few exceptions, Minicars is reasonably satisfied with our efforts and the results obtained. Our impression is that the Congress and the public of the United States are interested and impressed with the program's results, but somewhat disappointed with the rate and timing of the industry's incorporation of the technology. Through the project, the NHTSA foresaw in 1975 America's need for lightweight, safe, fuel economical vehicles, but was unable to convince the industry to produce such cars. The huge investments now being committed to retool automotive production do include slightly improved occupant protection, damageability and repairability, etc., but focus primarily on fuel economy. I would hope that public information derived from programs like this would increase consumer demand – and thereby create a sizeable market for high level safety performance. Otherwise, the highway carnage will have to get bad enough (or some other factor significant enough) to reflect itself in an economic marketplace reaction before RSV-type safety will be implemented by the manufacturers.

REFERENCES

1. Minicars, Inc., "Research Safety Vehicle, Final Report," Contract DOT-HS-4-00844, April 1975; and D.E. Struble, R. Petersen, B. Wilcox, D. Friedman, "Societal Costs, and Their Reduction by Safety Systems," Fourth International Congress on Automotive Safety, July 1975.

2. Minicars, Inc., "Research Safety Vehicle, Phase II Final Report," Contract DOT-HS-5-01215, November 1977.

3. "The Research Safety Vehicle: Present Status and Future Prospects," SAE No. 780603, June 1978; and "Status Report of Minicars' Research Safety Vehicle," Proceedings 7th International Technical Conference on ESVs, Paris, June 5-8, 1979, pp. 63-75.

4. "The Near-Term Prospect for Automotive Electronics: Minicars' Research Safety Vehicle," SAE No. 780858, September 1978.

5. D. Friedman, "The Production Feasibility of the RSV," SAE Passenger Car Meeting, Dearborn, Michigan, June 1980.

APPENDIX A

RSV BARRIER TESTS

Table A-1

Frontal Barrier Impact (Phase II)

Date: 5/12/76

RSV Speed: 81.79 km/h (50.8 mph)

	Driver	Right Front Passenger
HIC	753	722
Chest Gs (3 msec)	50	46
Left femur, kg (lbs)	668 (1470)	1456 (3200)
Right femur, kg (lbs)	591 (1300)	818 (1800)

Table A-2

Right Offset Frontal Barrier Impact (Phase II)

Date: 7/9/76

RSV Speed: 78.9 km/h (49.0 mph)

	Driver	Right Front Passenger
HIC	474	189
Chest Gs (3 msec)	55	30
Left femur, kg (lbs)	591 (1300)	445 (980)
Right femur, kg (lbs)	545 (1200)	314 (690)

Table A-3

Frontal Barrier Impact (Phase III)

Date: 10/7/78

RSV Speed: 80.77 km/h (50.17 mph)

	Driver	Right Front Passenger
HIC	375	497
Chest Gs (3 msec)	52	87
Left femur, kg (lbs)	N/A	523 (1150)
Right femur, kg (lbs)	545 (1200)	886 (1950)

Table A-4

Frontal Barrier Impact
(Phase IV Quick Look Results)

Date: 6/10/80

Location: Tsukuba, Japan

RSV Speed: 79.7 km/h (49.5 mph)

	Driver	Right Front Passenger
HIC	494	994
Chest Gs (3 msec)	51	46
Left femur, kg (lbs)	497 (1085)	581 (1278)
Right femur, kg (lbs)	607 (1335)	525 (1155)

APPENDIX B

RSV VEHICLE-TO-VEHICLE FRONTAL TESTS*

*Research Safety Vehicle Phase III results, unless otherwise noted.

Table B-1

Left Offset RSV-Volvo Frontal Impact (Phase II)

Date: 12/7/76

RSV Speed: 65.9 km/h (40.9 mph)

Volvo Speed: 65.9 km/h (40.9 mph)

	RSV Driver	RSV Right Front Passenger
HIC	230	215
Chest Gs (3 msec)	42	59
Left femur, kg (lbs)	1364 (3000)	545 (1200)
Right femur, kg (lbs)	636 (1400)	818 (1800)

Table B-2

First RSV-Impala Frontal Impact

Date: 8/7/79

RSV Speed: 58.8 km/h (36.5 mph)

Impala Speed: 58.8 km/h (36.5 mph)

	RSV Driver	RSV Right Front Passenger	Impala Driver
HIC	183	261	963
Chest Gs (3 msec)	36	29	40
Left femur, kg (lbs)	591 (1300)	364 (800)	136 (300)
Right femur, kg (lbs)	727 (1600)	273 (600)	500 (1100)

Table B-3

Second RSV-Impala Frontal Impact (RSV Underride)

Date: 11/14/79

RSV Speed: 57.2 km/h (35.5 mph)

Impala Speed: 44.0 km/h (27.3 mph)

	RSV Driver	Impala Driver
HIC	514	342
Chest Gs (3 msec)	55	70
Left femur, kg (lbs)	519 (1300)	455 (1000)
Right femur, kg (lbs)	727 (1600)	409 (900)

Table B-4

Third RSV-Impala Frontal Impact (RSV Override)

Date: 12/19/79

RSV Speed: 57.8 km/h (35.9 mph)

Impala Speed: 57.8 km/h (35.9 mph)

	RSV Driver	RSV Right Front Passenger	Impala Driver	Impala Right Front Passenger
HIC	813	2243	484	390
Chest Gs (3 msec)	74	70	21	30
Left femur, kg (lbs)	409 (900)	273 (600)	136 (300)	227 (500)
Right femur, kg (lbs)	409 (900)	364 (800)	91 (200)	182 (400)

APPENDIX C

RSV SIDE IMPACT TESTS

Table C-1

Volvo Into RSV Left Side at 90° (Phase II)

Date: 11/19/76

RSV Speed: 63.1 km/h (39.2 mph)

Volvo Speed: 63.1 km/h (39.2 mph)

	RSV Driver	RSV Right Front Passenger
HIC	66	39
Chest Gs (3 msec)	40	40
Pelvic Gs (3 msec)	35	26

Table C-2

Impala Into RSV Right Side at 90° (Phase III)

Date: 6/8/79

RSV Speed: 56.4 km/h (35.0 mph)

Impala Speed: 56.4 km/h (35.0 mph)

	RSV Right Front Passenger	RSV Right Rear Passenger
HIC	540	244
Chest Gs (3 msec)	32	65
Pelvic Gs (3 msec)	32	50

Table C-3

Renault 20 Into RSV Left Side at 90°
(Phase IV Quick Look Results)

Date: 5/28/80

Location: Lardy, France

RSV Speed: 0

Renault 20 Speed: 50 km/h (31 mph)

	RSV Driver	RSV Right Front Passenger	RSV Left Rear Passenger
HIC	46	57	42
Chest Gs (3 msec)	50	43	47
Pelvic Gs (3 msec)	42	15	40

Table C-4

Renault 20 Into RSV Right Side at 90°
(Phase IV Quick Look Results)

Date: 6/17/80

Location: Lardy, France

RSV Speed: 0

Renault 20 Speed: 65.7 km/h (40.8 mph)

	RSV Driver	RSV Right Front Passenger	RSV Left Rear Passenger
HIC	175	172	310
Chest Gs (3 msec)	80	50	80
Pelvic Gs (3 msec)	20	70	80

Table C-5

Datsun 510 Into RSV Left Side at 90°
(Phase IV Quick Look Results)

Date: 7/4/80

Location: Tsukuba, Japan

RSV Speed: 56.4 km/h (35 mph)

Datsun 510 Speed: 56.4 km/h (35 mph)

	RSV Left Front	RSV Left Rear	Datsun Left Front	Datsun Right Front
HIC	23	70	92	89
Chest Gs (3 msec)	28	61	19	16
Pelvic Gs (3 msec)	27	93	47	24

Table C-6

Datsun 510 Into RSV Right Side at 90°
(Phase IV Quick Look Results)

Date: 7/10/80

Location: Tsukuba, Japan

RSV Speed: 64.4 km/h (40 mph)

Datsun 510 Speed: 64.1 km/h (39.8 mph)

	RSV Right Front	RSV Right Rear	Datsun Left Front	Datsun Right Front
HIC	30	87	187	191
Chest Gs (3 msec)	56	84	24	23
Pelvic Gs (3 msec)	38	69	29	27

APPENDIX D

LARGE RSV IMPACT TESTS*

*Conducted under Phase III of the Research Safety Vehicle Program.

Table D-1

LRSV Frontal Barrier Impact

Date: 5/9/79

LRSV Speed: 62.8 km/h (39.0 mph)

	Driver	Middle Front Passenger	Right Front Passenger
HIC	174	169	178
Chest Gs (3 msec)	37	30	30
Left femur, kg (lbs)	523 (1150)	364 (800)	364 (800)
Right femur, kg (lbs)	500 (1100)	500 (1100)	455 (1000)

Table D-2

LRSV 30° Oblique Barrier Impact

Date: 7/20/79

LRSV Speed: 54.4 km/h (40 mph)

	Driver	Middle Front Passenger	Right Front Passenger
HIC	248	74	130
Chest Gs (3 msec)	32	25	35
Left femur, kg (lbs)	591 (1300)	273 (600)	568 (1250)
Right femur, kg (lbs)	455 (1000)	545 (1200)	273 (600)

Table D-3

SAE 1818 kg (4000 lb) Bogey Into LRSV Right Side at 90°

Date: 10/4/79

Bogey Speed: 48.3 km/h (30 mph)

	Right Front Passenger	Right Rear Passenger
HIC	182	627
Chest Gs (3 msec)	90	150
Pelvic Gs (3 msec)	100	105

Table D-4

SAE 1818 kg (4000 lb) Bogey Into LRSV Left Side at 90°

Date: 2/7/80

Bogey Speed: 41.2 km/h (25.6 mph)

	Driver
HIC	132
Chest Gs (3 msec)	55
Pelvic Gs (3 msec)	55