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 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

Figure 1. Research safety vehicle.

Figure 2. Gull wing doors.

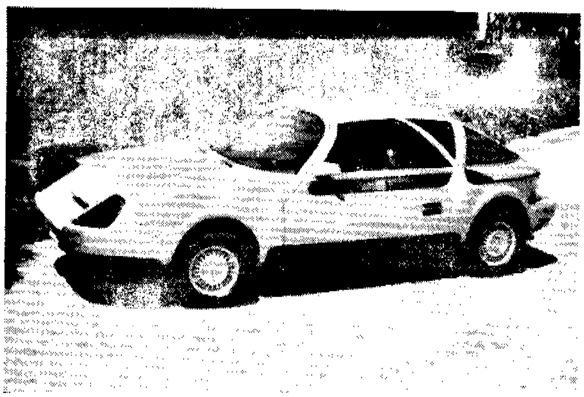

Figure 3. High technology research safety vehicle.

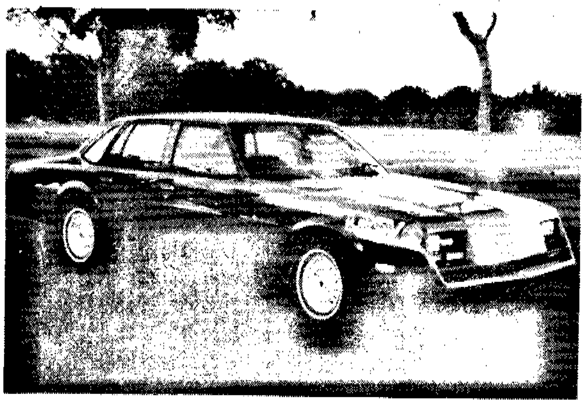

Figure 4. Large research safety vehicle.

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		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)	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 (km/h)	Speed (mph)	Bullet car injury levels	Target car injury levels* Front	Target car injury levels* 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 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

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

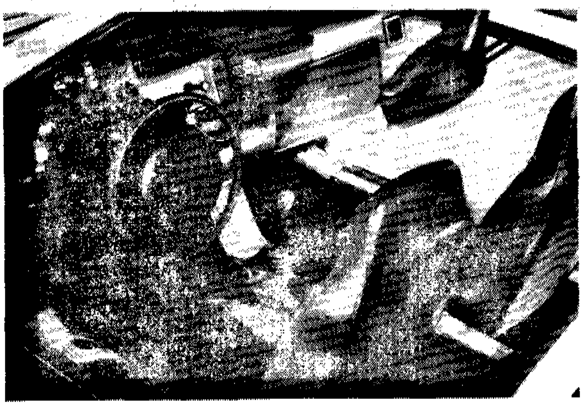

Figure 5. Front seat accommodations.

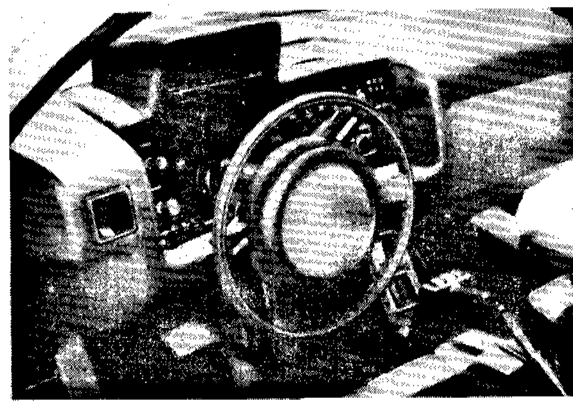

Figure 6. Electronic display.

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

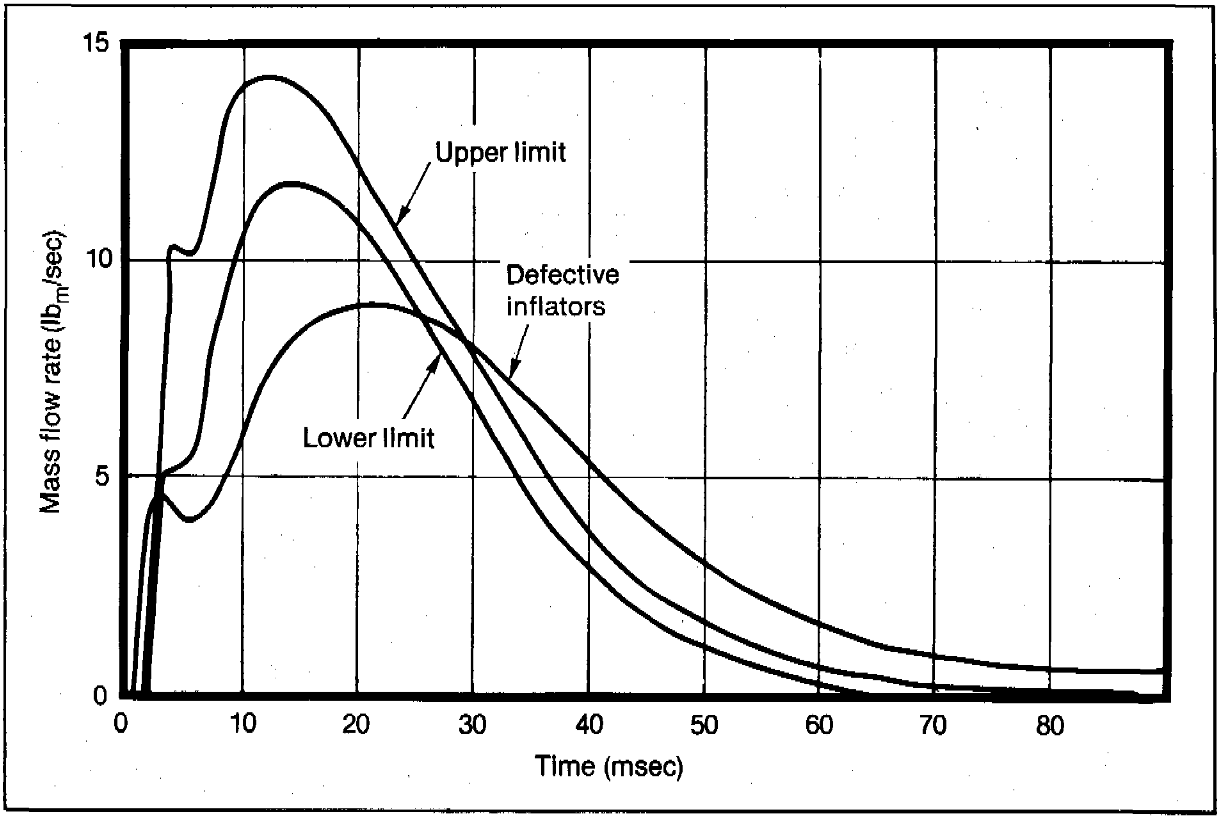

Figure 7. Inflator characteristics.

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		
	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		

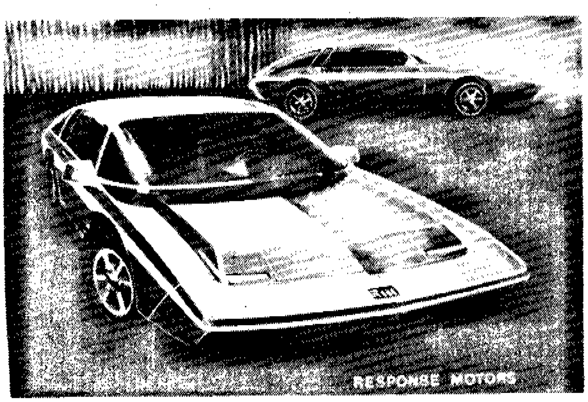

Figure 8. The luxury RSV.

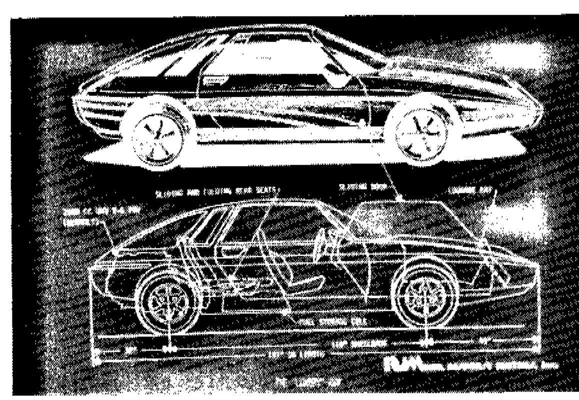

Figure 9. Features of the luxury RSV.

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 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 quaranteeing that consumer demand for a vehicle providing a substantially higher level of safety will be as high as was

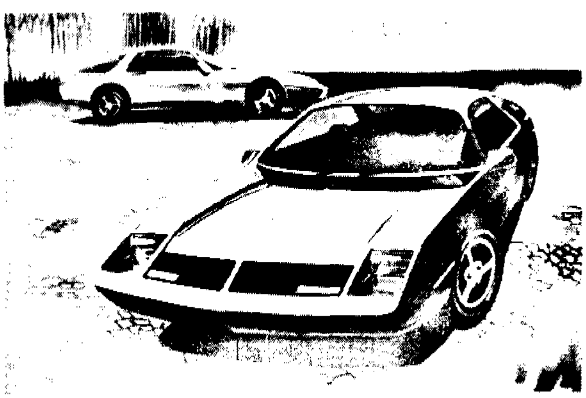

Figure 10. The standard RSV.

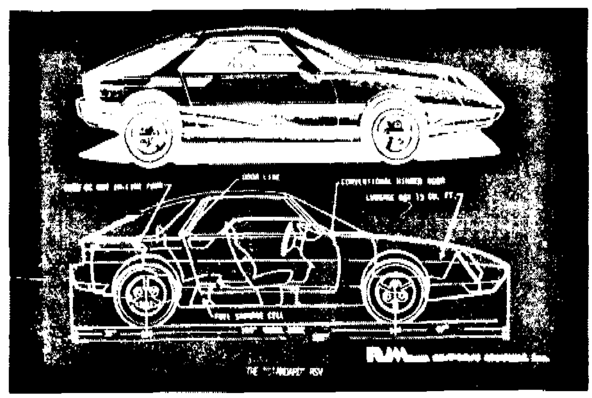

Figure 11. Dimensions of the standard RSV.

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-type safety will be implemented by the manufacturers.

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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
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.

Results of Handling, Stability, and Braking Tests of the Minicars RSV

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INTRODUCTION

For her share of the worldwide testing of the Minicars RSV, the Federal Republic of Germany agreed to test its handling and braking characteristics—as was done a year ago with the Calspan RSV. The task issued to the German Government was delegated by the BAST (Federal Highway Research Institute) as coordinator of the automobile manufacturers represented in the VDA (Automobile Industry Association).

Due to the outstanding cooperation of all participants, despite the sometimes poor weather conditions, it was possible to complete the manoeuvres required by the RSV specifications on time, as well as to carry out other additional tests.

TEST CONDITIONS

The test car used was the Minicars RSV M 5–10 (figure 1). General Data for the test car are shown in the table in figure 2.

Test equipment was installed in the car by Daimler-Benz. Manoeuvres requiring larger surface areas were carried out on the VW proving grounds in Ehra-Lessien, as was done with the Calspan RSV, while the other tests were performed at Daimler-Benz in Stuttgart. The test conditions complied with the RSV specifications. The following criteria were tested:

- braking in a straight line
- braking in a turn
- brake pedal force as a function of deceleration
- effectiveness of the parking brake
- steady-state yaw response
- transient yaw response
- steering returnability
- maximum lateral acceleration
- control at breakaway
- crosswind sensitivity
- steering control sensitivity
- pavement irregularity sensitivity
- slalom course
- passing time (acceleration)

In order to make a general assessment of the handling characteristics, the following vehicle parameters were also determined:

- turning circle diameter
- maximum speed
- drag coefficient
- kinematic changes in toe-in and camber
- suspension rate

Figure 3 lists the parameters to be measured and the transducers used.

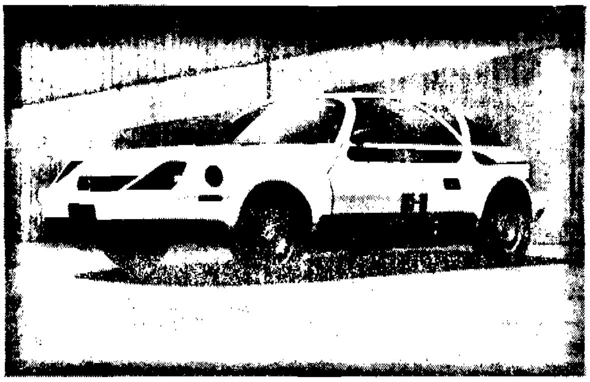


Figure 1. Minicars RSV.

Curb weight	2579 lbs
Weight (loaded to 60% capacity)	2986 lbs
Axle load distribution (vehicle loaded to 60% capacity)	46/54%
Track front	62 in
rear	62 in
Wheelbase	104 in
Tires	200/65 hr 370 Dunlop de Novo 2 run-flat

Figure 2. Minicars RSV general data.

The electronic test equipment arrangement is shown in figure 4. It consists of data acquisition and data processing. The data acquisition equipment was installed in a special test rack in the rear of the passenger compartment (figure 5). This consisted basically of an HP 2100 process computer for digitizing and editing, and a Columbia cassette unit for data storage. The data processing equipment was carried in a separate vehicle acting as a mobile computer centre (figure 6), equipped with a second cassette unit, an HP 9845 B desk computer and an HP 9872 A plotter for the computation and plotting of the diagrams required by the RSV specifications. This enabled rapid evaluation and checking of the recorded data immediately after each test run. It was the first time that data processing with a computer in the vehicle and at the test site had been used for tests of this kind.

TEST RESULTS

Meeting the RSV Specifications

In the manoeuvre braking in a straight line (figure 7), the maximum permissible stopping distances for both load conditions and all three brake system operating conditions were not exceeded. However, the stopping distance for the 100% load condition was only 6.8% below the requirement. The specified lane width (3.7 m) was maintained with only slight steering wheel corrections (< 10°).

Measuring parameters	**Transducer**
Yaw angle	Directional gyro
Yaw velocity	Directional gyro
Lateral acceleration	Stable platform
Forward velocity	Optical sensor
Wheel angle	Induct. displacement transd.
Steering wheel torque	Strain gauge bridge
Steering wheel angle	Potentiometer
Steering wheel velocity	Rate sensor
Stopping distance	Optical sensor
Course deviation	Measuring tape
Brake pedal force	Mech. pneumatic pressure transducer

Figure 3. Measuring parameters and transducers.

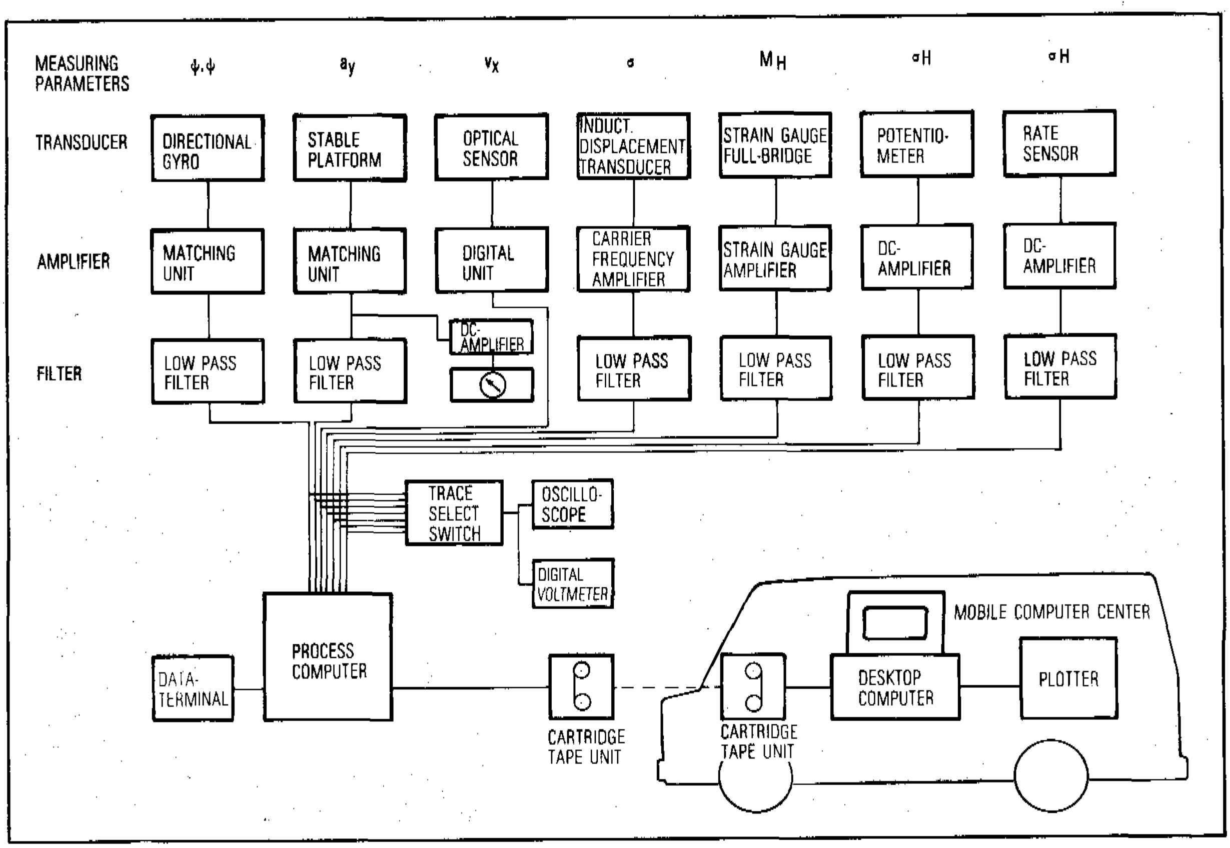


Figure 4. Minicars RSV measuring arrangement.

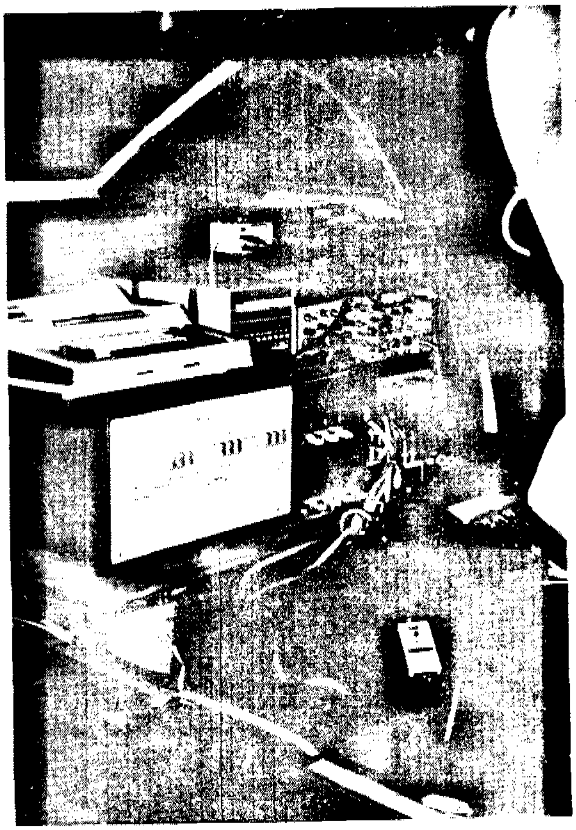


Figure 5. Test equipment in the test car.

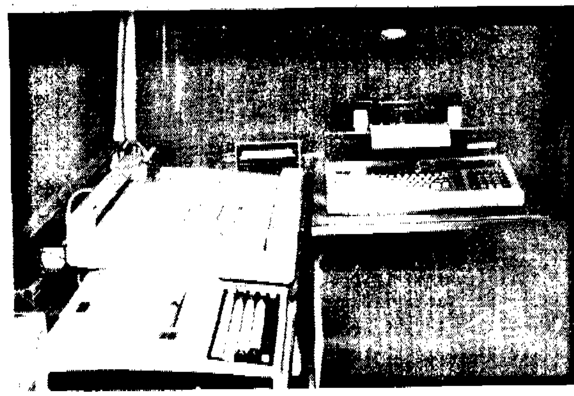


Figure 6. Test equipment in the mobile computer center.

Loading % capacity	Initial speed	Stopping distance	
		Required	Measured
60	60 mph	≤ 190 feet	160.4 feet
100			176.7 feet

Figure 7. Minicars RSV braking in a straight line.

Loading % capacity	Initial conditions	Stopping distance	
		Required	Measured
60	Radius 357 feet	90 feet	83.0 feet
	Speed 40 mph		
100	(Lat. Acc..3G)		87.6 feet

Figure 8. Minicars RSV braking in a turn.

The requirements for braking in a turn (figure 8) in a lane of 3.7 m width were also met, although the measured stopping distances of 83.0 ft and 87.6 ft were only slightly less than the allowed maximum of 90 ft. The main reason for this was the premature locking tendency of the wheels on the inside of the turn, which meant that greater decelerations could not be achieved within the limits specified for lane width and steering wheel correction (< 180°).

The brake pedal force for various, quasi-steady-state decelerations is shown in figure 9. With the brake system in fully operational condition, the pedal forces are to some extent less than the minimum values specified, i.e., up to 0.4 g deceleration for 100% loading and up to 0.6 g for 60% loading. Results under the other conditions (failure of brake booster or of front brake circuit) were within the permissible limits.

The effectiveness of the hand-operated parking brake was not sufficient to hold the vehicle on the 30% grade. With the brakes adjusted as they were, the mechanical stop detent for the hand-brake lever was reached before sufficient braking effect existed.

Figure 10 shows the steady-state yaw response for a lateral acceleration of 0.4 g. Over the entire speed range, the measured values lie within the given limits. Noticeable is the large difference between a left turn (ccw) and a right turn (cw), which made itself evident under steady-state conditions by different steering angles and under

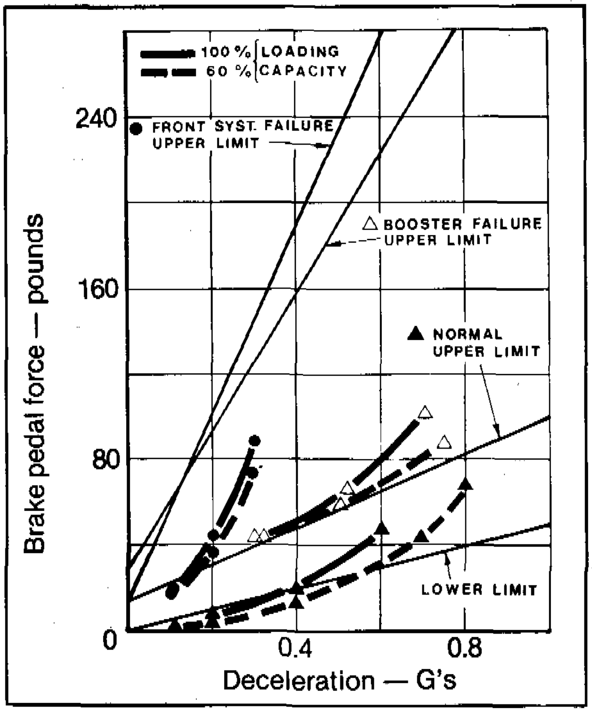


Figure 9. Minicars RSV brake pedal force versus vehicle deceleration.

transient conditions by different steering characteristics.

The transient yaw response as a result of a step input to the steering wheel (figures 11 and 12) exhibits characteristics typical of oversteer. The specified limits were not exceeded. The difference between right and left turn can be seen especially well at a speed of 70 mph.

Figures 13 to 15 show the returnability of the steering at speeds of 25 to 50 mph when the steering wheel is released in a steady-state turn at 0.4 g. The yaw velocity excursions are greater for left turn than for right turn. This could be caused by a greater aligning torque for left turn and asymmetric steering damping. The characteristic of the course angle (figure 13) shows that there is a slightly increasing tendency at 25 mph for left turn and a slightly decreasing tendency for right turn. Thus in both cases the vehicle turned slightly to the left when the steering wheel was released. The RSV specifications were met in almost all instances; only at 25 mph and for left turn (figure 14) did the remaining yaw ve-

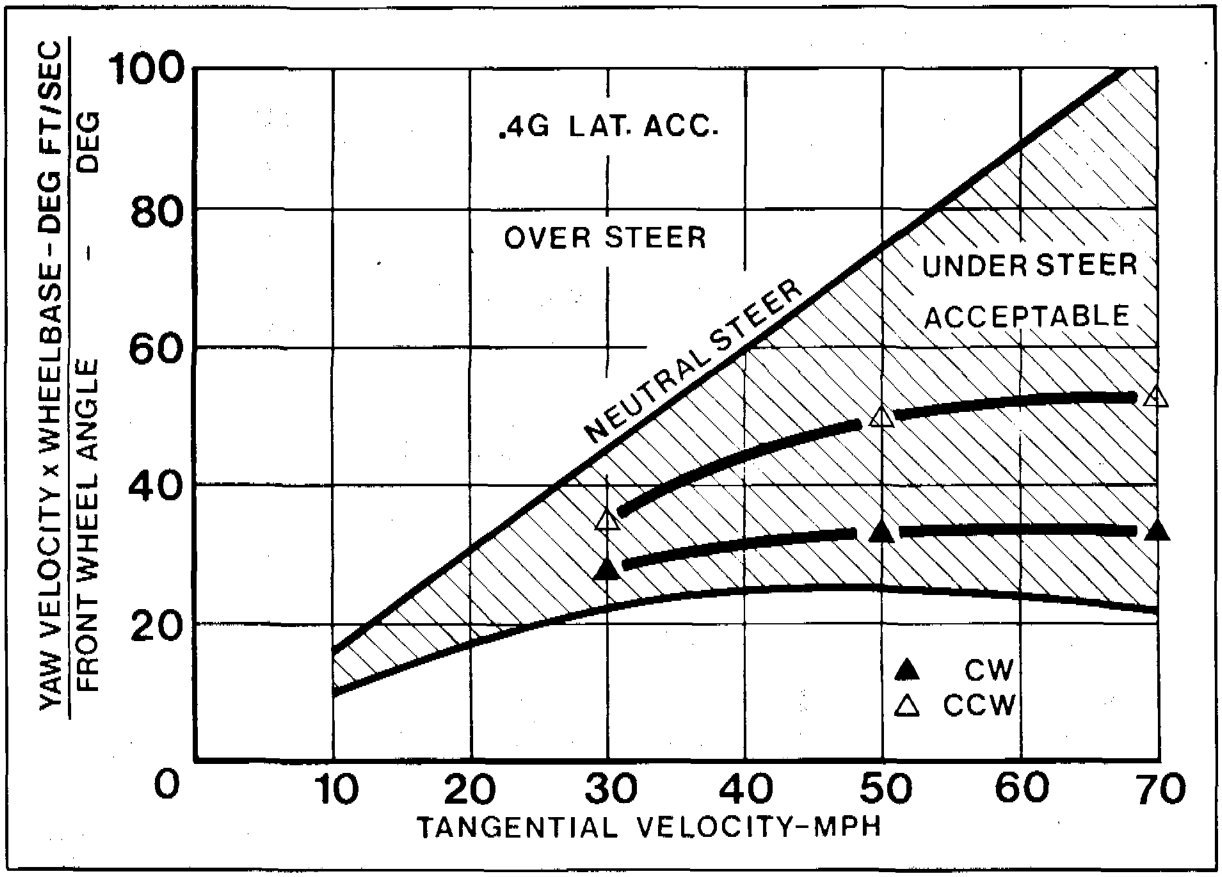


Figure 10. Minicars RSV steady-state yaw response.

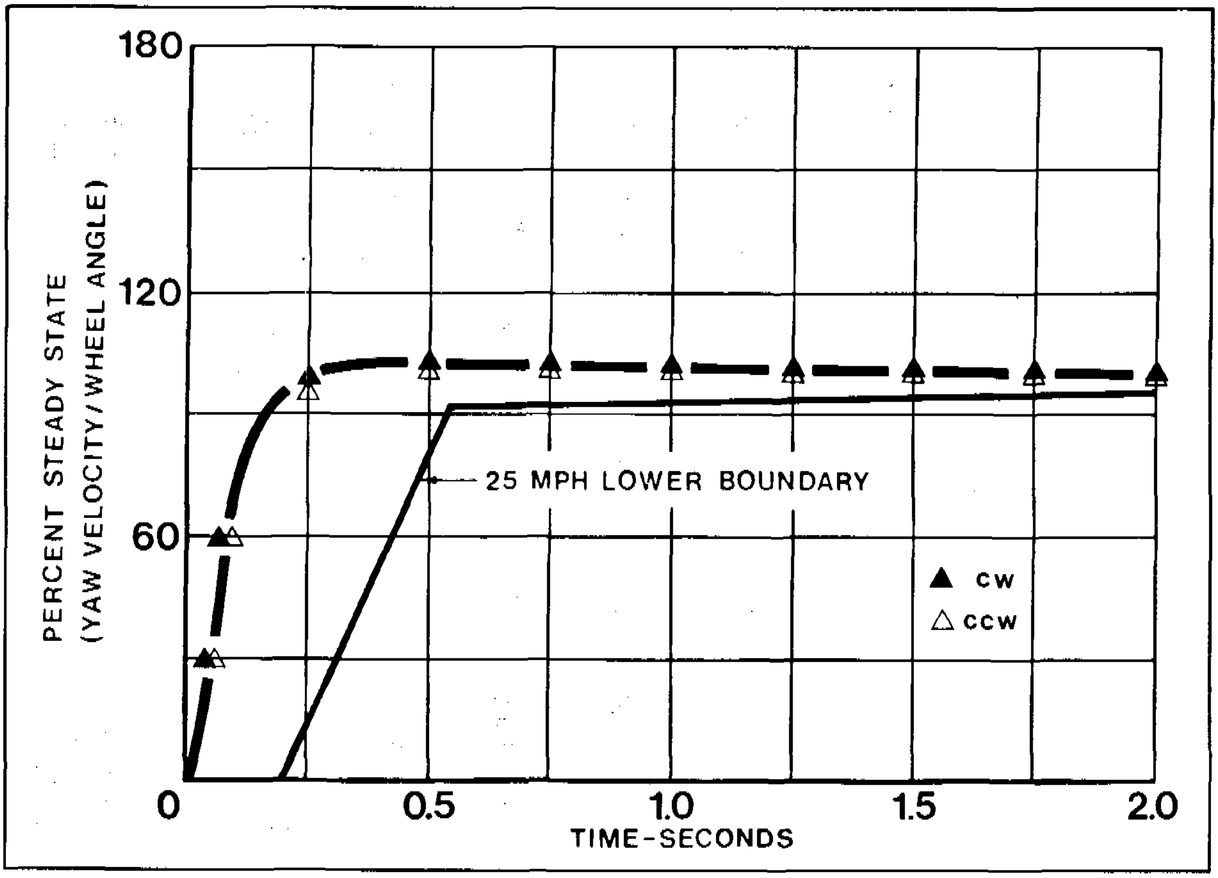


Figure 11. Minicars RSV transient yaw response at 25 mph.

locity lie somewhat above the maximum permissible limit.

Figure 16 shows the maximum lateral acceleration achievable with different tyre pressures. The requirements were fulfilled in all cases. For a short period of time it was possible to achieve about 10% higher values, but handling then was no longer stable.

The test conditions specified for measuring control at breakaway are so difficult to comply with that the test results were hardly reproducible. Consequently a graph of test results cannot be provided here.

However, the test can be described as completed on the basis of the subjective assessments of several skilled drivers and observers.

The crosswind sensitivity of the vehicle is shown in figure 17. The deviation from course is plotted against the distance covered 2 seconds after onset of the crosswind. The test values lie below the maximum permissible limit.

Figure 18 shows the steering control sensitivity at various driving speeds. Although the test values are considerably greater than the required minimum value, the steering was not judged to be heavy.

Testing directional stability after a defined pavement irregularity resulted in the permissible deviation from course after 2 seconds not being exceeded at 30 and 50 mph. At 70 mph, the deviation of 1.65 ft was greater than the permissible value of 1 ft.

The required minimum speed of 50 mph for the slalom course (figure 19) was exceeded, with an attained speed of 51.1 mph.

The acceleration ability of the vehicle was just sufficient to accelerate the vehicle from 30 to 65 mph in a maximum of 24 seconds with gear change as required. The average time was 23.8 seconds. The measured acceleration time from 50–70 mph of 19.2 seconds was well below the permissible value of 22 seconds.

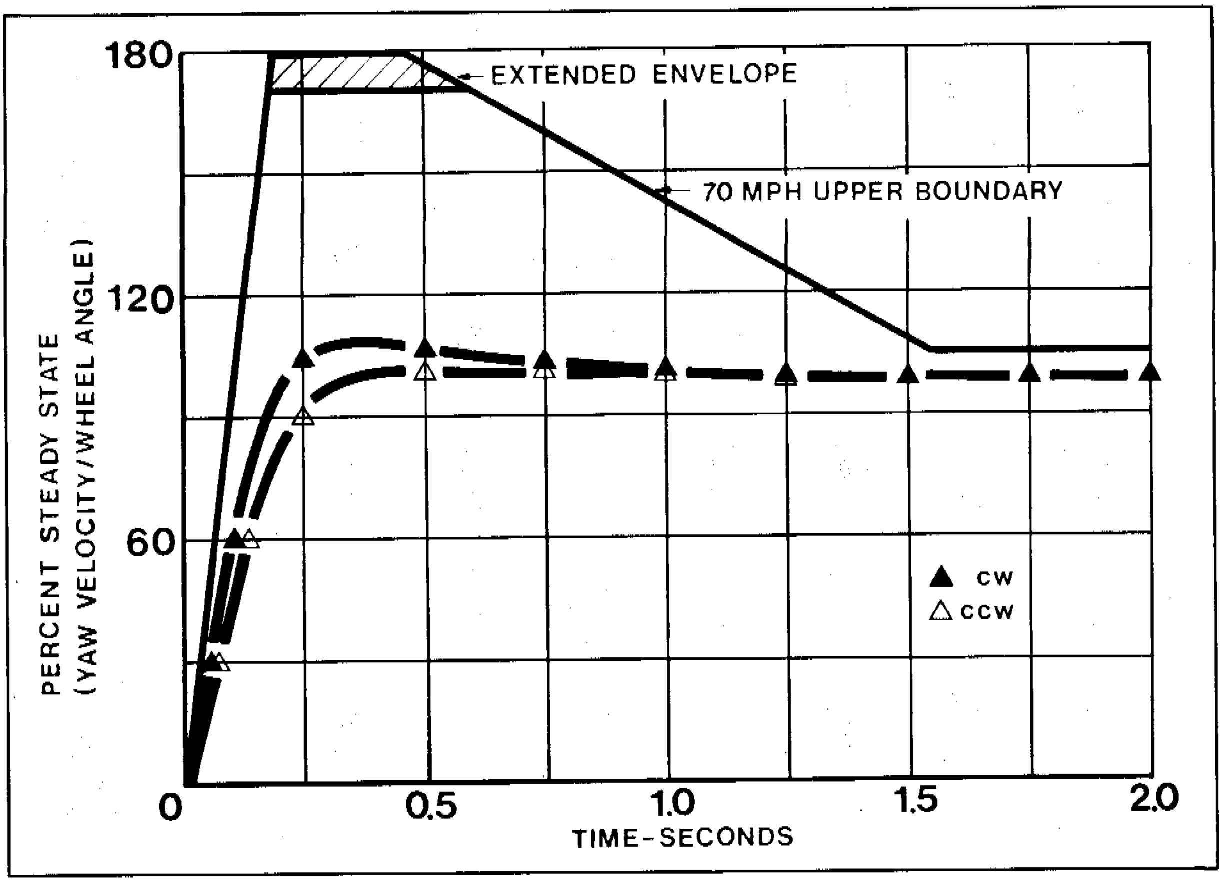


Figure 12. Minicars RSV transient yaw response at 70 mph.

Additional Measurements

To get a well-rounded picture of the vehicle, a few other relevant dynamic tests were carried out in addition to the RSV specifications. The results were as follows:

The turning circle diameter of 41.1 ft for right lock and 42.7 ft for left lock is a bit too large for a vehicle of this size. On right lock, the wheel on the inside of the turn rubbed against the body; even adjustment of the steering limit stop gave no improvement.

The maximum speed of 84.5 mph is very low for European conditions, and even in countries which impose speed limits for all types of roads would probably be just acceptable.

The drag coefficient determined for the vehicle's frontal area of 23.6 ft² (2.19 m²) was $c_w = 0.414$. In modern terms this value is relatively high, especially with regard to minimizing fuel consumption. There are some standard production cars which have much better values.

The kinematic change in toe-in of the front axle (10'/10 mm vertical wheel displacement) was very large compared to modern production vehicles. Roll mode particularly results in a severe worsening of the straight-ahead characteristics on an undulating surface.

On the other hand, only minimal changes in toe-in occur on the rear axle. The camber angle changes are normal.

The suspension rates measured for the front and rear axles point to indicate a very stiffly sprung vehicle. As no roll stabilizers are fitted, there is no difference between jounce and rebound mode and roll mode.

SUMMARY

According to the results of the tests carried out as prescribed by the RSV specifications, the Minicars RSV can be said to have met the requirements in general. In three cases some of the limit values were not met, and the vehicle just

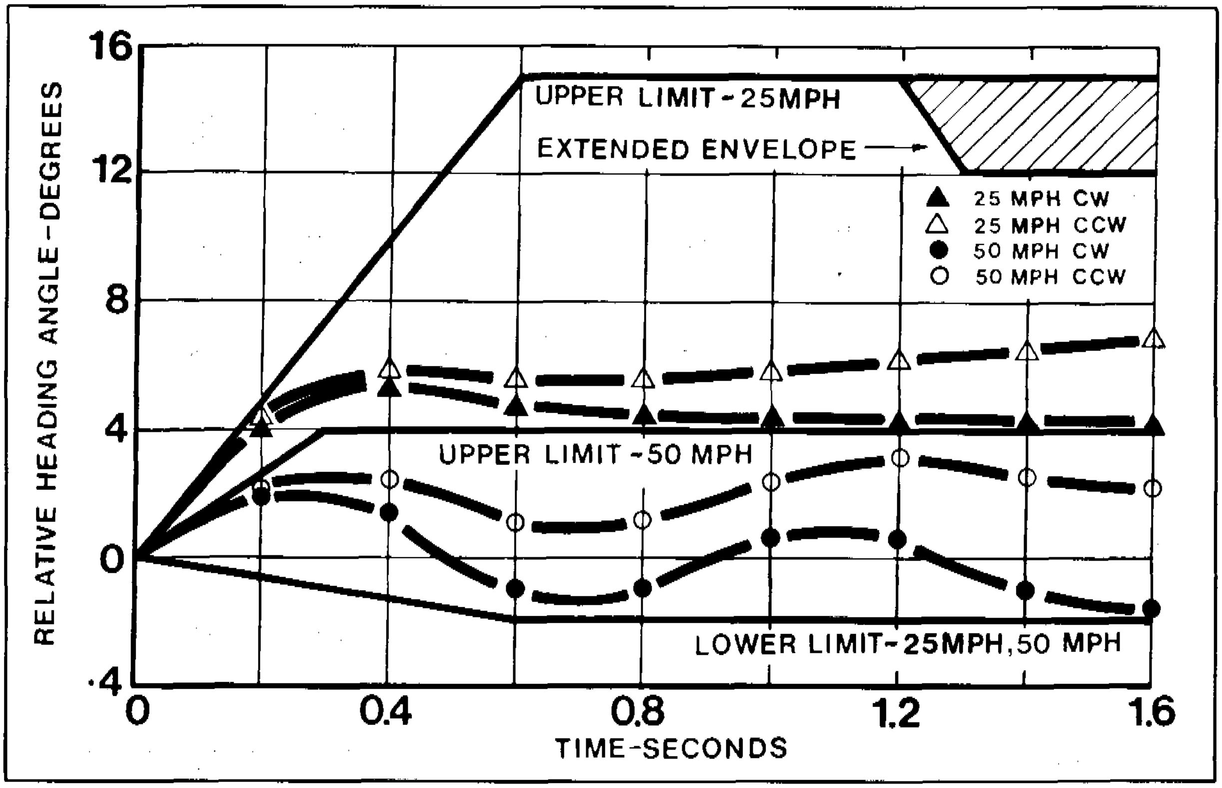


Figure 13. Minicars RSV Steering returnability free control heading.

barely met the required performance in some of the tests.

For example in the braking with quasi-steady-state decelerations test the pedal force is too low in the low and medium deceleration ranges with the brake system in fully operational condition. Only at higher decelerations do the pedal forces lie within the permissible limits.

The effectiveness of the parking brake on the 30% grade was insufficient and thus is a second unfulfilled requirement.

Directional stability with pavement irregularity negotiated at 70 mph was also below the required standard.

The requirements for both braking manoeuvres are only just met. For braking in a straight line as well as for braking in a turn, the stopping distance reserves are minimal. The safety margin for the turn manoeuvre in fully loaded condition is very small, at less than 3%.

In the steady-state yaw response test, the values achieved are within the stated limits. Noticeable, however, is the great difference between right and left turn.

This varying response is also evident in the steering returnability test. Here the time history of the relative course angle for the left turn is distinctly greater than that for the right turn. The final yaw velocity lies outside of the permitted tolerances.

CONCLUSIONS

Test Criteria

During the tests it became clear that some of the manoeuvres required by the RSV specifications are barely reproducible and therefore difficult to evaluate. It is recommended that such criteria should be altered or omitted from future tests.

For example, the tolerance range for the steering returnability test at 25 mph (figure 14) is smaller than the scatter of the test values and thus is not well chosen.

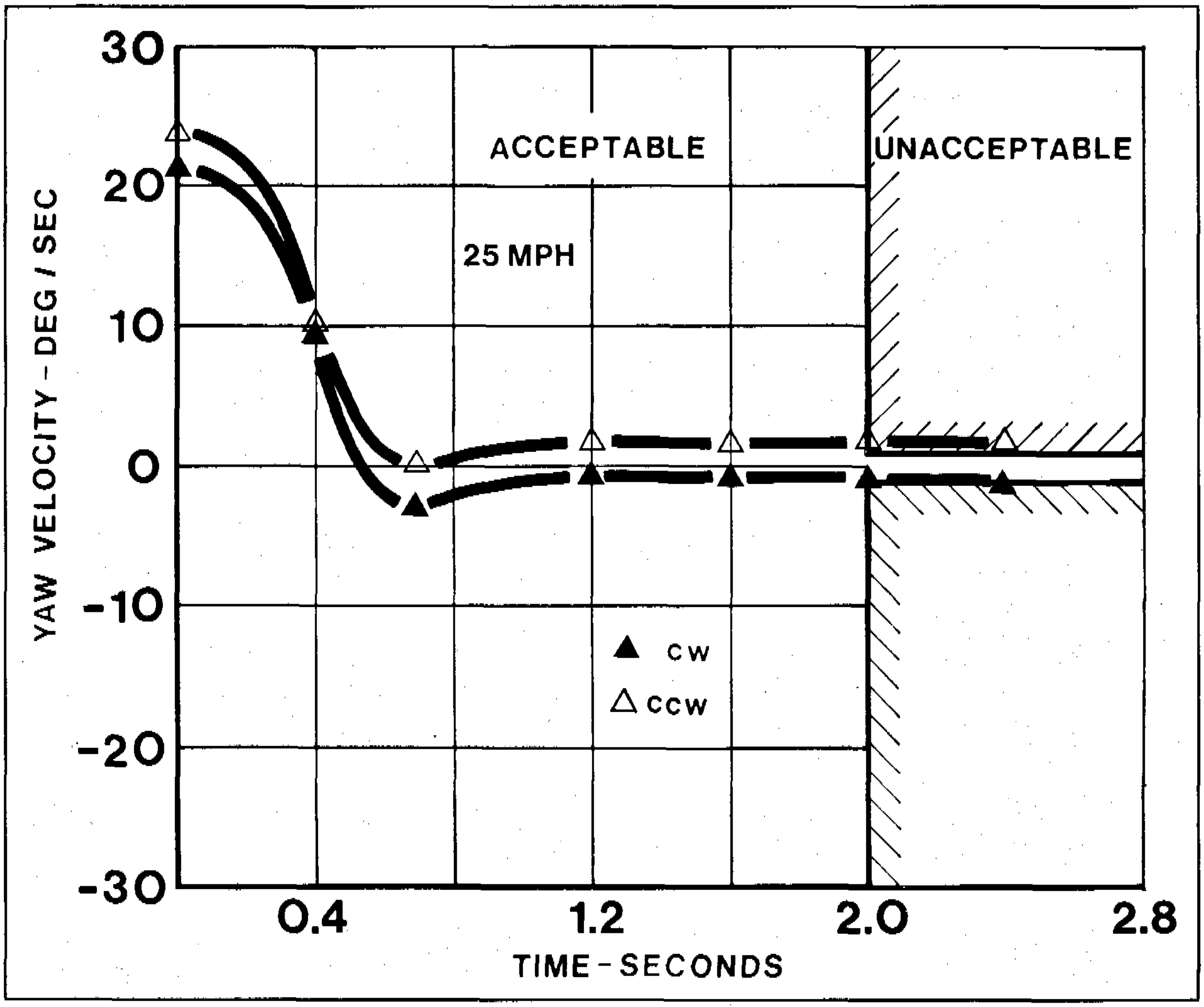


Figure 14. Minicars RSV returnability performance yaw rates at 25 mph.

The required lateral acceleration values for the steady-state circular turn are biased in favour of understeering vehicles. Demands made for non-specification tyre pressures should not be greater than those made for design values.

The test conditions for the control at breakaway test are so difficult to comply with that the test results are hardly reproducible. The specification should be modified.

For the test pavement irregularity sensitivity the permitted deviation from the course after 2 seconds at various speeds is a maximum of 1 ft. Course angle errors of just a few minutes when starting off, or road and wind influences create test value scatter which is greater than the required maximum deviation. The test is therefore not practical and should be changed.

The drastic steer and brake manoeuvre for testing overturning immunity is not reproducible and has no bearing on reality. For this reason this criteria was not tested, and it is recommended that it be omitted from the specifications.

Test Vehicle

Although research safety vehicle should represent the latest advances in active and passive safety, both of the vehicles tested so far from Calspan and Minicars have exhibited serious defects in basic design which would not allow safe operation in traffic. Accordingly, it seems as if these vehicles were designed primarily to meet certain specifications, which they do to a very great extent. This again is proof of the fact that

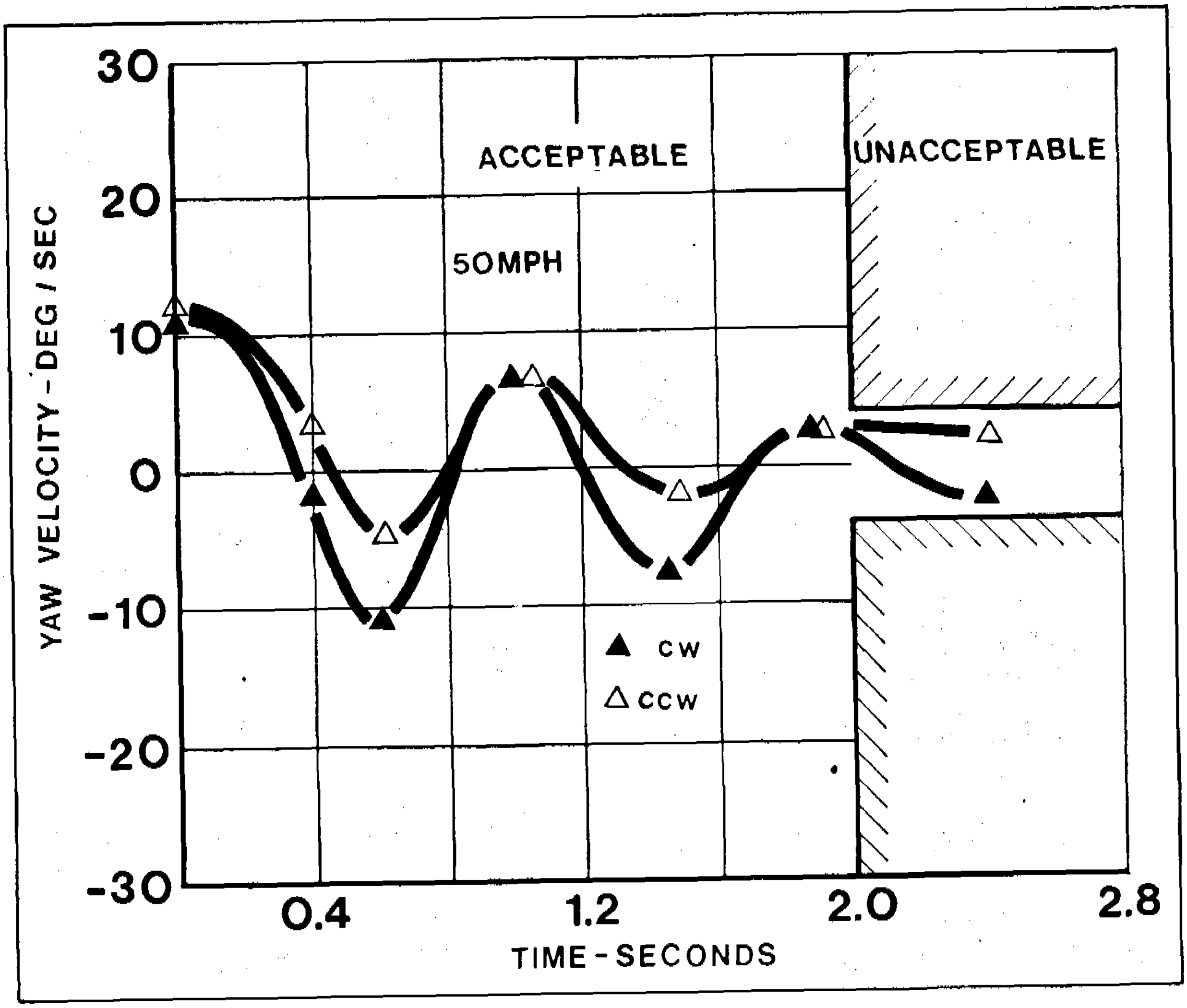


Figure 15. Minicars RSV returnability performance yaw rates at 50 mph.

SURFACE	TIRE PRESSURE	LATERAL ACCELERATIONS (G) FIXED CONTROL	
		REQUIRED	MEASURED
DRY CONCRETE OR ASPHALT	DESIGN VALUE	0.60	0.69
	120%	0.60	0.72
	80%	0.55	0.67
	120% FRONT 80% REAR	0.63	0.66
	80% FRONT 120% REAR	0.59	0.67
WET CONCRETE OR ASPHALT	DESIGN	$a_y(\text{WET}) = \left(\frac{\text{SKID NUMBER(WET)}}{\text{SKID NUMBER(DRY)}}\right) a_y(\text{DRY})$	–

Figure 16. Minicars RSV lateral accelerations.

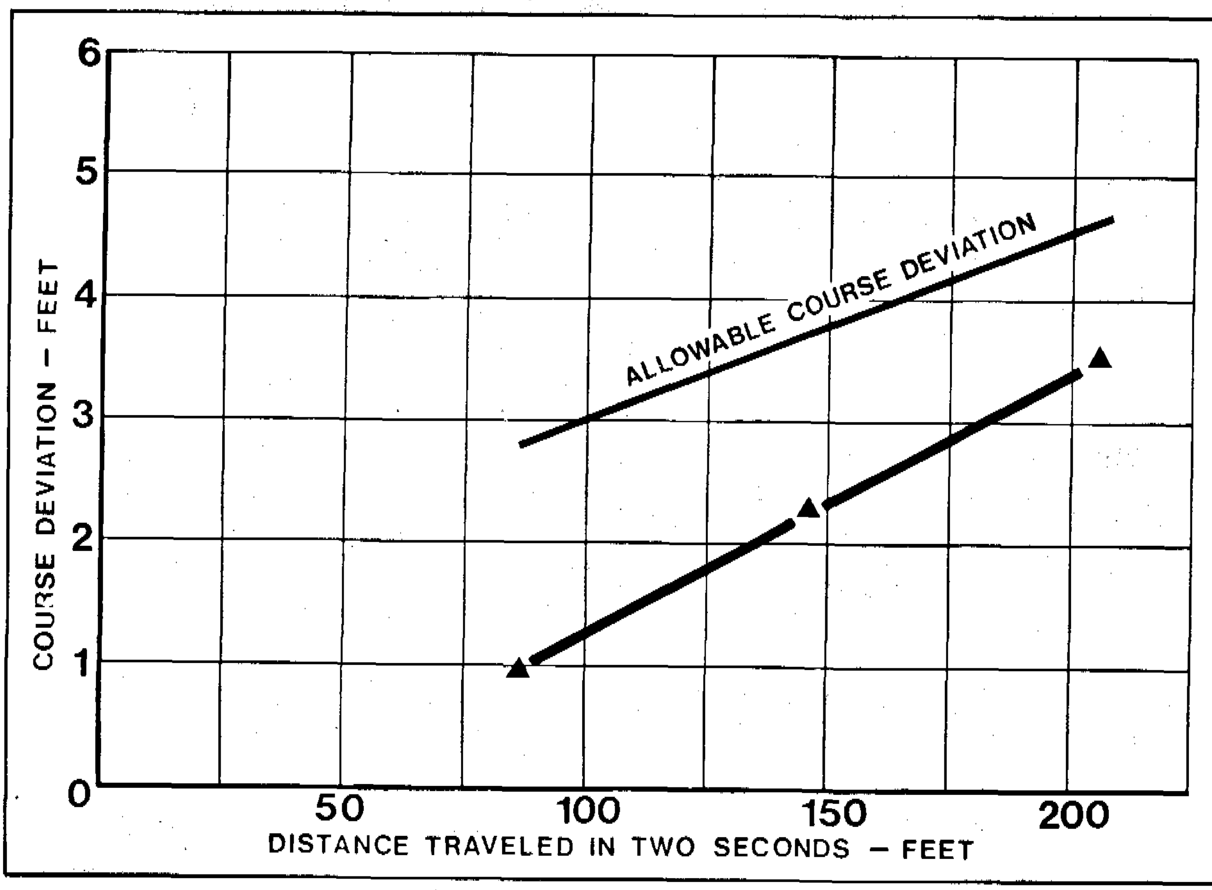
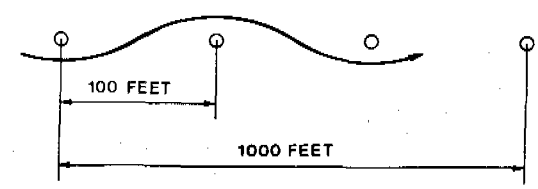


Figure 17. Minicars RSV crosswind sensitivity allowable course deviation by crosswind.

SPEED MPH	STEERING WHEEL TORQUE REQUIRED	STEERING WHEEL TORQUE MEASURED
30		16.1
50	≥ 5 IN. POUND	20.4
70		25.0

Figure 18. Minicars RSV steering control sensitivity.



MINIMUM AVERAGE VELOCITY REQUIRED	MINIMUM AVERAGE VELOCITY MEASURED
50 MPH	51.1 MPH

Figure 19. Minicars RSV overturning immunity—slalom course.

compliance with the specified test criteria is by no means a guarantee, that the vehicle will be adaptable to the demands of real traffic situations.

The Minicars RSV tested, although complying with the specifications, showed such weaknesses in its handling characteristics that operation of the vehicle was considered unsafe.

Despite frequent adjustments, there was extensive play in the very angular steering column train. This had a strong adverse effect on steering precision and straight-ahead stability. When driving in a straight line with the steering wheel held firmly, even slight irregularities in the road surface caused noticeable steering of the front wheels which resulted in corresponding changes in direction.

The handling characteristics on a test track with alternating left and right undulating surfaces is unacceptable. Even at moderate speeds, the steering corrections necessary are so great that the average driver is overtaxed, and even skilled drivers have difficulty in keeping the vehicle on the track. The kinematic oversteering effect causes a strong and difficult-to-control pushing effect when turning into a bend, and the steering lock applied has to be reduced in order to stabilize the vehicle. In the boundary speed range during a steady-state circular turn, there is asymmetry between left and right.

The insufficient pedal force makes steady braking difficult. In emergency stops the pedal was pushed to the floor, although no fading occurred. Readjustment of the linkage eliminated this fault but at the same time resulted in an ergonomically poor pedal position.

For reasons of installation space alone, the overall conception does not allow these details, which are important for active safety, to be harmonized satisfactorily.

Both vehicles built by Calspan and Minicars show clearly that a useful compromise between active and passive safety, as well as between usability and cost, could not be successfully found.

Report on Minicars RSV Tests

KENICHI GOTO
Japan Automobile Research Institute, Inc.

ABSTRACT

Japan Automobile Research Institute, Inc. (JARI) carried out three types of tests on the Minicars RSV's (hereafter referred to as M-RSV's) from April 1980 to July 1980, according to the "Memorandum of Agreements Concerning Test Program for Research Safety Vehicles" that had been concluded between the Department of Transportation (DOT) of the US government and the Ministry of International Trade and Industry (MITI) of the Japanese government.

- *Collision Tests*—The tests included a frontal collision test of a M-RSV against a fixed flat barrier, three side collision tests between each M-RSV and J-Car while both vehicles were running and a baseline side collision test between Japanese passenger cars while both vehicles were running.
- *Handling, Stability and Braking Performance Tests*—Tests were carried out on nine items for the handling and stability, and on three items for the braking performance of the M-RSV's.
- *Visibility Tests*—The field of direct view tests, the field of view tests and lighting equipment tests were carried out for the M-RSV's.

The foregoing three types of tests will be discussed in this report.

COLLISION TESTS

1. Outline of Collision Tests

Collision tests were carried out aimed at the collection of various data for the evaluations of occupant protection performance, compatibility and aggressivity of the M-RSV's.

Collision Modes

Collision modes and impact velocities of the five tests were as follows (refer to Figure 1.1).

Test No. 1—M-RSV (M5–9) frontal impact into fixed flat barrier at 79.6 km/h (49.5 mph).

Test No. 2—Side collision of M-RSV (M5–8) front into J-Car driver's side of 90°, both at 56 km/h (35 mph).

Test No. 4—Side collision of J-Car front into M-RSV (M5–8) driver's side of 90°; both at 56 km/h (35 mph).

Test No. 5—Side collision of C-Car front into J-Car driver's side of 90°; both at 56 km/h (35 mph).

Test No. 6—Side collision of J-Car front into M-RSV (M5–8) passenger's side of 90°; both at 64 km/h (40 mph).

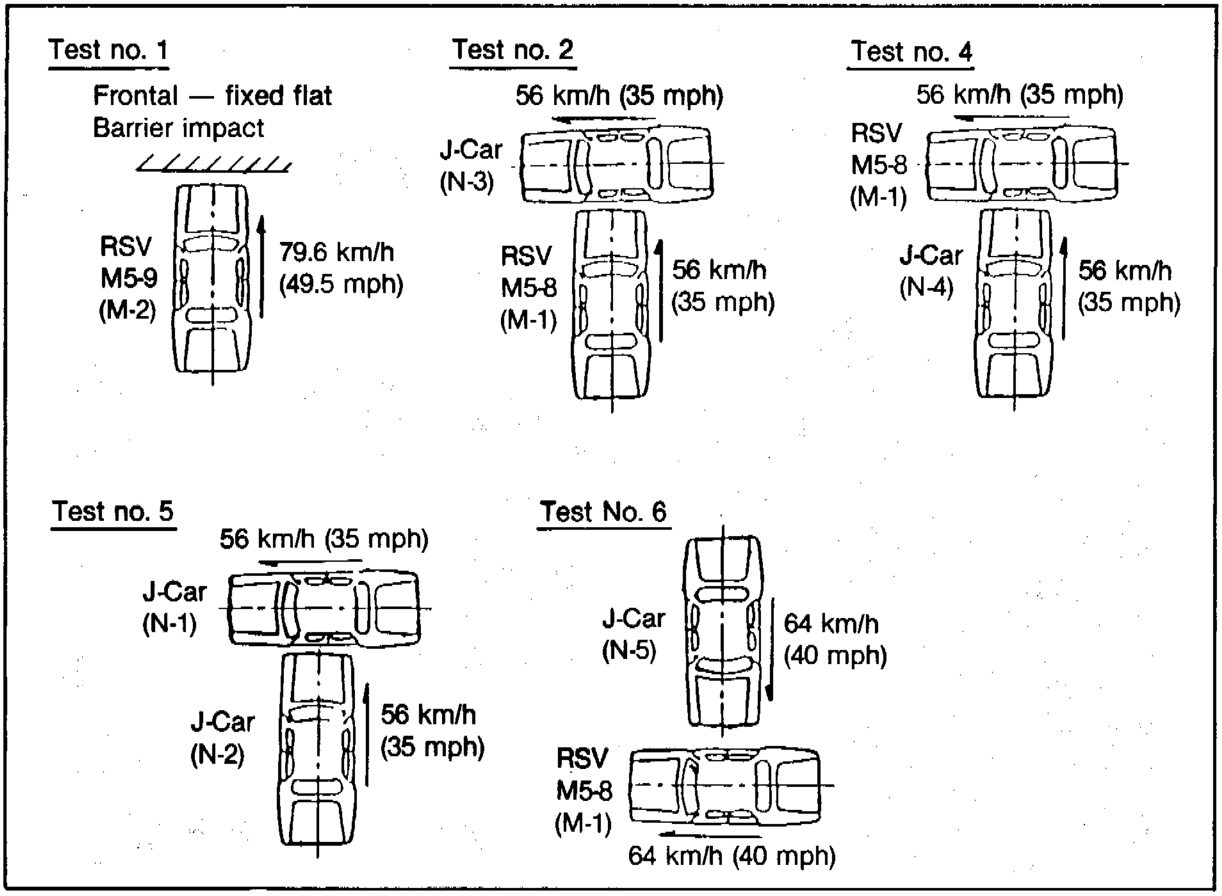


Figure 1.1. Collision modes between M-RSV's and J-Cars.

Test Vehicles

J-Cars were selected under conditions that they were equivalent to M-RSV's in terms of the curb weight given in the initial program and number of seats and doors, having the same vehicle type and specifications with those exported to the USA (however, the M-RSV's curb weight increased during developing, becoming heavier than J-Cars by 170 kg or so).

Five J-Cars were used in the tests, and they were temporarily named as "N–1" through "N–6" respectively. For convenience of preparation, the M5–8 and the M5–9 were also renamed temporarily as "M–1" and "M–2" respectively (refer to Figure 1.1).

Table 1.1 shows the major specifications and occupant restraint systems of the vehicles.

Dummies

Four AM 50 percentile Hybrid-II dummies approved by the Part-572 were used in the tests.

Test Equipment, Measurements and Data Processing

The M-RSV collision tests were carried out at the same crash test facility of JARI used for the Calspan/Chrysler RSV test. Electronic, optical, vehicle body measurements and their data processing were almost same as Calspan/Chrysler tests.

2. Test Results

Frontal-Fixed Flat Barrier Impact Test

The M-2 was used as the test vehicle, and a frontal-fixed flat barrier impact test was carried out at the nominal impact velocity of 79.6 km/h, which resulted in the actual impact velocity of 79.7 km/h. Two dummies were mounted on the left frontal seat and the right front seat of the vehicle.

Table 2.1 shows the outline of the measured test results. Figure 2.1 shows the vehicle body

Table 1.1. Major specifications of M-RSV and J-CAR.

	M-RSV	J-CAR
Overall length (mm)	4500	4305
Overall height (mm)	1400	1390
Overall width (mm)	1800	1600
Curb weight (kg)	1166	994
Restraint systems		
L.F.	St'g wheel air bag	3P. seat belt [E.L.R.]
R.F.	Air bag	3P. seat belt [E.L.R.]
L.R. , R.R.	3P. seat belt with force limiter [E.L.R.]	2P. seat belt [E.L.R.]

deformation-time, as analyzed from high speed films. Figure 2.2 shows the vehicle conditions at the time of the maximum displacement. Figure 2.3 shows the compartment dimensions of the M-2 before and after collision.

1) *Left Front Dummy's Test Results*. The left front dummy's restraint system of the M–2 was a steering air bag. As seen in the high speed films, the air bag started its inflation at 19ms or so after impact, and the dummy's chest and the chin contacted the air bag at about 29ms and 37ms respectively. The air bag completed its inflation at 55ms or so, and the dummy's entire face contacted the air bag at 60ms or so. The dummy suddenly started rotating anticlockwise at 78ms or so, and because of this phenomenon the dummy's head angular acceleration value around the Z axis increased to 5319 rad/s^2. The inflation of the air bag completed before the forward travel of the dummy. Hence the operation of the air bag was satisfactory.

The HIC and the SI of the dummy were 494 and 444 respectively, both meeting the injury criteria set forth by FMVSS 208. The loads on the dummy's femurs protected by knee pads also satisfied the said injury criteria.

2) *Right Front Dummy's Test Results*. The M–2 right front dummy's restraint system was an air bag installed at the glove box unit. Judging by the high speed films, the air bag started to inflate at 19ms or so after impact, and the dummy's chest contacted the air bag at 29ms or so. Approximately at 33ms after impact, the air bag and the dummy's chin contacted each other, then the dummy's entire face contacted the air bag at the same time with the completion of the air bag inflation of 53 ms or so. As the air bag completed its inflation prior to the initiation of the dummy's violent motions, the operation of the air bag was satisfactory.

Consequently, the HIC and the chest SI of the dummy's head were 994 and 542 respectively, both meeting the FMVSS–208 injury criteria. The axial loads on the dummy's femurs protected by knee pads also satisfied the injury criteria.

Side Collision Tests

The test conditions of four side collision tests were as follows: the bullet vehicle centerline was collided against the vertical line going through the hip point of the dummy seated at the target vehicle front seat as the target collision position.

The nominal impact velocity in the tests No. 2, 4 and 5 was set as 56 km/h, and the bullet vehicle was collided against the target vehicle driver's seat side. In the test No. 6, the target impact velocity was set as 64 km/h, and the bullet vehicle was collided against the target vehicle passenger's seat side.

Tables 2.2–2.5 indicate the outlines of results in each test. Figures 2.4–2.19 show relative displacements as analyzed from the high speed films, the conditions of vehicles upon maximum displacements, vehicle body dimensions and vehicle interior dimensions. Figure 2.20 shows continuous photographs of vehicle behaviors at intervals of 50ms as taken out from the high speed films. Table 2.6 shows rotational angles of the vehicles at intervals of 50ms, assuming that the angle was zero upon collision.

Table 2.1. Outline of frontal-fixed flat barrier impact test results (Test no. 1).

Car no.	M – 2
Test weight (kg) Impact angle (deg) Impact position (mm) Impact velocity (km/h) Max. crush (mm) Max. intrusion (mm)	1375 91°50′ 95 left 79.7 815 220
Restraint	L.F.--air bag R.F.--air bag

Observations (car no. --- M-2)	
Glazing	Front windshield cracked entirely and right door glass cracked.
Doors	Upper part of the right door was deformed slightly, right and left door hinges were deformed, unable to open both doors after crash, rear hatch lid fully open upon collision.
Restraints	Both air bags operated properly.
Fuel systems	No leakages.

Car No.		M — 2	
Dummy position		L.F.	R.F.
Vehicle max. acc. (G) (Near C.G of vehicle)	R X Y * Z	37 – 37 – 13 – 13	
Occupant injury criteria	HIC HSI CSI	494 655 444	994 1136 542
Dummy head max. acc. (G)	R X Y * Z	57 – 51 – 18 20	80 – 75 – 20 23
Dummy head max. angular acc. (rad/s^2)	X Y ** Z	2619 – 2340 5319	– 1405 – 3280 2321
Dummy chest max. acc. (G)	R X Y * Z	50 – 41 – 25 – 10	45 – 45 – 7 – 10
Dummy pelvis max. acc. (G)	R X Y * Z	43 – 42 – 7 – 10	35 – 34 7 – 12
Dummy femur max. load (kg)	R. L.	– 607 – 493	– 525 – 581
Seat belt max. load (kg)	S T	— —	— —

* The maximum values of acceleration of the dummies and vehicle bodies represent the values where the holding time in the spike exceeded 3 ms.

** Each dummy head angular acceleration values calculated by nine accelerometers method.

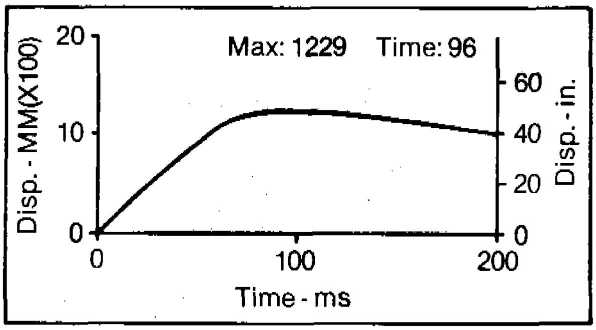
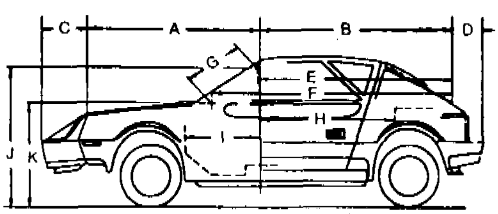


Figure 2.1. Vehicle body deformation (M–2).

Figure 2.2. Upon maximum displacement.



	Pre-test (mm)		Post-test (mm)	
	L.S.	R.S.	L.S.	R.S.
A	1765	1750	1240	1060
B	1965	1965	1965	1955
C	475	485	225	330
D	320	320	310	315
E	1975	1975	1975	1950
F	2435	2425	2400	2370
G	735	730	735	730
H	1390	1385	1385	1385
I	780	780	645	560
J	1390	1385	1370	1360
K	995	990	970	940

Figure 2.3. Compartment dimensions before and after collision (M–2).

1) *Comparisons of Dummy Test Results.* The left front dummy and the right front dummy of the M–1 had a steering air bag and an air bag installed at the glove box respectively. Both air bags were such that they started to inflate when the vehicle acceleration reached the set acceleration level for each air bag upon collision (the level setting was unknown to JARI). Restraint systems for the left rear dummy and the right rear dummy were three-point seat belts, each of which had a force limiter inserted between the seat belt anchor and E.L.R.

The restraint systems for the N–3 and N–1 left front dummies were three-point seat belts with E.L.R., and those for the left rear dummies were two-point seat belts with E.L.R.

Figure 2.21 shows comparisons of HIC's, SI's, etc. of the left front dummy and the left rear dummy of the target vehicles (N–3, M–1 and N–1) and the comparison of the M–1 dummies with different impact velocities.

- Comparison of the left front dummies (Side collisions with impact velocity of 56 km/h).

Dummy head (HIC): Since the air bag of M–1 did not inflate, the dummy was placed under unrestrained conditions upon collision. High speed films indicate that the door side padding started to intrude into the compartment immediately after collision, and contacted the shoulders, hips, etc. of the dummy moving toward the struck side with postures nearly the same to those at the initial stage. Afterward, the dummy traveled to the right forward direction while keeping the contact with the padding and, on the other hand, 56 and 88 respectively.

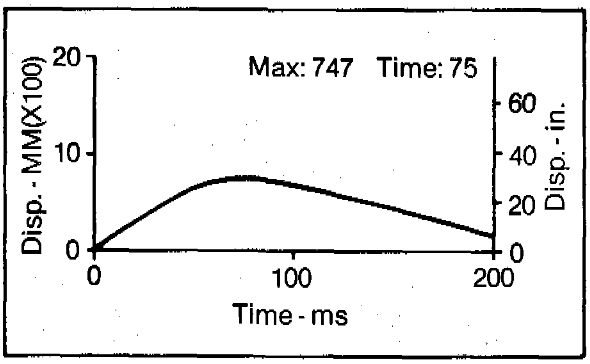


Figure 2.4. Relative displacement between N-3 and M-1.

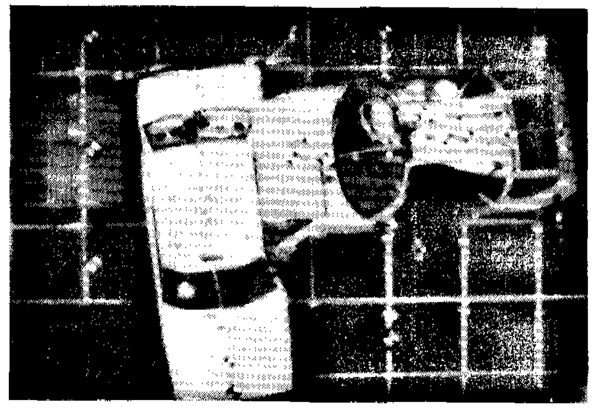
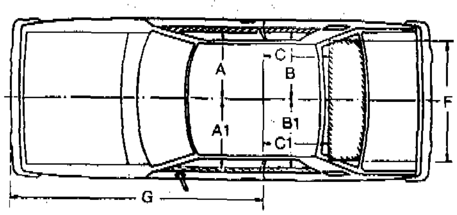
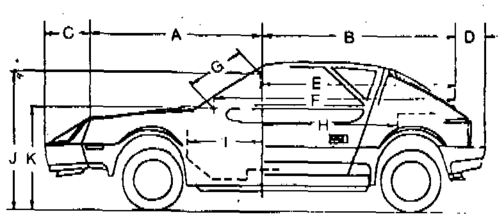


Figure 2.5. Upon maximum displacement.



	Pre-test (mm)	Post-test (mm)
A	660	675
A1	665	525
B	660	685
B1	665	460
C	695	700
C1	695	675
F	1300	1290
G	2590	2600

Figure 2.6. Compartment dimensions before and after collision [N - 3].



	Pre-test (mm)		Post-test (mm)	
	L.S.	R.S.	L.S.	R.S.
A	1765	1765	1740	1710
B	1975	1960	1970	1955
C	475	480	315	345
D	310	315	310	315
E	2015	2000	2015	2000
F	2445	2420	2440	2440
G	630	635	630	635
H	1390	1380	1385	1375
I	780	800	780	790
J	1370	1375	1370	1375
K	1010	1010	1025	1030

Figure 2.7. Compartment dimensions before and after collision [M - 1].

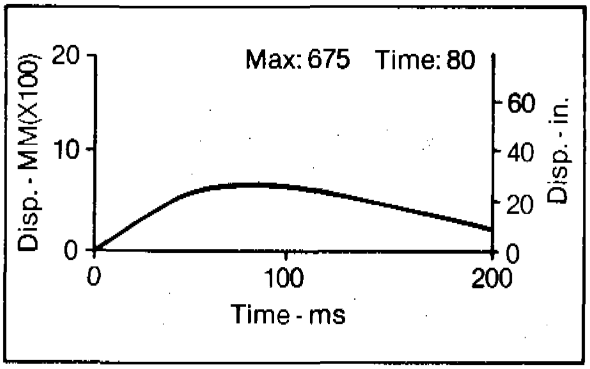


Figure 2.8. Relative displacement between M-1 and N-4.

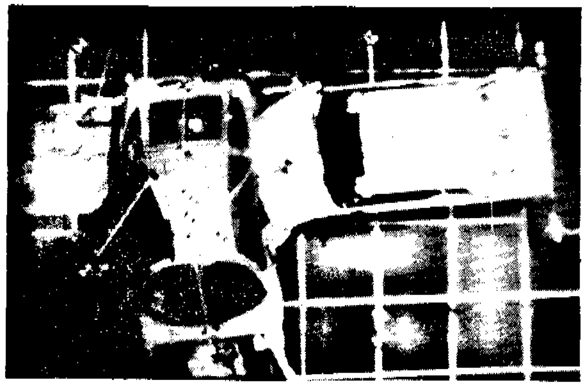
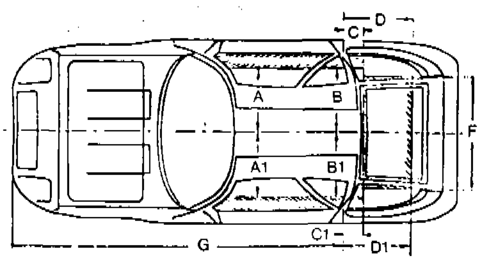
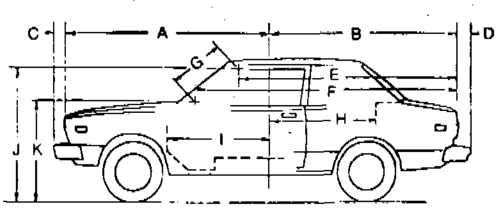


Figure 2.9. Upon maximum displacement.



	Pre-test (mm)	Post-test (mm)
A	630	630
A1	640	535
B	670	670
B1	670	580
C	250	250
C1	230	245
D	760	755
D1	740	755
F	1120	1110
G	3225	3205

Figure 2.10. Compartment dimensions before and after collision [M - 1].



	Pre-test (mm)		Post-test (mm)	
	L.S.	R.S.	L.S.	R.S.
A	2015	2015	1635	1925
B	1940	1940	1940	1945
C	170	175	75	110
D	175	175	175	175
E	2245	2250	2245	2250
F	2680	2685	2670	2685
G	575	575	575	575
H	1100	1110	1110	1110
I	1090	1050	1065	1045
J	1320	1325	1325	1290
K	960	965	960	925

Figure 2.11. Compartment dimensions before and after collision [N - 4].

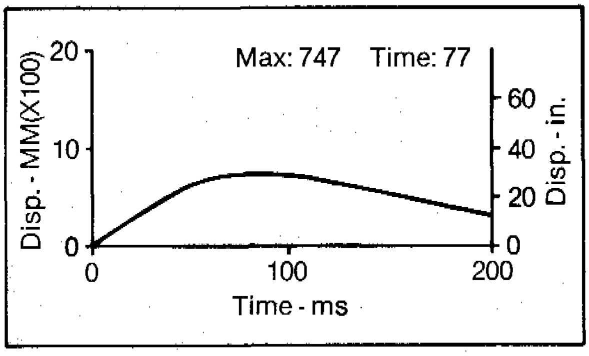


Figure 2.12. Relative displacement between N-1 and N-2.

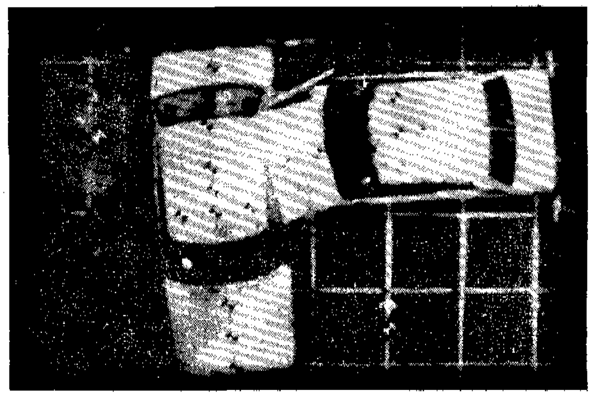
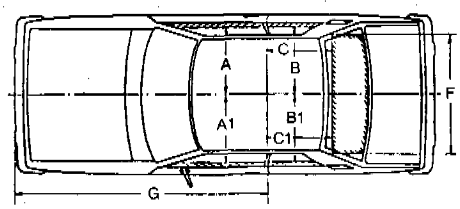
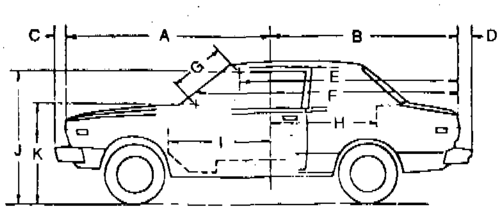


Figure 2.13. Upon maximum displacement.



	Pre-test (mm)	Post-test (mm)
A	660	670
A1	660	530
B	660	660
B1	665	435
C	700	695
C1	695	675
F	1300	1230
G	2590	2625

Figure 2.14. Compartment dimensions before and after collision [N - 1].



	Pre-test (mm)		Post-test (mm)	
	L.S.	R.S.	L.S.	R.S.
A	2015	2015	1650	1820
B	1940	1940	1940	1940
C	170	170	150	45
D	180	175	175	175
E	2245	2245	2240	2245
F	2680	2685	2675	2685
G	575	585	575	580
H	1105	1105	1105	1100
I	1090	1055	1070	1045
J	1315	1310	1315	1280
K	960	965	960	930

Figure 2.15. Compartment dimensions before and after collision [N - 2].

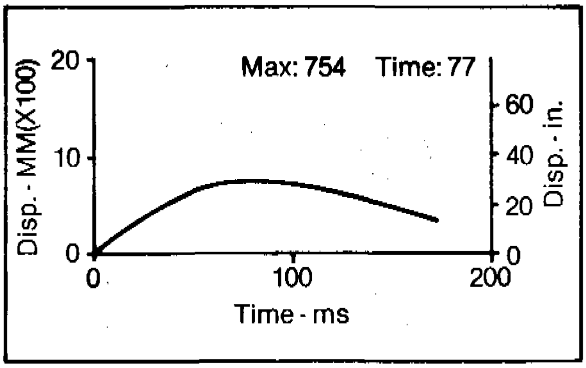


Figure 2.16. Relative displacement between M-1 and N-5.

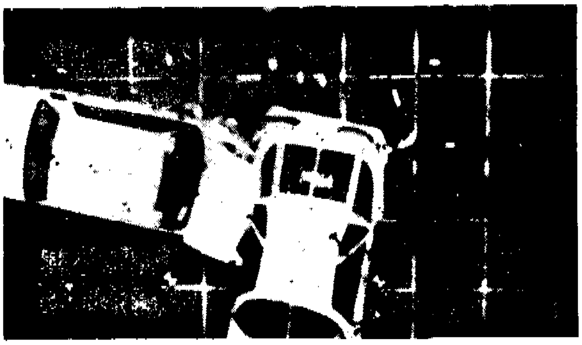
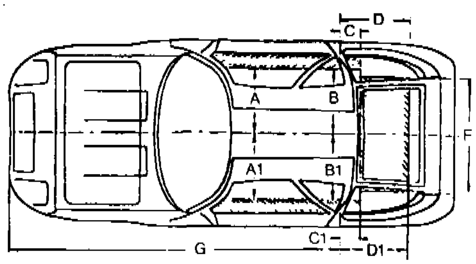
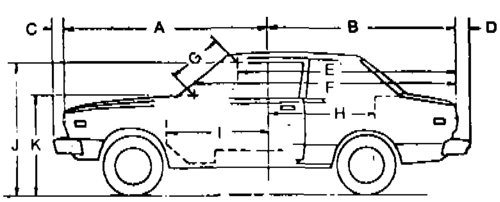


Figure 2.17. Upon maximum displacement.



	Pre-test (mm)	Post-test (mm)
A	630	555
A1	500	595
B	670	560
B1	580	605
C	250	270
C1	245	220
D	755	790
D1	755	730
F	1110	1090
G	3205	3235

Figure 2.18. Compartment dimensions before and after collision [M - 1].



	Pre-test (mm)		Post-test (mm)	
	L.S.	R.S.	L.S.	R.S.
A	2015	2015	1790	1575
B	1940	1940	1940	1940
C	170	170	35	175
D	180	175	175	175
E	2240	2245	2245	2250
F	2685	2685	2685	2675
G	575	575	575	575
H	1105	1105	1110	1110
I	1080	1050	1070	1045
J	1310	1315	1240	1305
K	960	965	865	950

Figure 2.19. Compartment dimensions before and after collision [N - 5].

Table 2.2. Outline of side collision test results (Test no. 2).

Car no.	M — 1	N — 3
Test weight (kg)	1381	1223
Impact angle (deg)	88° 30′	
Impact position (mm)	0 (The bullet car hit the mark)	
Impact velocity (km/h)	56.1	56.4
Max. crush (mm)	185	300
Max. intrusion (mm)	0	260
Restraint	L.F.—Air bag R.F.—Air bag	L.F.—3P.Seat belt (ELR) L.F.—2P.Seat belt (ELR)

Observations (Car no. — M-1)	
Glazing	No abnormalities.
Doors	No abnormalities.
Restraints	Both air bags operated properly.
Fuel systems	No leakages.

Observations (Car no. — N-3)	
Glazing	Left door glass was damaged, front windshield cracked slightly.
Doors	Left door was medium damage, unable to open or close left door after collision.
Restraints	Both seat belts operated properly.
Fuel systems	No leakages.

Car no.		M — 1		N — 3	
Dummy position		L.F.	R.F.	L.F.	L.R.
Vehicle max. acc. (G) (Near C.G, of vehicle	R	13		22	
	X	−11		−11	
	Y	−7		−16	
	*Z	−2		18	
Occupant injury criteria	HIC	82	83	56	127
	HSI	186	119	67	194
	CSI	46	70	68	129
Dummy head max. acc. (G)	R	33	25	20	43
	X	−32	−19	17	−19
	Y	−14	−13	13	27
	*Z	11	14	15	36
Dummy head max. angular acc. (rad/s^2)	X	−3687	3433	−1942	−3406
	Y	−3749	−2963	−1179	2482
	**Z	−1465	−1906	−1144	−2229
Dummy chest max. acc. (G)	R	26	21	27	39
	X	−26	−21	−9	12
	Y	−6	−15	26	39
	*Z	−7	4	−3	9
Dummy pelvis max. acc. (G)	R	22	20	58	32
	X	−16	−13	−10	−15
	Y	−16	−19	58	29
	*Z	−12	−7	−5	−5
Dummy femur max. load (kg)	R.	−113	54	70	−126
	L.	−385	−109	63	−367
Seat belt max. load (kg)	S	—	—	153	—
	T	—	—	—	—

*The maximum values of acceleration of the dummies and vehicle bodies represent the values where the holding time in the spike exceeded 3 ms.
**Each dummy head angular acceleration values calculated by nine accelerometers method.

Table 2.3. Outline of side collision test results (Test no. 4).

Car no.	M — 1	N — 4
Test weight (kg)	1357	1223
Impact angle (deg)	89° 40'	
Impact position (mm)	100 Forward from Driver's H.P.	
Impact velocity (km/h)	56.7	56.3
Max. crush (mm)	205	470
Max. intrusion (mm)	110	25
Restraint	L.F.—Air bag L.R.—3P.Seat belt (ELR)	L.F.—3P.Seat belt (ELR) R.F.—3P.Seat belt (ELR)

Observations (Car no. — M-1)	
Glazing	Left door glass and left rear windshield cracked.
Doors	Left door was medium damage, unable to open or close left door, rear hatch lid full opened upon collision.
Restraints	Steering air bag did not operate, L.R. three-point seat belt operated properly.
Fuel systems	Outlet nozzle of fuel pump was broken but no leakages.

Observations (Car no. — N-4)	
Glazing	Front windshield cracked slightly.
Doors	Left door was slight damage. However all doors could be opened and closed after collision.
Restraints	Both seat belts operated properly.
Fuel systems	No leakages.

Car no.		M — 1		N — 4	
Dummy position		L.F.	L.R.	L.F.	R.F.
Vehicle max. acc. (G) (Near C.G, of vehicle	R*	25		24	
	X	−7		−18	
	Y	25		−19	
	*Z	−10		19	
Occupant injury criteria	HIC	23	70	92	89
	HSI	42	108	115	108
	CSI	63	141	59	48
Dummy head max. acc. (G)	R	16	31	18	21
	X	−7	9	−17	−20
	Y	16	29	−7	−7
	*Z	10	27	15	11
Dummy head max. angular acc. (rad/s²)	X	−2056	−5249	861	1517
	Y	965	−1377	−1145	1319
	**Z	−1105	2932	1124	791
Dummy chest max. acc. (G)	R	26	44	18	15
	X	3	−14	−17	−15
	Y	26	42	−5	−10
	*Z	−7	−11	−9	−10
Dummy pelvis max. acc. (G)	R	25	61	27	24
	X	−6	−12	−23	15
	Y	24	54	−22	−17
	*Z	−7	−8	−15	−10
Dummy femur max. load (kg)	R.	−199	172	−70	−133
	L.	−93	−642	−425	−137
Seat belt max. load (kg)	S	—	128	371	310
	T	—	—	252	256

*The maximum values of acceleration of the dummies and vehicle bodies represent the values where the holding time in the spike exceeded 3 ms.

**Each dummy head angular acceleration values calculated by nine accelerometers method.

Table 2.4. Outline of side collision test results (Test no. 5).

Car no.	N — 1	N — 2
Test weight (kg)	1223	1223
Impact angle (deg)	90° 20′	
Impact position (mm)	150 Forward from Driver's H.P.	
Impact velocity (km/h)	55.8	56.5
Max. crush (mm)	380	380
Max. intrusion (mm)	330	20
Restraint	L.F.—3P.Seat belt (ELR) L.R.—2P.Seat belt (ELR)	L.F.—3P.Seat belt (ELR) R.F.—3P.Seat belt (ELR)

Observations (Car no. — N-1)	
Glazing	Front windshield cracked slightly, left door glass and left rear windshield were damaged.
Doors	Left door was medium damage, unable to open or close left door after collision.
Restraints	Both seat belts operated properly.
Fuel systems	No leakages.

Observations (Car no. — N-2)	
Glazing	Front windshield cracked slightly.
Doors	Left door was slight damage, but all doors could be opened and closed after collision.
Restraints	Both seat belts operated properly.
Fuel systems	No leakages.

Car no.		N — 1		N — 2	
Dummy position		L.F.	L.R.	L.F.	R.F.
Vehicle max. acc. (G) (Near C.G, of vehicle	R	23		23	
	X	− 9		− 22	
	Y	20		− 20	
	*Z	− 14		18	
Occupant injury criteria	HIC	88	117	98	40
	HSI	122	177	119	51
	CSI	298	413	61	29
Dummy head max. acc. (G)	R	28	41	20	15
	X	− 10	− 13	− 19	− 12
	Y	22	28	− 7	− 9
	*Z	24	33	14	9
Dummy head max. angular acc. (rad/s²)	X	− 3706	− 4067	2126	1305
	Y	− 1261	− 1866	1822	− 1153
	**Z	2118	− 1578	1115	− 910
Dummy chest max. acc. (G)	R	52	68	20	14
	X	− 6	− 7	− 20	− 11
	Y	52	68	− 5	− 12
	*Z	− 9	− 8	− 8	− 6
Dummy pelvis max. acc. (G)	R	80	60	24	16
	X	− 9	− 13	− 10	− 8
	Y	80	53	− 19	− 15
	*Z	− 6	− 8	− 16	− 6
Dummy femur max. load (kg)	R.	88	225	54	62
	L.	− 153	− 570	− 166	− 58
Seat belt max. load (kg)	S	318	—	459	255
	T	—	—	334	177

*The maximum values of acceleration of the dummies and vehicle bodies represent the values where the holding time in the spike exceeded 3 ms.
**Each dummy head angular acceleration values calculated by nine accelerometers method.

Table 2.5. Outline of side collision test results (Test no. 6).

Car no.	M — 1	N — 5
Test weight (kg)	1351	1223
Impact angle (deg)	88° 10′	
Impact position (mm)	120 Forward from Passenger's H.P.	
Impact velocity (km/h)	64.4	64.1
Max. crush (mm)	160	435
Max. intrusion (mm)	140	10
Restraint	R.F.—Air bag R.R.—3P.Seat belt (ELR)	L.F.—3P.Seat belt (ELR) R.F.—3P.Seat belt (ELR)

Observations (Car no. — M-1)	
Glazing	Front windshield cracked slightly, right door glass and right rear windshield cracked.
Doors	Right door was slight damage, opened upon collision and able to open but unable to close for right door.
Restraints	Passenger air bag did not operate, R.R. three-point seat belt operated properly.
Fuel systems	Fuel filler pipe and body near by fuel filler cap were deformed but no leakages.

Observations (Car no. — N-5)	
Glazing	Front windshield cracked slightly.
Doors	No abnormalities.
Restraints	Both seat belts operated properly.
Fuel systems	No leakages.

Car no.		M — 1		N — 5	
Dummy position		R.F.	R.R.	L.F.	R.F.
Vehicle max. acc. (G) (Near C.G, of vehicle	R	26		26	
	X	−9		−22	
	Y	−23		20	
	*Z	−7		26	
Occupant injury criteria	HIC	30	87	187	191
	HSI	81	139	221	230
	CSI	84	451	88	91
Dummy head max. acc. (G)	R	20	33	26	27
	X	−7	−8	−23	−25
	Y	19	−24	−17	4
	*Z	9	30	19	22
Dummy head max. angular acc. (rad/s^2)	X	2581	4372	3579	1065
	Y	1261	−1087	1552	1450
	**Z	−2654	1140	2292	1807
Dummy chest max. acc. (G)	R	24	73	22	22
	X	7	−10	−18	−22
	Y	123	−71	19	5
	*Z	−7	−14	−12	−11
Dummy pelvis max. acc. (G)	R	31	61	26	25
	X	−6	−6	17	−20
	Y	−31	−58	17	18
	*Z	−5	−13	−10	−17
Dummy femur max. load (kg)	R.	−56	—	−141	84
	L.	−187	170	139	90
Seat belt max. load (kg)	S	—	119	300	502
	T	—	—	255	508

*The maximum values of acceleration of the dummies and vehicle bodies represent the values where the holding time in the spike exceeded 3 ms.
**Each dummy head angular acceleration values calculated by nine accelerometers method.

Figure 2.20. Vehicle motion after side collision.

Table 2.6. Rotation of target and bullet vehicle after side collision.

Car no.	N-3	M-1	M-1	N-4	N-1	N-2
Time (ms)	Rotation (degrees)		Rotation (degrees)		Rotation (degrees)	
0	0.0	0.0	0.0	0.0	0.0	0.0
50	2.0	2.1	1.1	0.7	1.6	0.5
100	12.9	13.3	7.5	8.3	10.5	8.9
150	25.3	25.4	17.1	21.3	22.2	21.9
200	36.9	36.8	26.8	32.9	33.7	32.9

+ : anticlockwise

Dummy Chest (SI): For the M–1 and N–1 dummies, traces of contacts between the shoulders and inside units of doors were observed, and each SI was 63 and 298 respectively. Thus the effect of the padding for shoulder protection was demonstrated for each of them. No clear traces of contacts between the N–3 dummy's shoulders and vehicle interiors were evident, and the SI was 68.

Dummy Pelvis: The maximum values of the pelvis resultant acceleration of the N–3, M–1 and

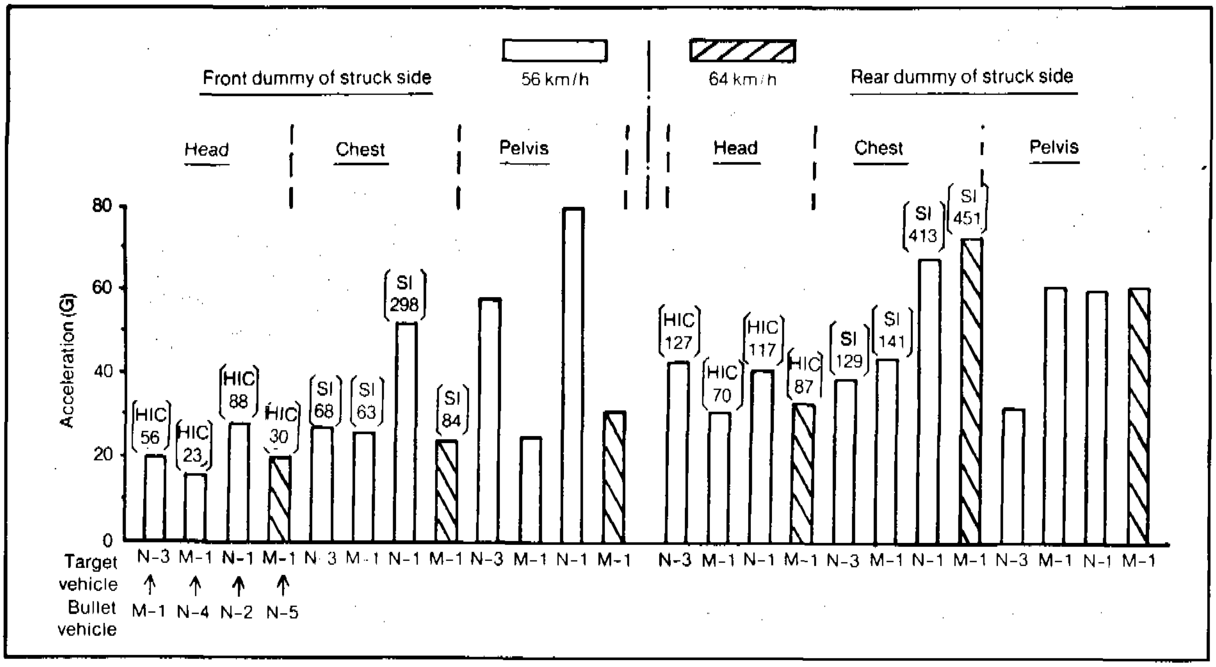


Figure 2.21. Comparison of dummy's results of target vehicles.

N–1 dummies were 58, 25 and 80G respectively. The low value of the M–1 dummy was probably due to the effect of the padding for pelvis protection installed at the door inside, as well as to the fact that the intrusion into the compartment was smaller than other vehicles.

- Comparisons of left rear dummies (Side collision with impact velocity 56 km/h).

Dummies (HIC): No evident traces of contacts between the dummy's head and the vehicle interior structures were observed for the N–3, M–1 and N–1. The HIC of each dummy was 127, 70 and 117 respectively.

Dummy Chest (SI): As for the M–1 and N–1 dummies, traces of contacts between the shoulders and vehicle interior structures were observed. The SI of each was 141 and 413 respectively, demonstrating the effect of the padding installed in the M–1 vehicle compartment.

For the N–3 dummy, no evident traces of the contact between the shoulders and vehicle interior structures were found, and the SI was 129.

Dummy Pelvis: The maximum resultant acceleration of each dummy's pelvis was 32G for the N–3 dummy which was the lowest of the three dummies, followed by 61 and 60G of the M–1 and N–1 dummies.

- **Comparisons of results of M–1 dummies between 56 km/h and 64 km/h impact velocities.**

The HIC, SI and the maximum value of pelvis resultant acceleration were nearly the same for the left front dummy and the right front dummy. The HIC and the maximum value of pelvis resultant acceleration were nearly the same for the left rear dummy and the right rear dummy, but the SI of the right rear dummy was nearly the threefold of left rear dummy's SI.

The comparison of test results of the front dummies and rear dummies shows that the pelvis resultant accelerations and SI's of the former were lower by 50% or so of the latter. This is possibly attributed in part to the fact that the center of collision of the bullet vehicle against the target vehicle shifted from the front seat side to the rear seat side as time passed by after collision. It is also possible, however, that the paddings for the front seat dummies had better characteristics than the paddings for the rear seat dummies in terms of occupant protection effects.

2) *Comparisons of Acceleration Waveforms of M–1 and N–1.* In the side collision tests with the normal impact velocity of 56 km/h, the M–1 and N–1 were used as target vehicles collided by J-Cars. Figures 2.22–2.28 show comparisons of

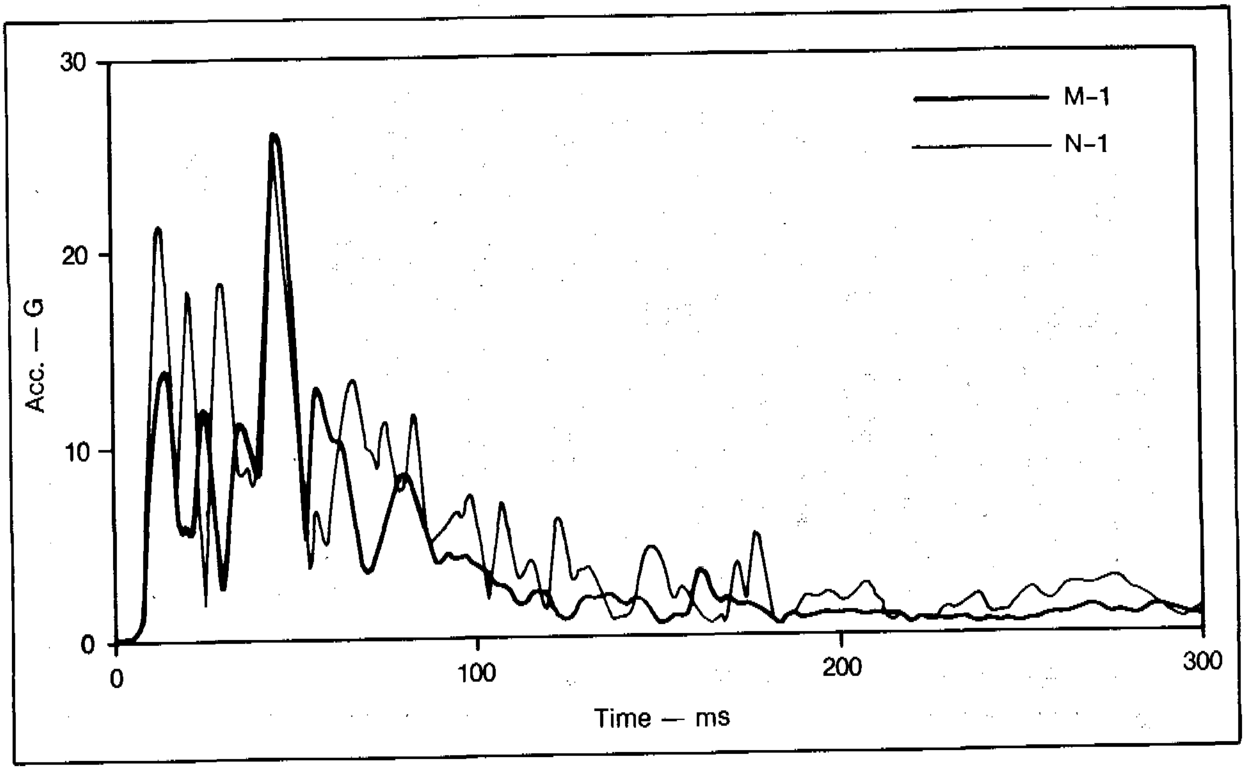


Figure 2.22. Comparison of Tunnel Resultant Acceleration of M-1 and N-1.

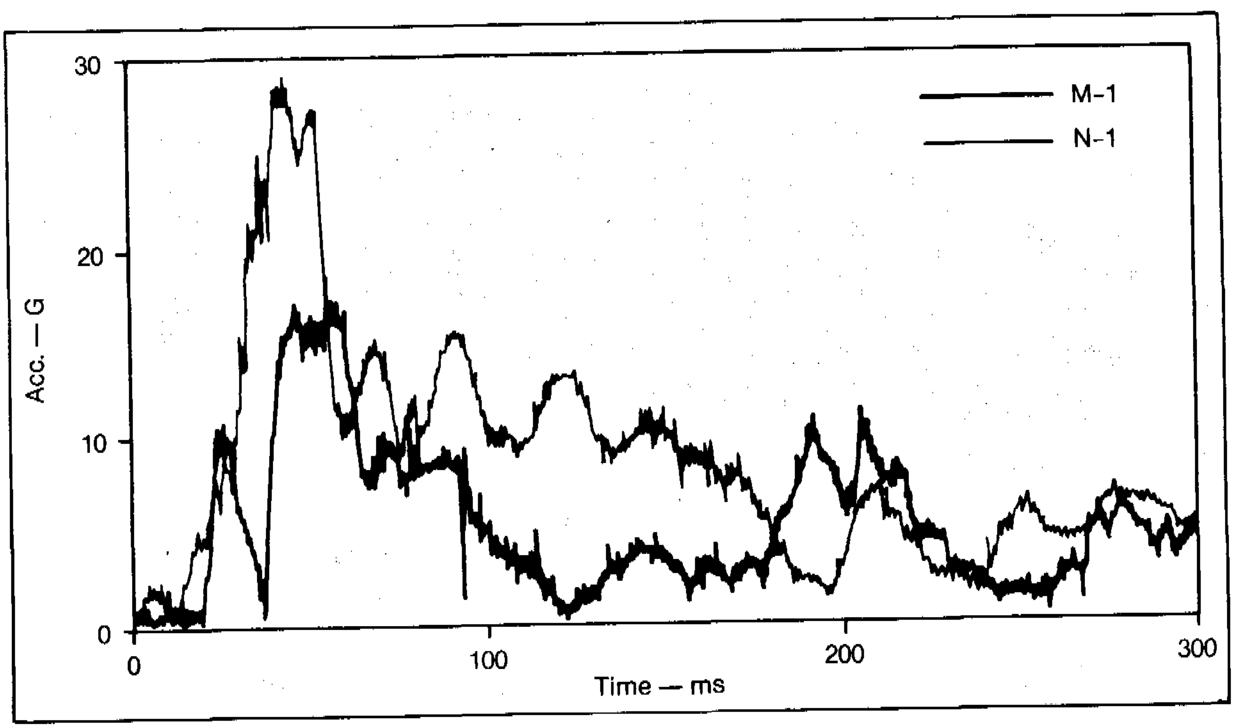


Figure 2.23. Comparison of M-1 and N-1 left front dummy's resultant head acceleration.

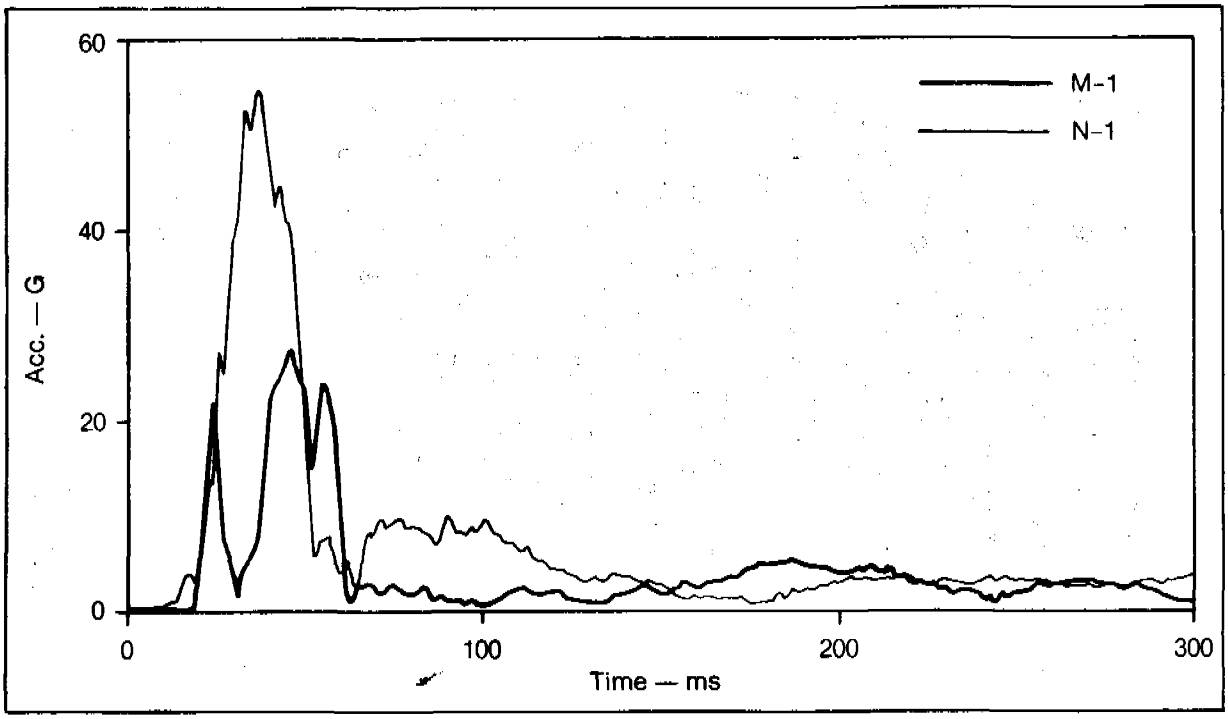


Figure 2.24. Comparison of M-1 and N-1 left front dummy's resultant chest acceleration.

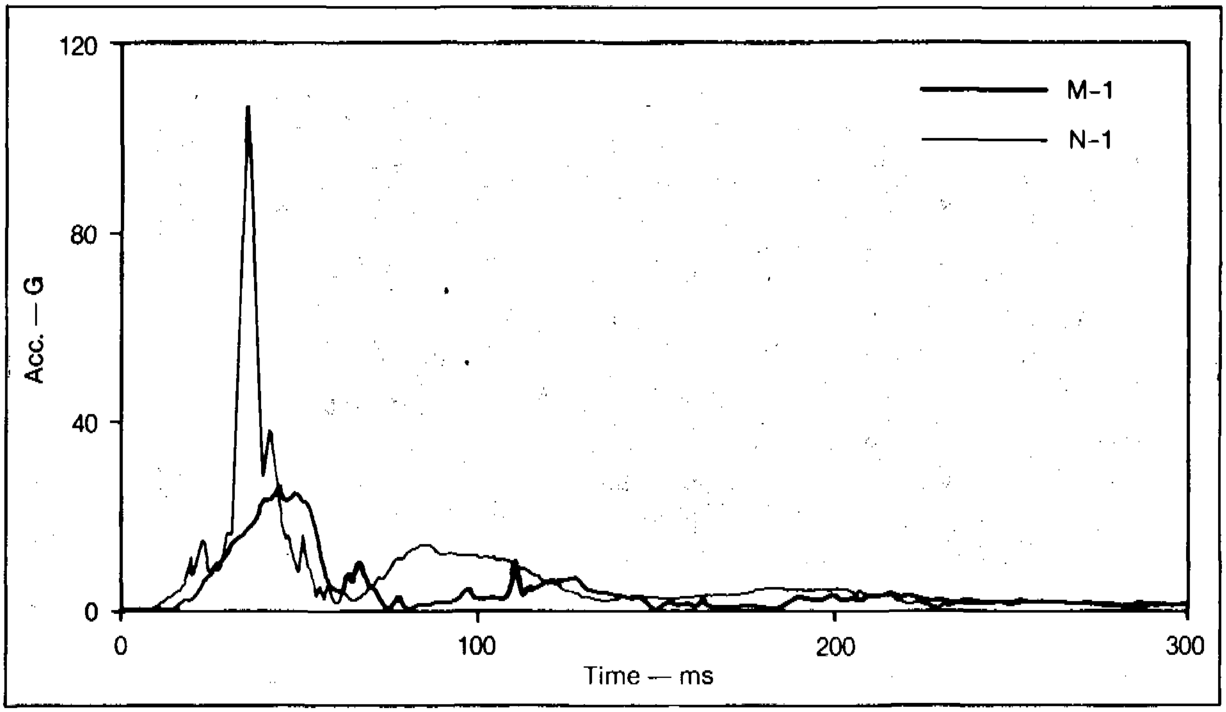


Figure 2.25. Comparison of M-1 and N-1 left front dummy's resultant pelvis acceleration.

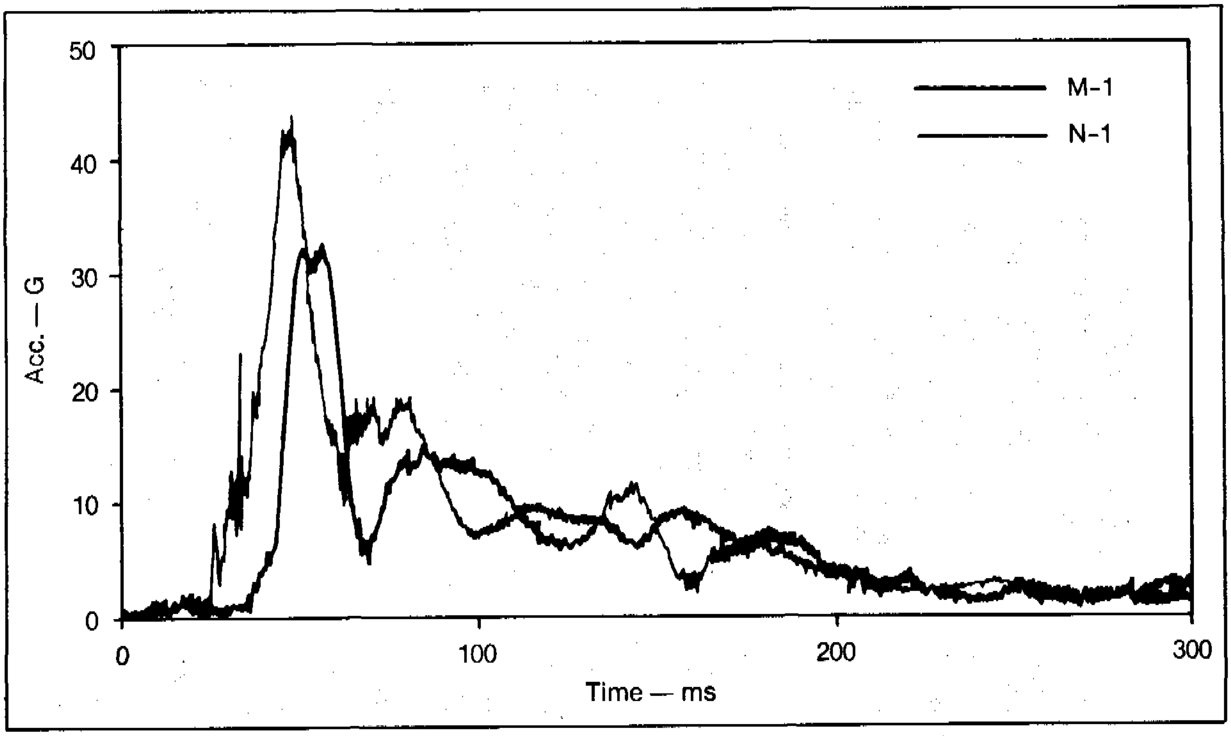


Figure 2.26. Comparison of M-1 and N-1 left rear dummy's resultant head acceleration.

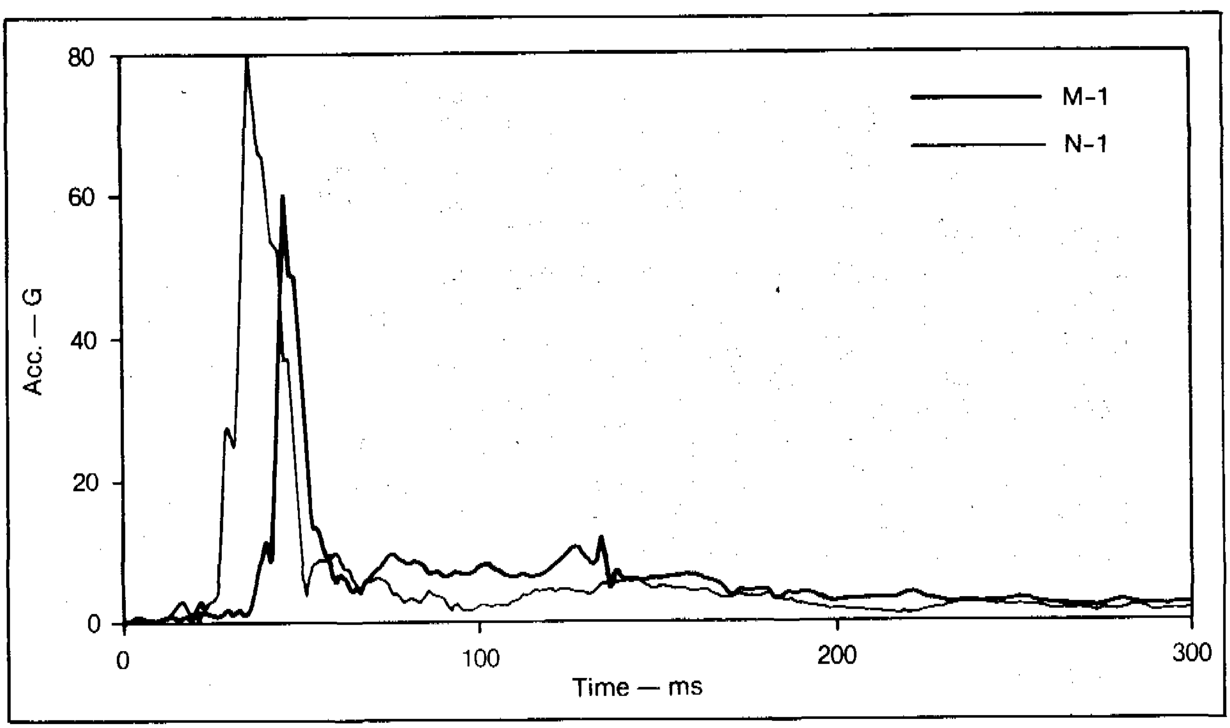


Figure 2.27. Comparison of M-1 and N-1 left rear dummy's resultant chest acceleration.

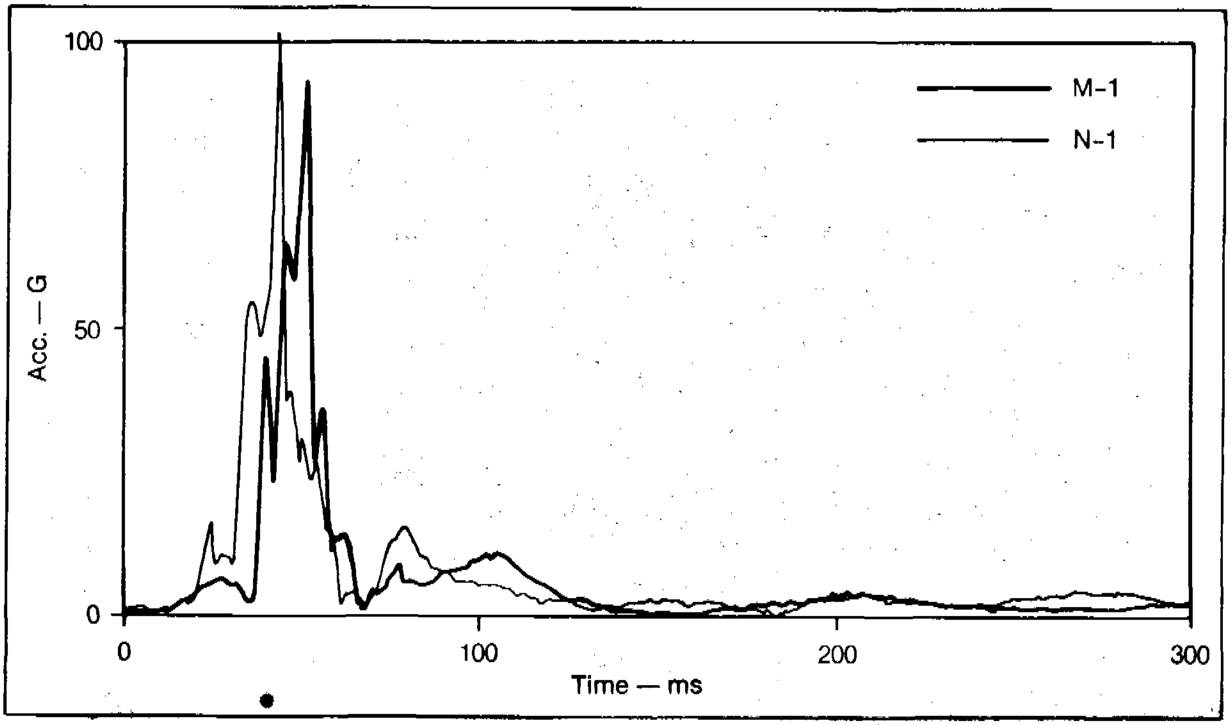


Figure 2.28. Comparison of M–1 and N–1 left rear dummy's resultant pelvis acceleration.

tunnel resultant accelerations of the M–1 and N–1 collided by equivalent J-Cars and resultant accelerations of left front and left rear dummies.

The tunnel resultant accelerations indicate that waveforms, durations, etc. were similar though peak acceleration values at the initital stage were different.

It is well-known fact that F-S curve, which represents a buffering material with the highest energy absorption characteristics with the limited thickness, is rectangular. The observations of the M–1 left front dummy's chest and pelvis resultant accelerations from this point of view (Figures 2.24 and 2.25) show satisfactory results since they are of proper forms without spikes caused by the bottoming of the paddings.

Compared with the above results, the left rear dummy's chest and pelvis resultant accelerations (Figures 2.27 and 2.28) show significant spikes caused by the bottoming of the paddings and impacts against rigid objects, which are similar to the results of the N–1 dummies without special paddings.

From the foregoing results, it is judged that the paddings for the front dummies of the M–1 were more desirable than those of rear dummies, in terms of thickness, etc.

3) *Vehicle Body Deformations.* Figure 2.29 shows the maximum deformations and maximum intrusions of all vehicles used in the side collision tests. The figure indicates no significant intrusions into compartments of bullet vehicles.

The M–1 showed the smallest values of all in terms of bullet vehicle maximum deformation, and target vehicle's maximum deformation and intrusion. The maximum deformations and maximum intrusions observed at the left and right sides of the M–1, which was used as the target vehicle in 56 km/h and 64 km/h side impacts, were nearly the same.

Figures 2.30–2.37 are Moire photographs of the N–3, M–1 (left side and right side) and N–1 used as the target vehicles, before and after collision.

SUMMARY

Frontal-Fixed Flat Barrier Impact

The test was carried out at the impact velocity of 79.7 km/h. The conditions of inflation of two air bags installed at the front seats of M–2 was satisfactory. Consequently, the left front dummy's HIC was 494, the chest SI was 444, and femur loads were 607 and 493 kg. The right front

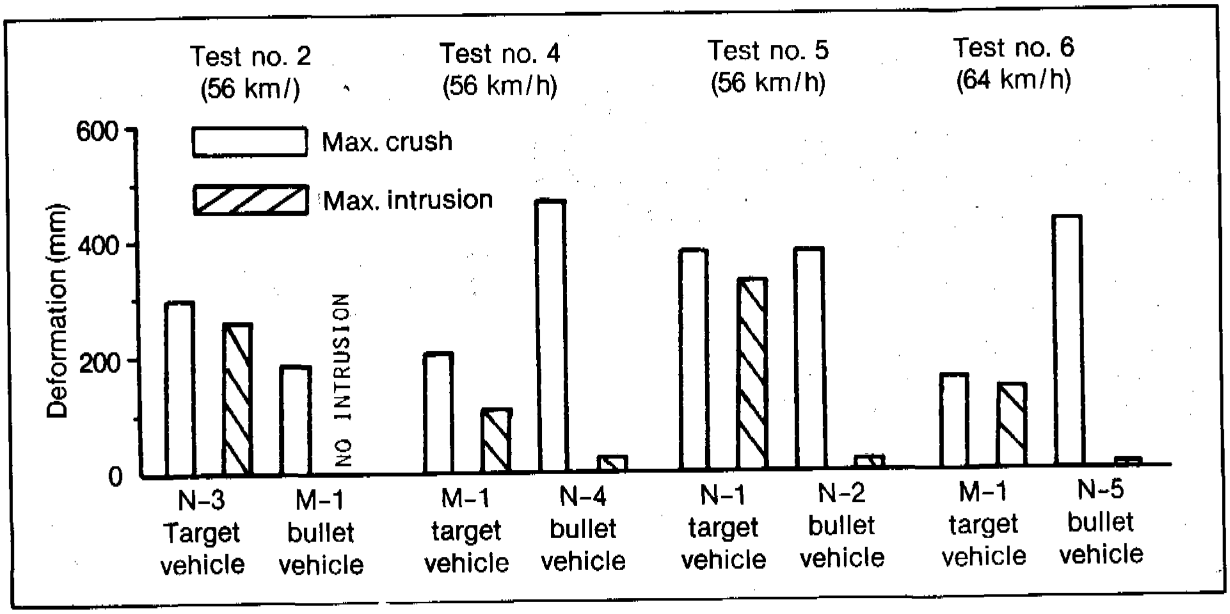


Figure 2.29. Deformation of test vehicles used in side collision.

dummy's HIC was 994, the chest SI was 542 and femur loads were 525 and 581 kg. All the chest peak G's were also below 60G. All the results by both dummies, therefore, satisfied FMVSS–208 injury criteria.

Side Collisions

Right angle side collisions were carried out at the nominal impact velocity of 56 km/h for three times and at the nominal impact velocity of 64 km/h once, while both target and bullet vehicles were running.

- The HIC's, chest peak G's and femur loads of four dummies of the target vehicle M–1 at impact velocities of 56 km/h and 64 km/h satisfied FMVSS–208 injury criteria, except chest peak G of the right rear dummy in Test No. 6.
- The vehicle deformation at the struck side of the M–1 (target vehicle) having reinforced vehicle structures was significantly smaller than those of the N–3 and N–1.
- The pelvis acceleration of the M–1 front dummies were markedly reduced owing to the effect of paddings installed inside the doors and the suppression of intrusions.
- The right door of the target vehicle M–1 (at the impact velocity of 64 km/h) started to open about 1.2 sec. after the collision due to the impact of the right front dummy, and the dummy slid out from the compartment immediately before the vehicle stop (about 1.9 sec. after the collision) along the door. The rear dummies, however, restrained by three-point seat belts did not experience the rejection out of the compartment. Some measures, therefore, will be required to prevent the occurrence of secondary injuries that may be caused by the rejection of occupants out of vehicle compartment.

HANDLING, STABILITY AND BRAKING PERFORMANCE

The M-RSV was a vehicle having curb weight 1166 kg (2571 lb) and wheelbase 2.642 m (104 in). The tires mounted on the vehicle were flat proof tires of size 200/65 HR 370 (Dunlop Denovo 2).

All the tests were carried out on the test courses of JARI (cement concrete and asphalt paved roads having skid numbers between 70 and 80 stipulated by ASTM standard) by skilled test driver. The loading condition for the handling and stability tests was set to 60 percent of the load corresponding to four passengers. The loading condition for the braking performance tests was set to the gross vehicle weight equivalent (GVW) in which weights of four passengers and trunk were included.

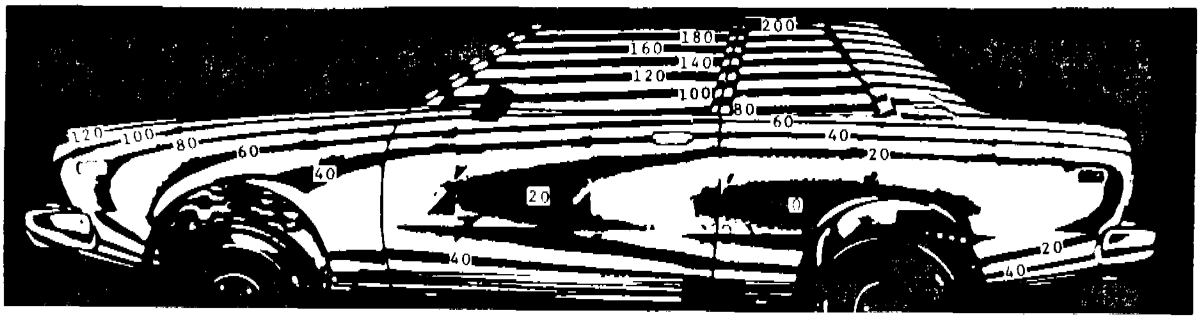


Figure 2.30. Moire'photograph before collision [N-3] — Test no. 2.

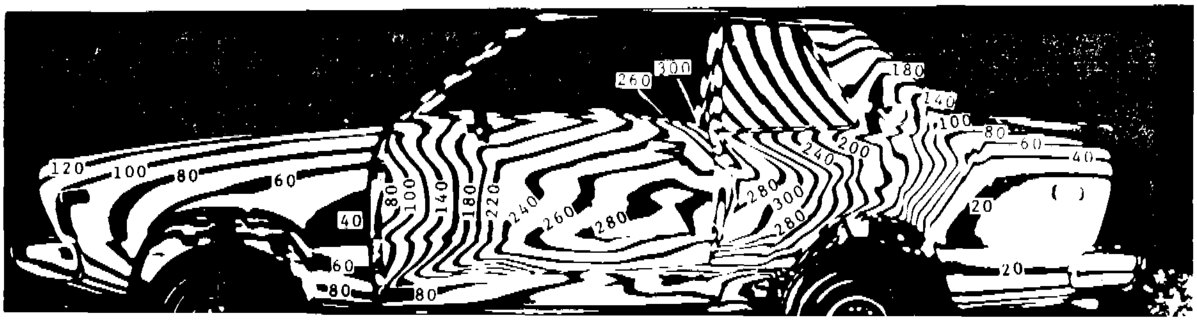


Figure 2.31. Moire'photograph after collision [N-3] — Test no. 2.

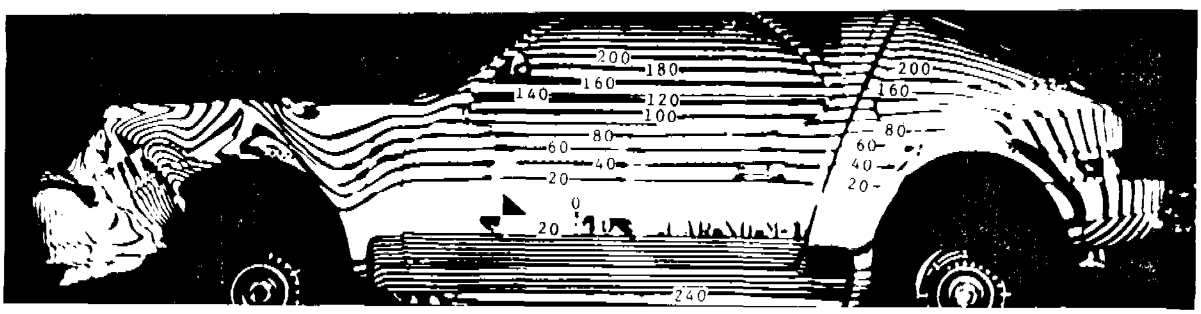


Figure 2.32. Moire'photograph after collision [M-1-2] — Test no. 4.

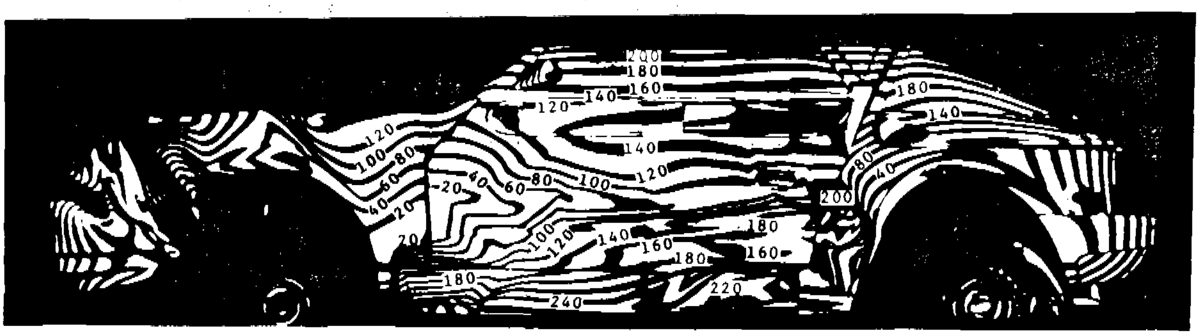


Figure 2.33. Moire'photograph after collision [M-1-2] — Test no. 4.

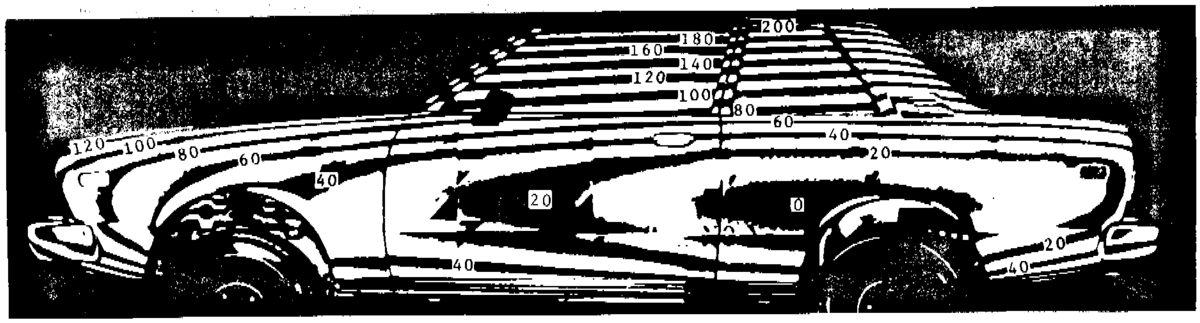


Figure 2.34. Moire'photograph before collision [N-1] — Test no. 5.

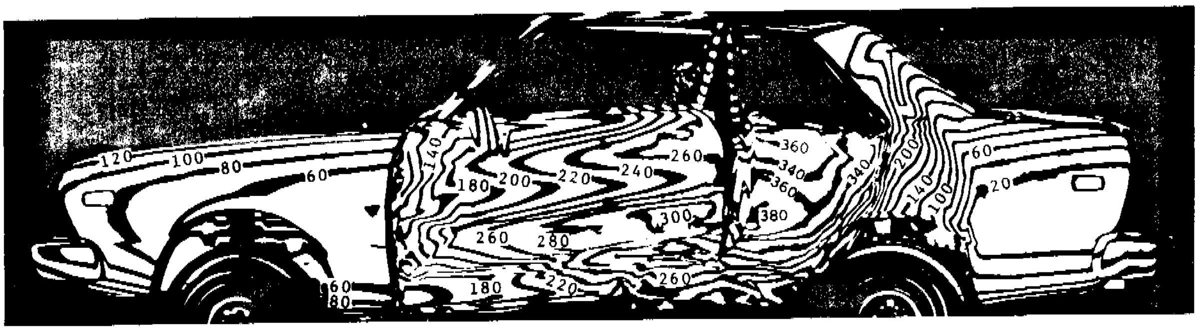


Figure 2.35. Moire'photograph after collision [N-1] — Test no. 5.

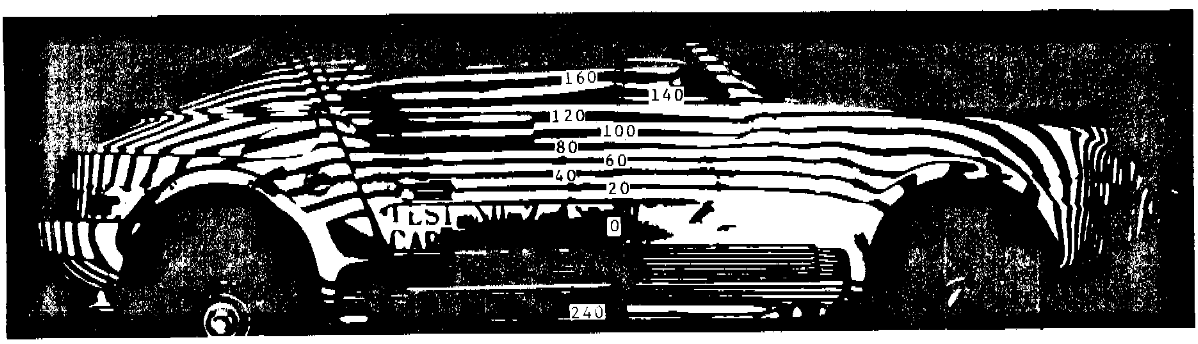


Figure 2.36. Moire'photograph before collision [M-1-3] — Test no. 6.

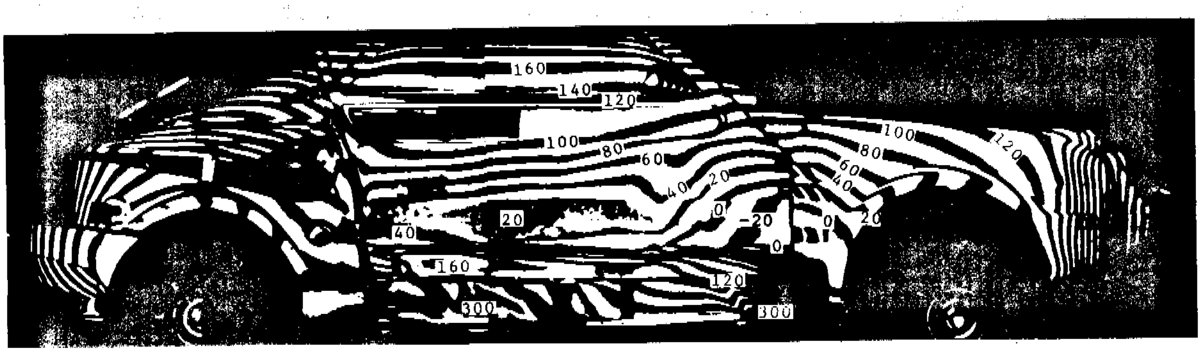


Figure 2.37. Moire'photograph after collision [M-1-3] — Test no. 6.

To verify the steady state steering characteristics, the test vehicle was subjected to steady state circular turns according to the specified vehicle velocities and lateral accelerations. The value obtained by dividing the steering wheel angle by the steering overall gear ratio (19.3) was used as the front wheel angle. The test results are shown in Figure 1.1, which met the range of the RSV Specification.

Transient Yaw Response

To verify the transient steer characteristics, a ramp-stepwise steering input was applied to the vehicle while it was being driven straight at the vehicle velocities of 40 km/h and 110 km/h with steering wheel angular velocity 500 deg/s or higher, so that final steady state lateral acceleration became 0.4g. The test results are shown in Figure 1.2. Since the "time zero" in the Figure was when one half of the total steer input amplitude was reached, some values were observed prior to the time zero. Except for the starting point, all other results met the RSV Specification.

Returnability

To confirm the behaviours of the vehicle when the driver's hands were released from the steering

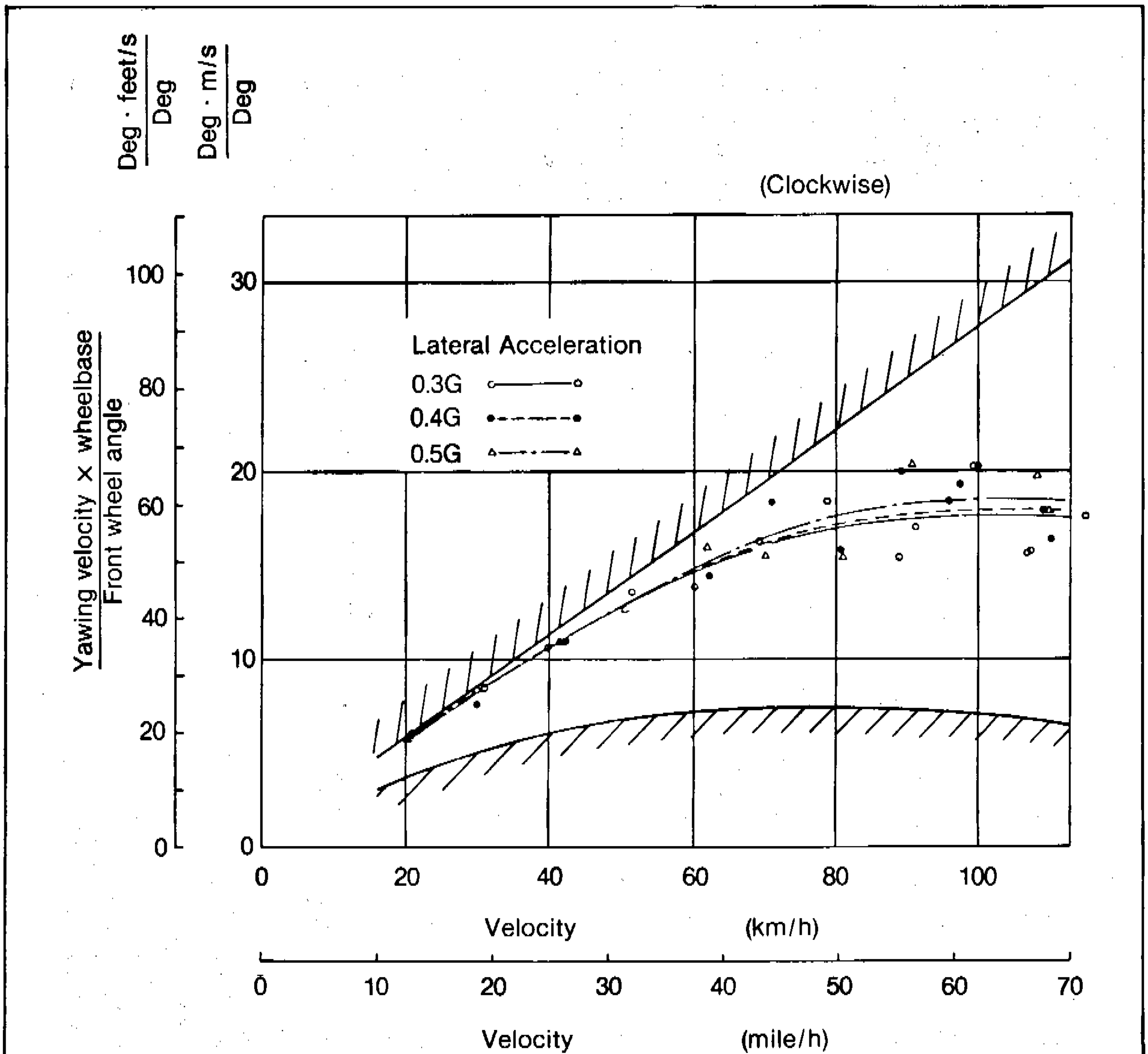


Figure 1.1. Steady state yaw response.

wheel while the vehicle was turning, the steering wheel was completely released from the driver's hands at predetermined points while the vehicle was making a steady state circular turn at the

specified vehicle velocities and
tions. The test results are indicate
and 1.4, all of which met the RSV
except the results of CW at 40 km/

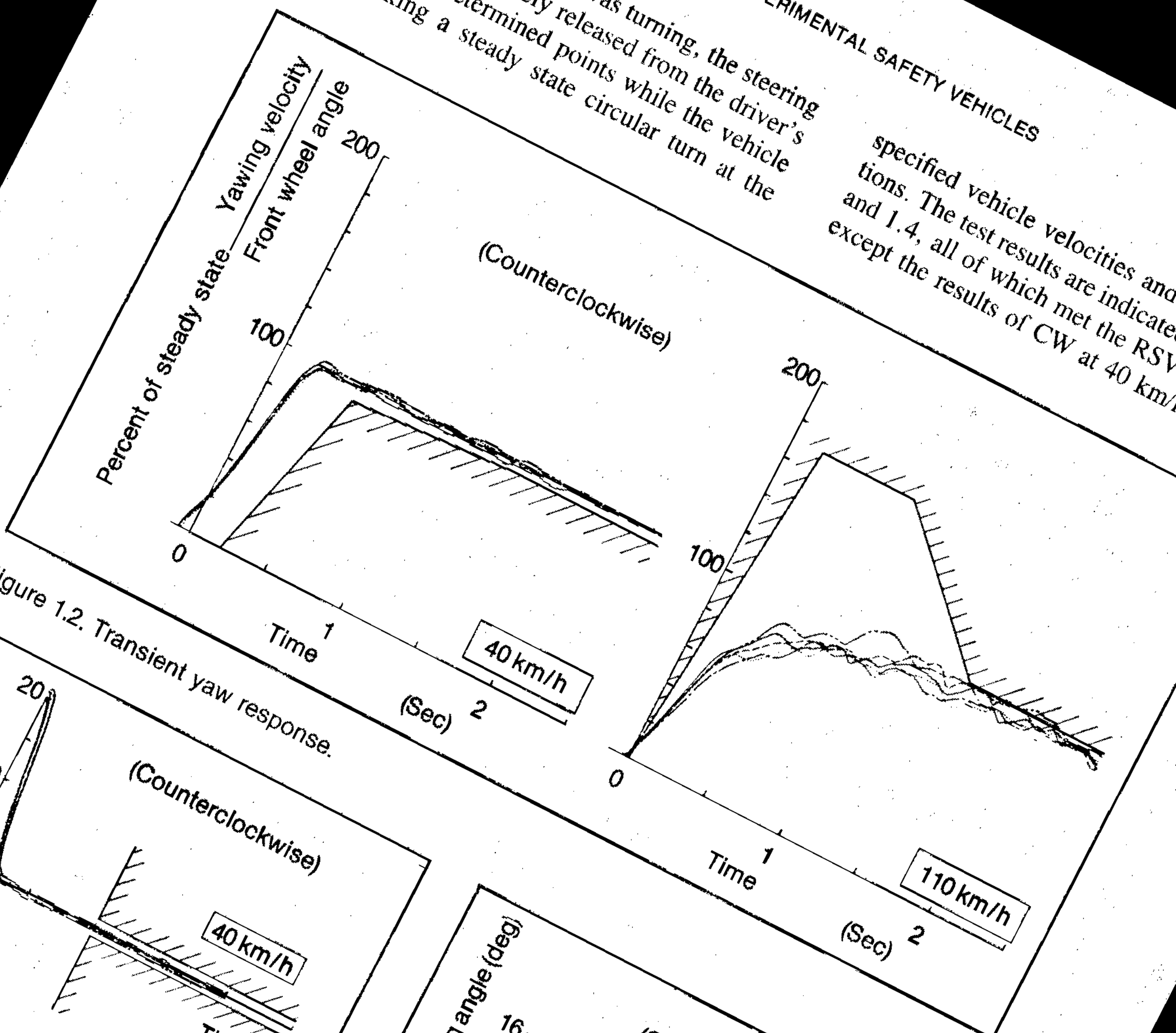
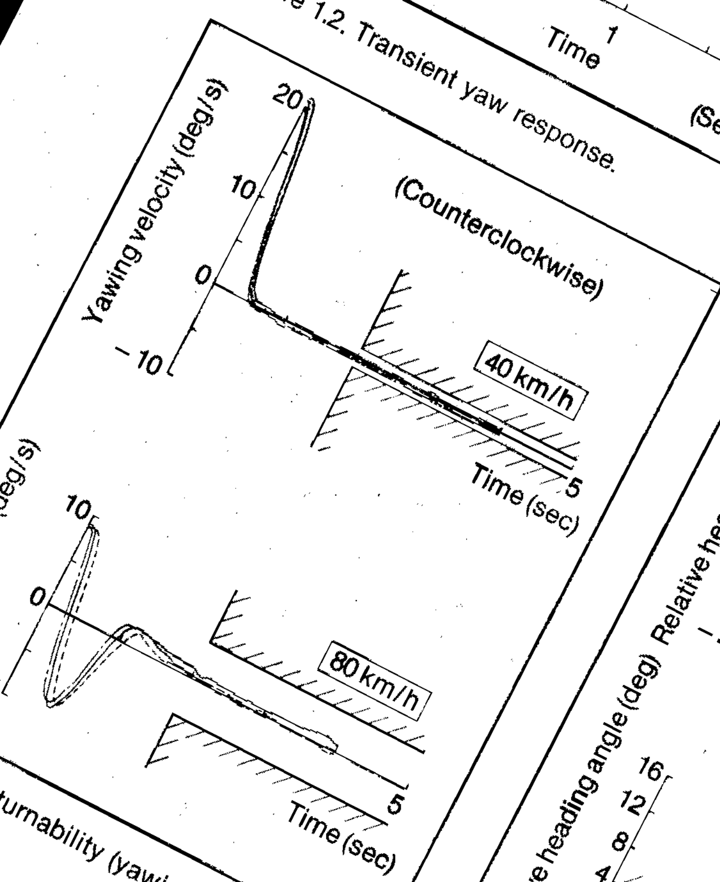


Figure 1.2. Transient yaw response.



turnability (yawing velocity).

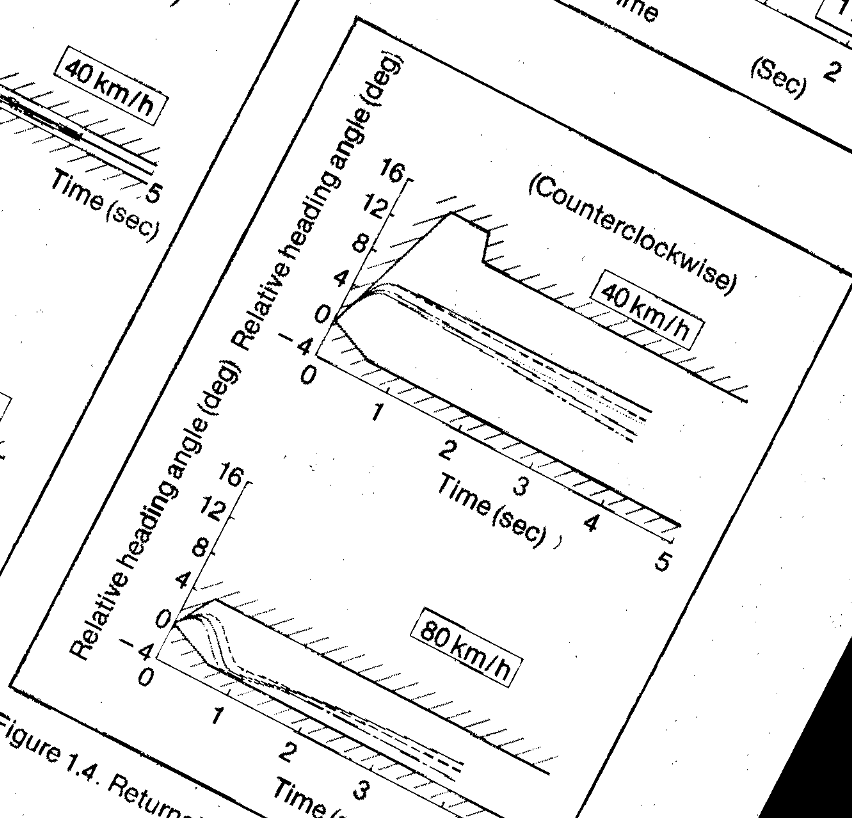


Figure 1.4. Return

2. Handling

Lateral Acceleration

This test was to see whether or not lateral acceleration of the vehicle could clear the specified values while the vehicle keeps steady-state circular motion. The results are shown in Figure 2.1. The values indicate those at the peak in each test sub-item, and do not necessarily represent the maximum attainable on the vehicle. This RSV met the Specification throughout all test sub-items.

Control at Breakaway

The vehicle should return to an original circular path within 4 sec. when the throttle is shut at the position of 3 m deviation outward from that original circle after a gradual acceleration to cause that deviation. The original steady-state circular motions are with maximum lateral acceleration under fixed control. The radii of 30 m and 70 m in combination with two directions of CW and CCW are specified. The results are shown in Figure 2.2, in which percents of successes to total test times were added. In case of tests on 30 m radius, the percents of successes concerning both tests of CW and CCW indicated more than 60%. On the contrary, in case of tests on 70 m radius, the percents of successes were very few (CW14%, CCW18%). The contents of unsuccessful tests were almost spin-out.

Crosswind Sensitivity

The test vehicle was run in front of a crosswind generator, with the steering wheel fixed, towards the straight foward direction. The vehicle running locus in 2 seconds after the receipt of crosswind was measured by a course deviation measuring equipment. The test results are shown in Figure 2.3. Although the results over the vehicle velocity of 100 km/h to the left crosswind slightly exceeded the RSV Specification, the test results at the other conditions satisfied the Specification.

Pavement Irregularity Sensitivity

The test vehicle was operated in a forward direction with the steering wheel fixed on the course which pavement had a fixed ridge. The lateral deviation from the course was measured 2 seconds after ridge contact. As shown in Figure 2.4, the test results had tendencies which slightly exceeded the RSV Specification for less than vehicle velocity of 80 km/h at both conditions.

Steering Control Sensitivity

The vehicle was operated steadily on a circular path with yaw angular velocity of 2 deg/sec. Figure 2.5 represents the test results, showing some scattered data. The test results satisfied the RSV Specification. The test vehicle had a manual steering system (no power assist).

3. Overturning Immunity

Although two test items, i.e., the drastic steer and brake maneuver test which is the combination of steering and braking, and the slalom course test with pylons were required by the RSV Specification, our test was limited to the slalom test due to test schedule limitations.

Slalom

The test was carried out by operating the test vehicle at a velocity of 80 km/h on a slalom course with 11 pylons spaced at 30 m intervals. In this test, the vehicle velocities were so adjusted that the vehicle velocity upon entering the course and the average vehicle velocity while running on the pylon course did not go below the specified velocity. The test vehicle did not overturn in each of the three tests.

4. Braking Performance

Braking Effectiveness

To demonstrate the relationship between the deceleration and the brake pedal force of the test vehicle, the test was carried out for three different cases; i.e., in case of normal system operation, servo (booster) failure and partial system failure (front system failure and rear system failure). The test results are shown in Figures 4.1, 4.2, 4.3 and 4.4. Although all the test results satisfied the RSV Specification, the deceleration which caused lockups of wheels could not be gained. Especially, the maximum deceleration in case of front system failure was about 0.2g. The pedal force against the deceleration of 0.6g under normal conditions was 14 kg, and the ratio (servo multiplying factor) of the pedal force between the normal condition and where the booster failed at the deceleration of 0.4g was approximately 2.1.

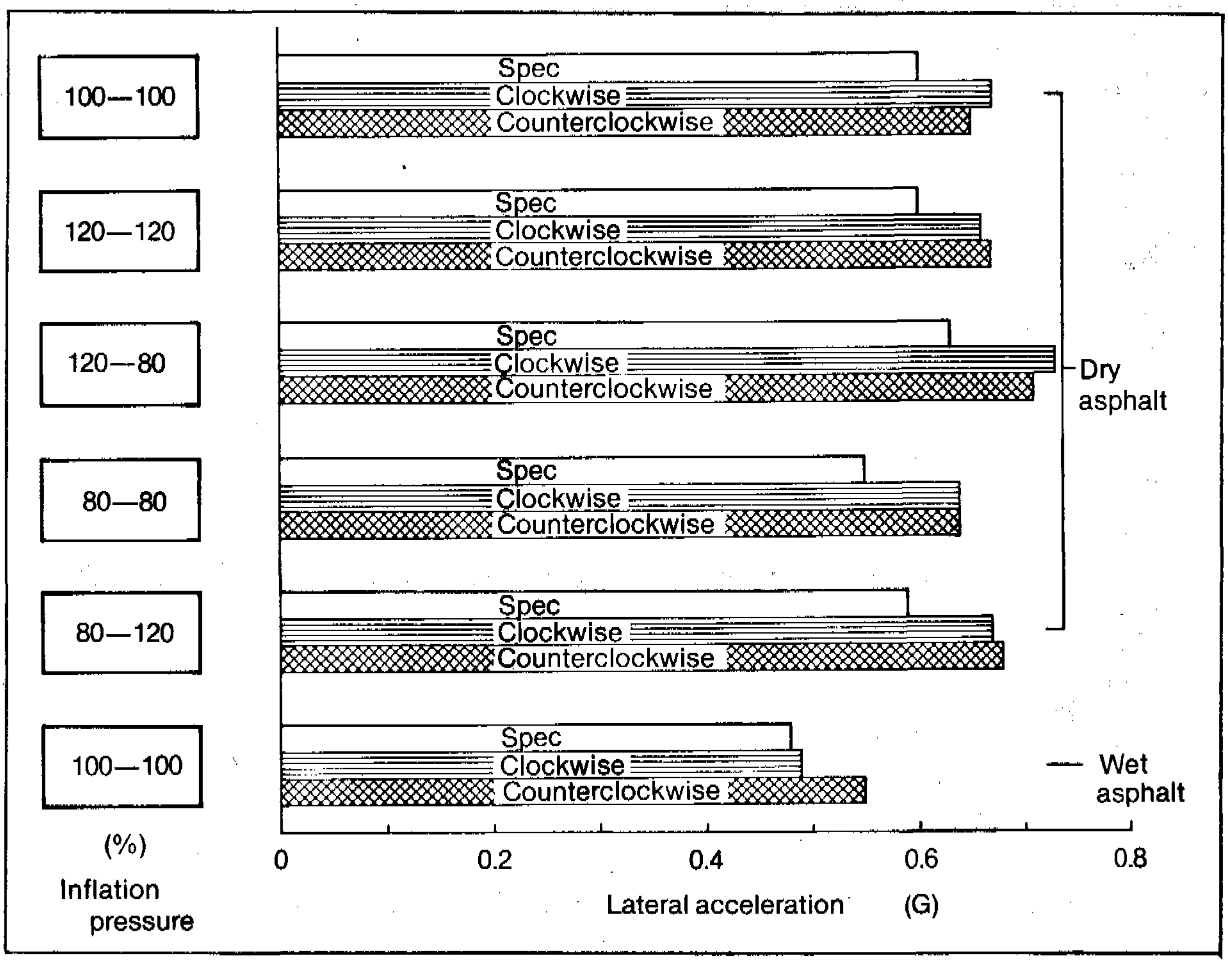


Figure 2.1. Lateral acceleration.

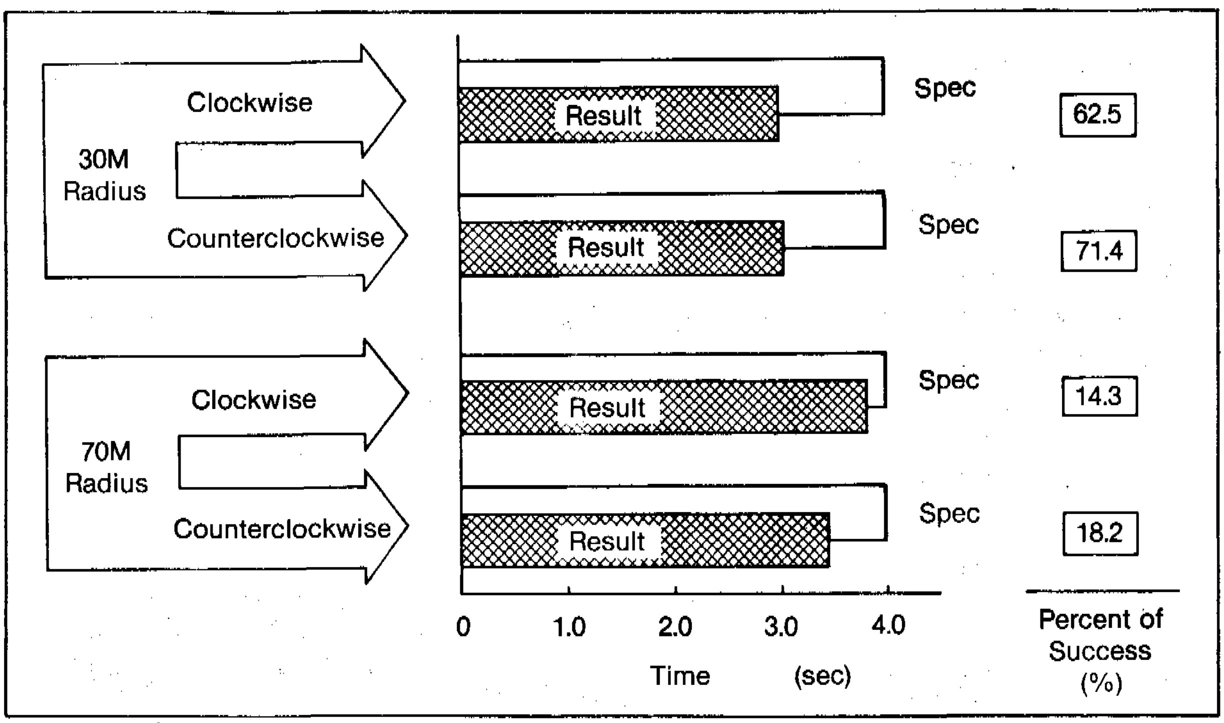


Figure 2.2. Control at breakaway.

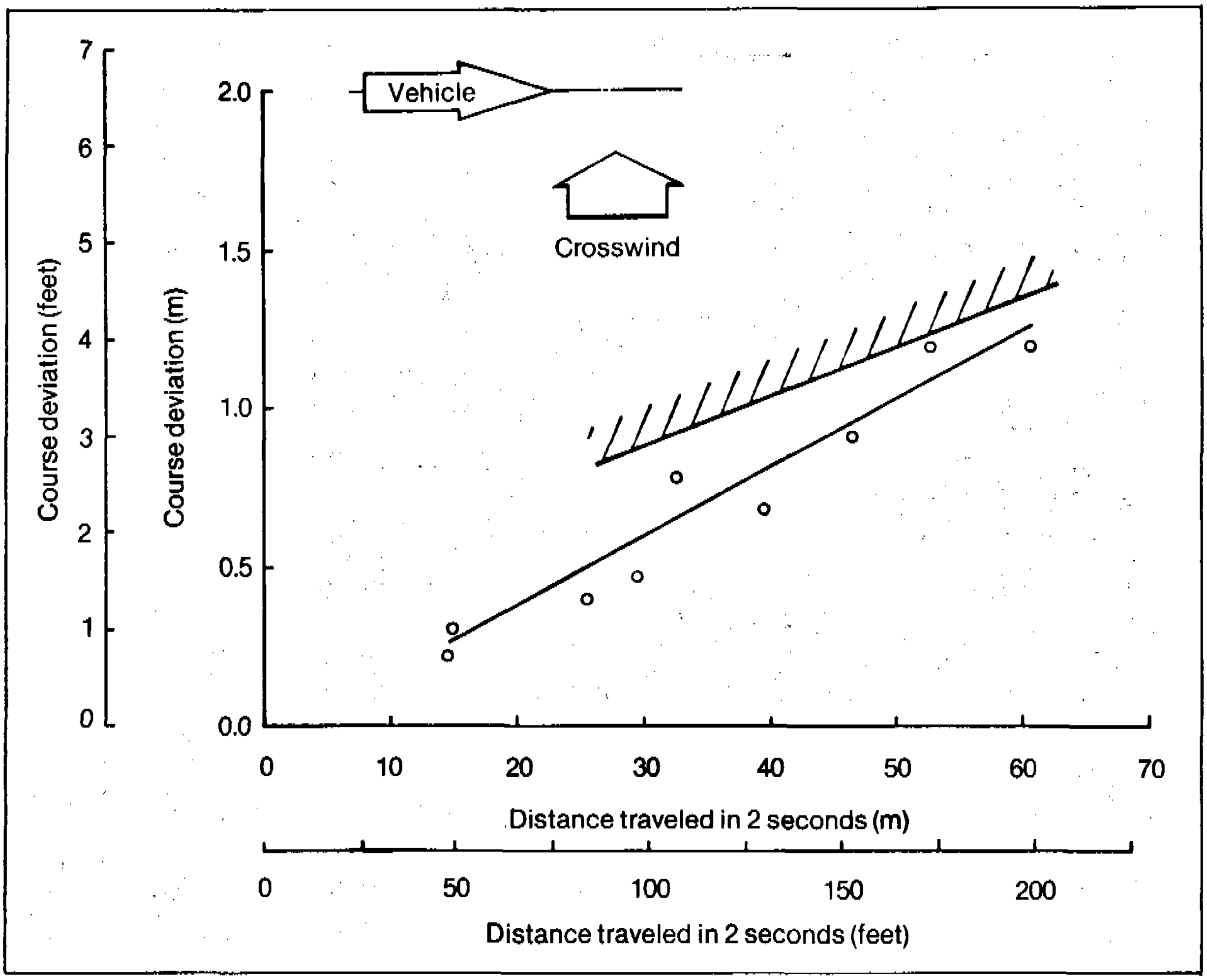


Figure 2.3. Crosswind Sensitivity.

Stopping Distance

To check the distance necessary to bring the vehicle to a stop from a predetermined vehicle velocity, straight line braking tests were carried out three times for each condition of normal system operation, servo (booster) failure and partial failure. The initial vehicle velocity was set as 96 km/h, and the width of the lane was as 3.7 m. As shown in Figure 4.5, the test results show that the vehicle stopped at shorter distances than those in the RSV Specification except in case of front system failure. The stopping attitude was also good. The vehicle did not deviate from the lane 3.7 m in width, and stopped without causing lockups of wheels as mentioned in the section of brake effectiveness.

Tests for braking in a turn under normal condition were also carried out. The vehicle was subjected to braking while operating in a circular path of radius 108.8 m (357 ft) at a velocity of 64 km/h. Figure 4.6 shows the results. The test vehicle stopped with very shorter distance than the RSV Specification in the both cases of CW and CCW. In these cases, the stopping attitude was also good, and vehicle did not go out of the lane 3.7 m in width.

Parking Brake

The parking brake test was conducted using an inclined road of 30 percent grade. In this test, a service brake was employed to stop the test vehicle. An operational force was applied in steps to the parking brake lever to release the service brake in such a manner that the vehicle could be maintained under stationary conditions for larger than 5 minutes. But, the M-RSV could not be

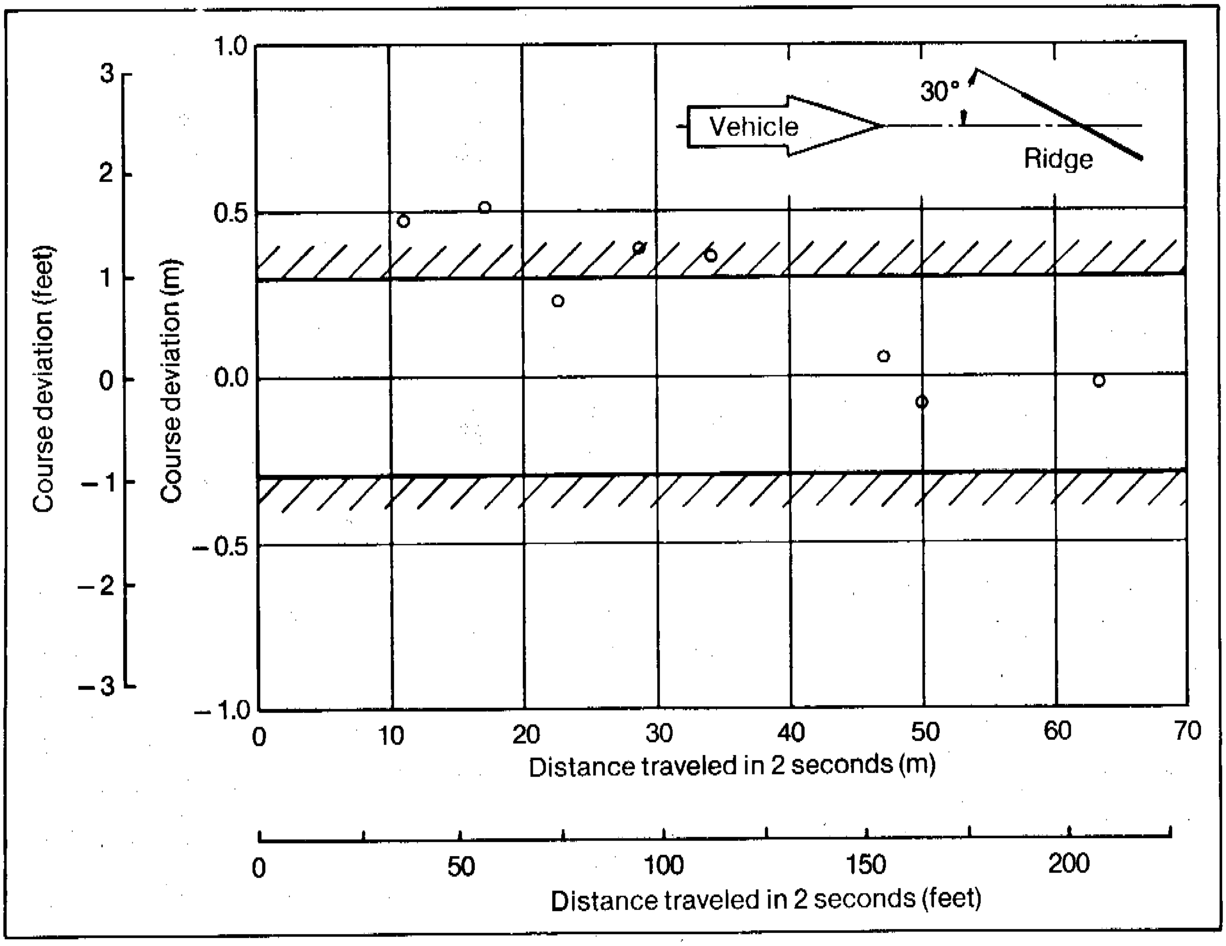


Figure 2.4. Pavement irregularity sensitivity.

stopped by parking brake on the inclined road of 30 percent grade.

5. Some Considerations

The summary of test results of the M-RSV concerning handling, stability and braking performance was indicated in Table 1. Secondly, a comparison of performance characteristics was made between the RSV and Japanese cars having the same vehicle weight and number of seats, which was one of research objectives.

The characteristics of kinetic performance are affected not only by the vehicle weight but also by the dimensions represented by wheelbase, as well as by drive mechanism such as FF (Front Engine, Front Drive) or FR (Front Engine, Rear Drive), and the kinetic characteristics of other vehicle components. Therefore, a direct comparison is not possible between the RSV and Japanese cars even though the vehicle weight and

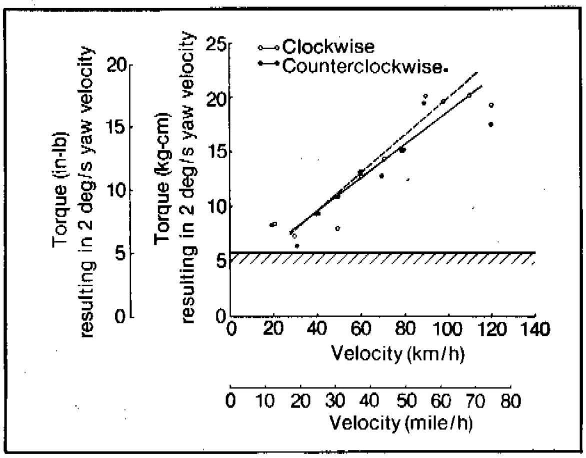


Figure 2.5. Steering control sensitivity.

the number of seats are identical, due to the difference in the wheelbase and the drive mechanism. Especially, the rear drive mechanism by the transverse mid-engine, which was adopted

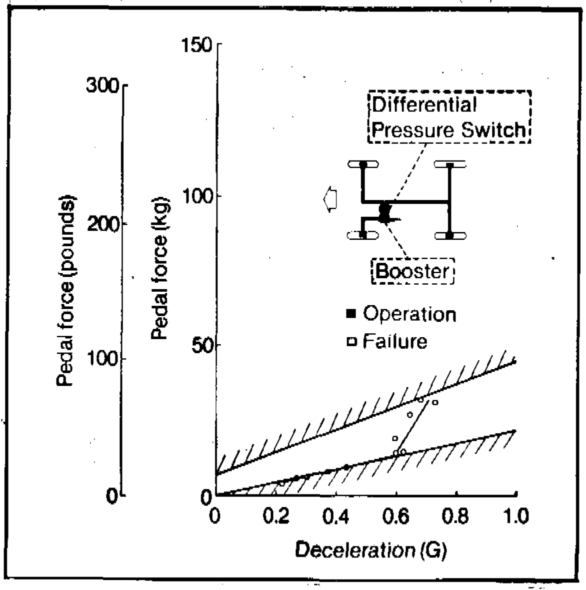


Figure 4.1. Brake effectiveness for normal system operation.

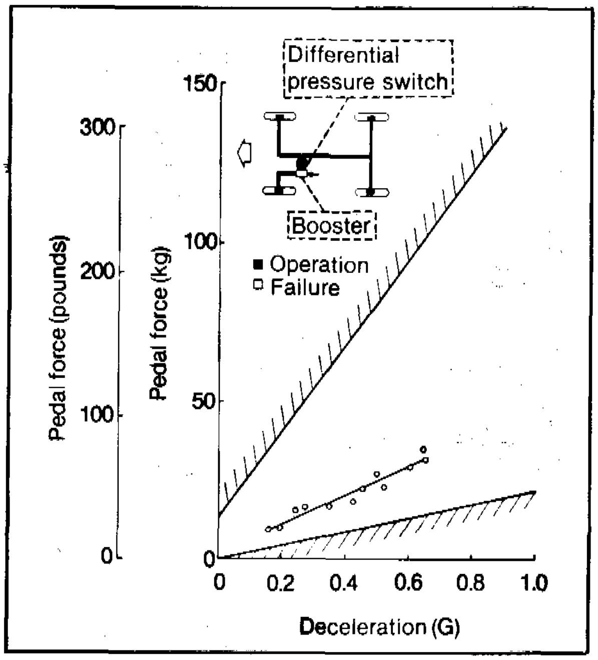


Figure 4.2. Brake effectiveness for booster failure.

by the M-RSV, did not correspond to a Japanese car in the market.

Then, a comparison was mainly made here between the results of the M-RSV and the kinetic performance characteristics of Japanese cars that were obtained from the available performance data. The handling and stability characteristics were compared in terms of understeer characteristics, while the braking performance was compared in terms of brake effectiveness.

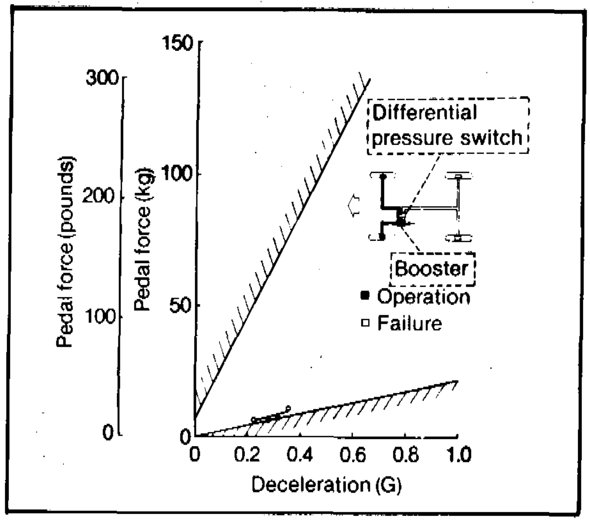


Figure 4.3. Brake effectiveness for rear system failure.

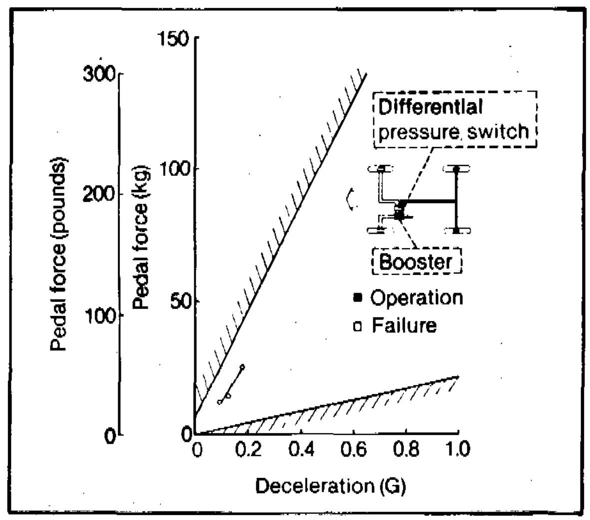


Figure 4.4. Brake effectiveness for front system failure.

Figure 5.1 is the comparison of the test results of the M-RSV and linear analysis for steady state yaw response against a lateral acceleration of 0.4g. Here the constant K represents what is called "stability factor," that may be defined by the following equation.

$$\frac{(\text{Yaw angular velocity}) \times (\text{wheelbase})}{(\text{front wheel angle})} = \frac{V}{1 + KV^2}$$

(V: vehicle velocity)

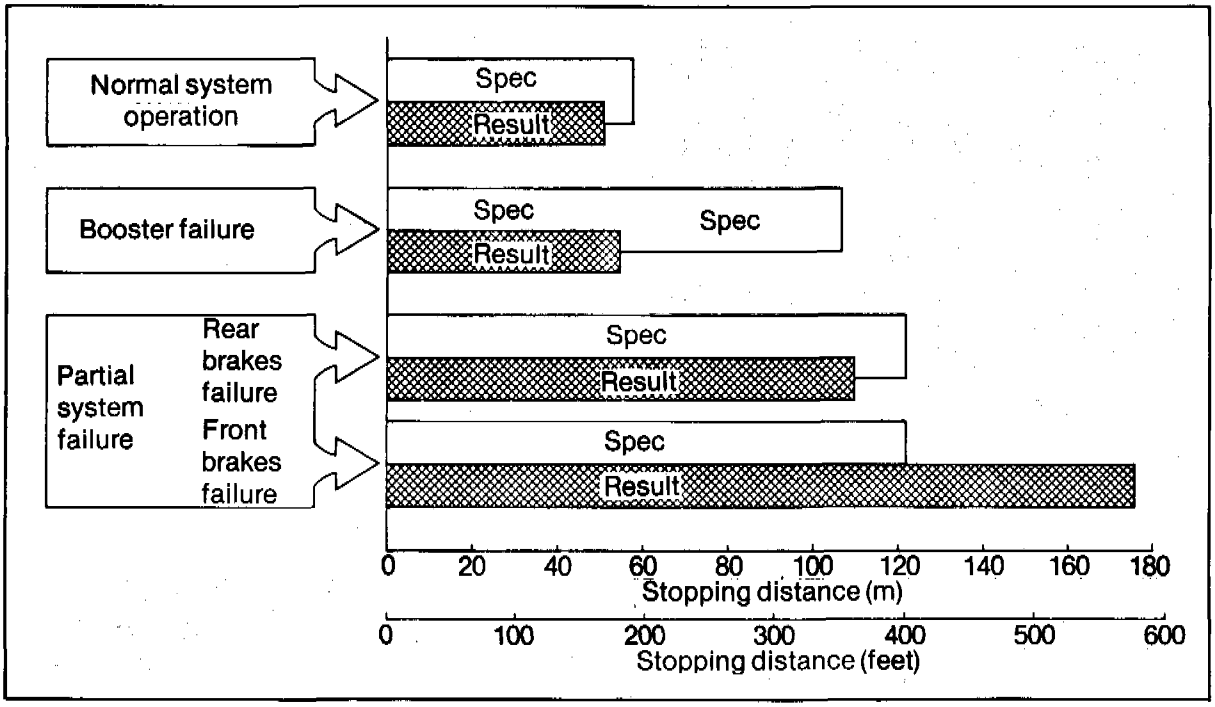


Figure 4.5. Stopping distance for straight line braking.

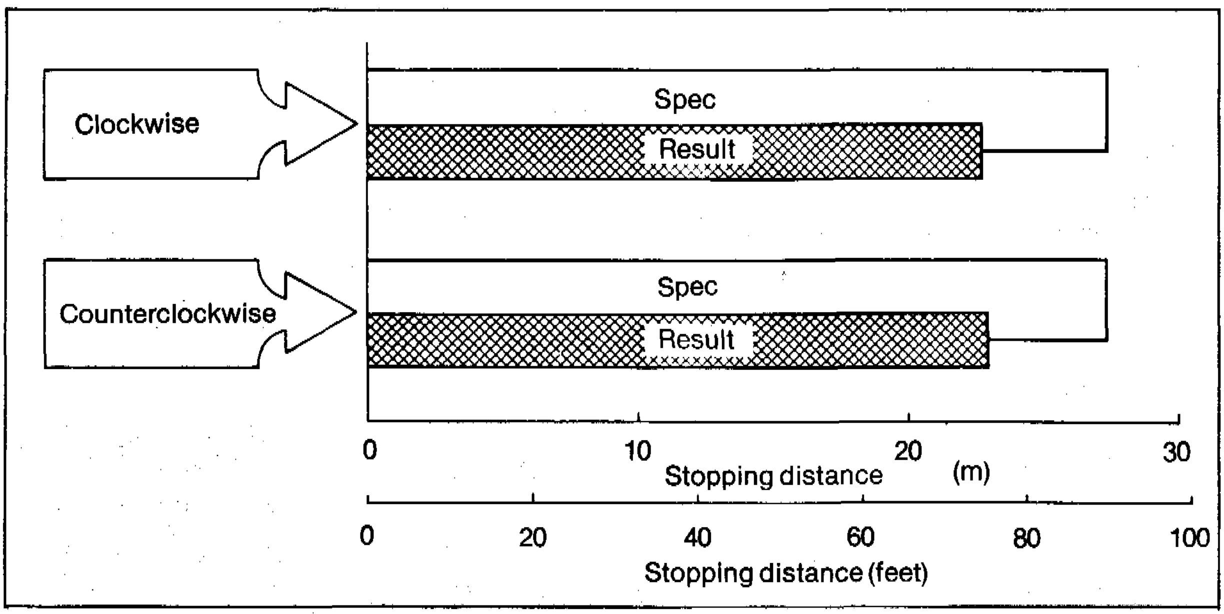


Figure 4.6. Stopping distance for braking in a turn.

The degree of understeer can be obtained from the value of stability factor K. In Figure 5.1, it is found by comparison of the test results and the calculated values obtained by linear analysis that the understeer is $K=0.0005 \sim 0.0010\ s^2/m^2$ for the both turnings (CW and CCW). Figure 5.2 shows a comparison of steer characteristics between the M-RSV and 76 models of Japanese passenger cars. From this Figure, it is found that the degree of understeer of the M-RSV are considerably smaller than the average characteristics of Japanese cars.

Table 1. Summary of handling, stability and braking performance test results of M-RSV.

Requirement	Test procedure	Criteria	Requirement met
1. Steady state yaw response	Steady turn, CW & CCW (V = 20 ~ 120 km/h)	Envelope Trend	Yes Not clear
2. Transient yaw	Ramp-step steer, Left & right (V = 40, 110 km/h)	Envelope	Yes
3. Returnability	Steady turn, CW & CCW (V = 40, 80 km/h)	Yaw velocity at 2.0 sec. Yaw envelope	Yes (Except CW of V = 40 km/h) Yes (Except CW of V = 40 km/h)
4. Lateral acceleration	Fixed control, CW & CCW	100%F&R (Design value of tire pressure) 120%F&R 80%F&R 120%F, 80%R 80%F, 120%R 100%F&R (wet)	Yes Yes Yes Yes Yes Yes
5. Control at breakaway	Fixed radius, CW & CCW (30 m & 70 m radius)	Path convergence in 4 sec.	Yes (30 m) No (70 m)
6. Crosswind sensitivity	22 m/s crosswind gust, Left & right (V = 20 ~ 120 km/h)	Course deviation at 2.0 sec.	Yes (Less than 100 km/h)
7. Steering control sensitivity	Fixed yaw rate turn, Left & right (V = 20 ~ 120 km/h)	Torque exceedence	Yes
8. Pavement irregularity	2.5 cm ridge, Left & right (V = 20 ~ 120 km/h)	Course deviation	Yes (More than 80 km/h, Data: scattered)
9. Overturning immunity	Slalom (30 m spacing)	No rollover	Yes
10. Brake effectiveness	Normal system operation Partial failure (1), (2) Booster failure	Envelope Envelope Envelope	Yes Yes Yes
11. Stopping distance	Normal system operation Straight-line curve, CW & CCW Partial failure (1) Rear failure (2) Front failure Booster failure	 Less than 57.9 m Less than 27.4 m Less than 121.9 m Less than 121.9 m Less than 106.7 m	 Yes Yes Yes No Yes
12. Parking brake	30% grade Uphill Downhill	Actuation effort Less than 40 kg Less than 40 kg	 No No

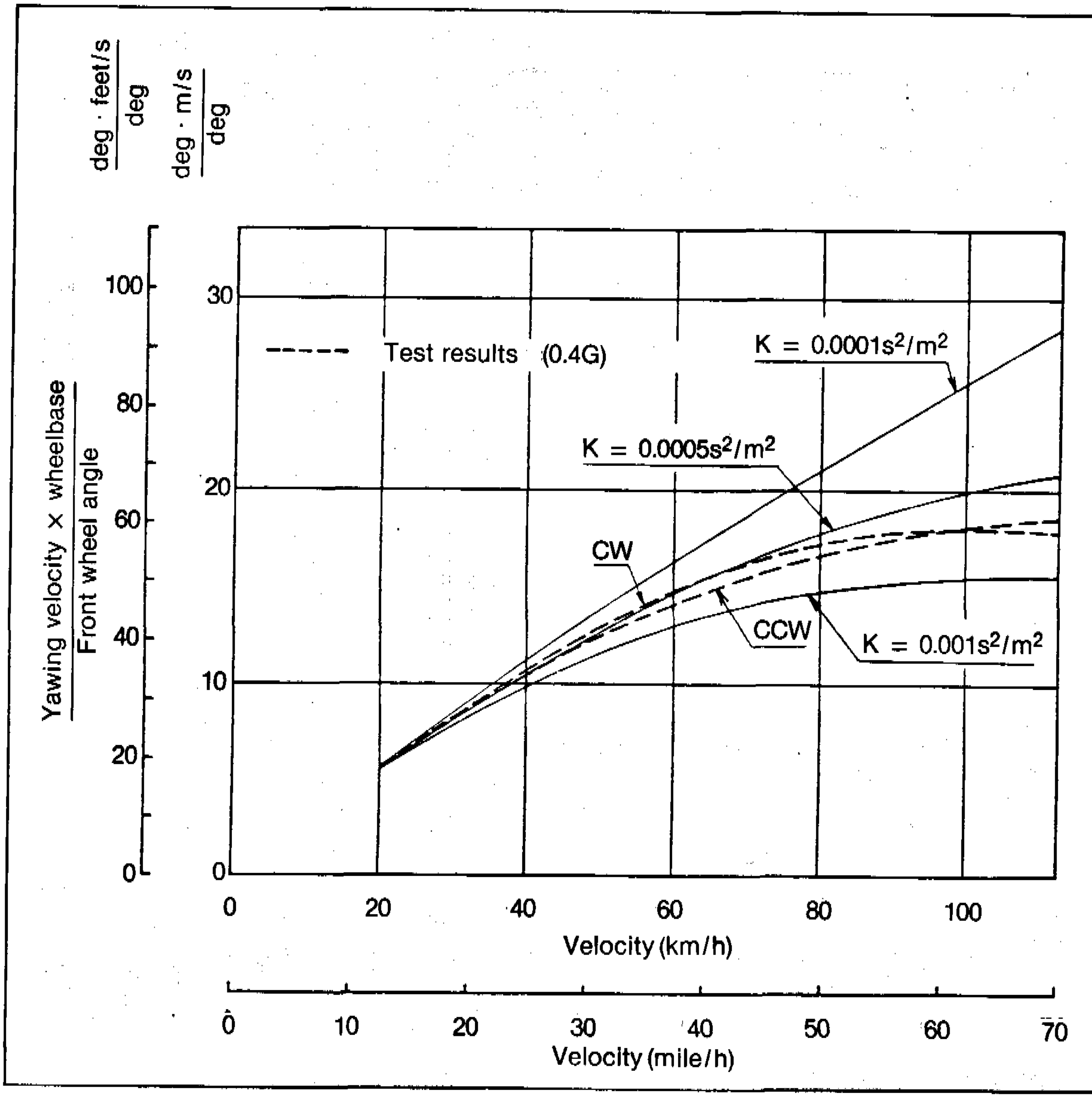


Figure 5.1. Comparison of test results and linear analysis for steady state yaw response.

Figure 5.3 is a comparison of brake pedal force against a deceleration 0.6g between the M-RSV and 73 models of Japanese cars. It is found that the test results agree fairly well with the mean values of Japanese cars.

VISIBILITY TESTS

Concerning the visibility performance of the M-RSV, tests were carried out for the field of direct view, the field of indirect view and the lighting devices. Since the design attitude of the body and the location of R-point were not indicated on the tested vehicle, a SAE 3DM was placed in the vehicle according to SAE J 826b, and the H-point was obtained to make it as the reference point.

1. Field of Direct View Tests

Tests for the field of direct view were carried out to determine the extents in meeting the re-

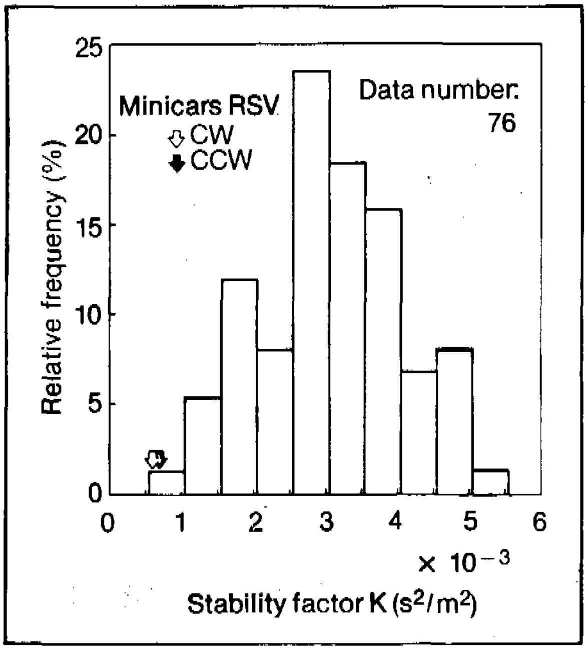


Figure 5.2. Histogram of stability factor at 0.4g lateral acceleration of Japanese cars.

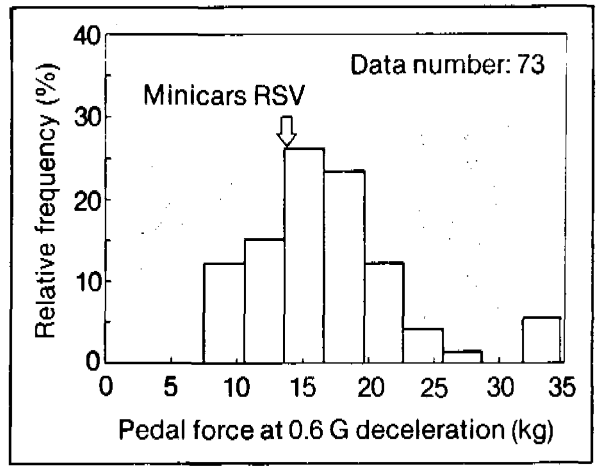


Figure 5.3. Histogram of pedal force at 0.6g deceleration of Japanese passenger cars.

Table 1. Field of direct view.

Requirements			Test results				Compliance
1) Monocular obstruction angles, etc.	Total obstruction angle	Total longitudinal width		Total obstruction angle (from V_1)	(from V_2)	Total long. width	
Zone I (LF)	≤11°	------	Zone I	15.8°	14.0°	------	NG
Zone II (RF)	≤11°	------	Zone II	9.1°	9.3°	------	OK
Zone IV (LR)	≤24°	------	Zone IV	20.3°	17.7°	------	OK
Zone III (LR)	------	≤ 105% of that in Zone IV	Zone III	----------------		95.8% V_1 96.8% V_2	OK
2) Binocular obstruction angles.	Number of obstructions	Total obstruction angle		Number of obstructions	Total obstruction angle		
Zone I	≤1	≤6°	Zone I	1	14.0°		NG
Zone II	≤1	≤6°	Zone II	1	7.4°		NG
3) Unobstructed forward field of direct view. Unobstructed within viewing area A viewed from V_1 and from V_2, etc.			No obstruction.				OK
4) Luminous transmittance of windshield: 70%			67.4%				NG

quirements set forth in "FMVSS Proposed New Standard, Field of Direct View (Docket No. 70–7; Notice 5)."

The implemented test items and the outlines of the test results were as indicated in the following (refer to Table 1 for the details).

Monocular Obstruction Angles. The obstruction angle in the Zone I (A pillar at the driver's side) did not meet the requirement. The obstruction angles in the Zones II, III and IV met the requirement respectively.

Binocular Obstruction Angles. The obstruction angle in the Zone I and the Zone II did not meet the requirement.

Present or Absence of Obstructions in Viewing Area "A". Obstructions did not exist in the Viewing Area A, hence the requirement was met.

Luminous Transmittance of Windshield. The luminous transmittance was under 70%, hence the requirement was not met.

2. Field of Indirect View Tests

Tests for the field of indirect view were carried out to determine the extent in meeting the requirements for the field of indirect view set forth in "Rear View Mirror Systems, FMVSS 111—Proposed Amendment [Docket No. 70–3a; Notice 4]. The implemented test items and the outlines of the test results were as indicated in the following (refer to Table 2 for the details).

Field of View Without Test Occupants. While the inside rear view mirror met the requirement, the driver's side outside rear view mirror (left door mirror) and passenger's side outside rear view mirror (right door mirror) did not meet the requirement.

Field of View With Test Occupants. The requirement was met for the Target Q, but the requirement for the Targets SL and SR was not met.

3. Lighting Devices Tests

Dual beam rectangular headlamps sold on the US market (made by Guide, Type 2B were equipped on the M-RSV. In the tests, luminous intensity distributions of headlamps were measured, and iso-luminous intensity diagrams were prepared.

Table 2. Field of indirect view (rearview mirror systems).

Requirements		Test results		Compliance
1) Field of view without test occupants.				
a) Mirror system:	95% of Target Q.	Room mirror:	100% of Target Q.	OK
Single plane mirror:	75% of Target Q.	----due----		OK
b) Single plane mirror:	75% of Target SL.	Left door mirror:	42.7%* of Target SL, (73.6%** of Target SL).	NG
c) Non-convex mirror, or convex mirror, with R = 40 – 60 in.:	75% of Target SR.	Right door mirror:	4.7%* of Target SR. (31.3%** of Target SR).	NG
2) Field of view with test occupants.				
Mirror system:	65% of Target Q,	a) 99.2% of Target Q,		OK
	65% of Target SL,	b) 43.0%* of Target SL,		NG
	65% of Target SR.	c) 4.7%* of Target SR.		NG

* with req. of S5.5.3/FMVSS 111-PA [Dkt 71-3a; Not .4]
** without req. of S5.5.3/---due--.

Results of Simulated Car-to-Pedestrian Collisions With the Minicars Research Safety Vehicle

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ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) and the European Experimental Vehicles Committee (EEVC) collaborated in carrying out 12 vehicle-pedestrian collisions by means of an experimental safety vehicle (RSV) developed by Minicars on the crash test facility of the Federal Highway Research Institute (BASt).

Seven tests were carried out with a 50 percent male dummy and five tests with a 50 percent 6 year old child dummy varying the contact areas or location of impact on the hood and collision speeds between 15 and 25 mph.

The loads on the pedestrian dummies were measured by means of the accelerations in the various parts of the body. The tests were filmed using several high speed cameras.

INTRODUCTION

The aim of the investigation and the tests themselves were largely identical with those conducted with a Calspan RSV at Volkswagen in 1978. A report on these tests was given at the 7th ESV Conference[1].

TEST CONFIGURATION

The test configuration is shown on Figure 1.

The car was accelerated on the approach lane, to the impact speed and disconnected from the endless cable 2 m before the collision. The car passed a laser light barrier to check the speed and hit the fully exposed pedestrian, who had been released from a gallow. The car's braking system was automatically activated in the moment of impact.

The primary impact of car and pedestrian was filmed from above and from the side and the secondary impact between pedestrian and street was filmed from the side. The camera was operated at a rate of 500 frames per second.

Dummy Instrumentation

Two different pedestrian dummies were used for the tests:

- 50 percent male dummy, Type Humanoid 572–50 p
- 50 percent child dummy, 6 years old, Type Sierra 492–106.

The dummies were equipped with triaxial accelerometers in the head, chest, and pelvis. In addition the legs of the adult dummy were equipped with accelerometers built into the knees and feet in lateral direction. The accelerometer's range was 250 g. The measuring data were recorded, via pulse code modulation (PCM), on magnetic tape, inputted in a large-scale computer by means of a process computer and processed for evaluation.

Test Vehicle

An explosion sketch of the Minicars RSV is found on Figure 2.

The vehicle is characterized by a long hood and a V-shaped front-end design. The front face, the fenders, and the trunk hood—the car has a rear engine—consist of flexible plastic. Behind the soft face there is an integrated foam bumper system which is not damaged in crashes up to 10 mph. The bumper is easy to replace. Headlamps and windshield wipers are concealed.

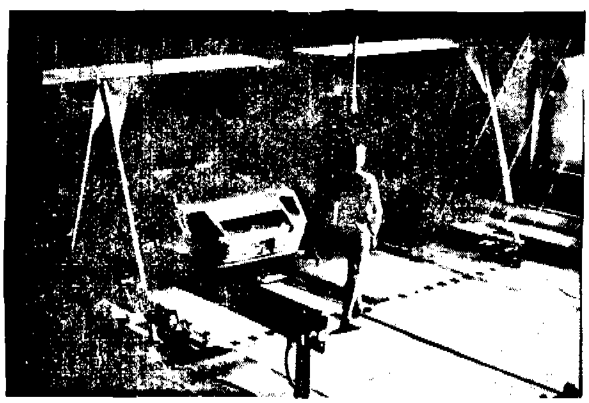

Figure 1. Test configuration for car-to-pedestrian accidents.

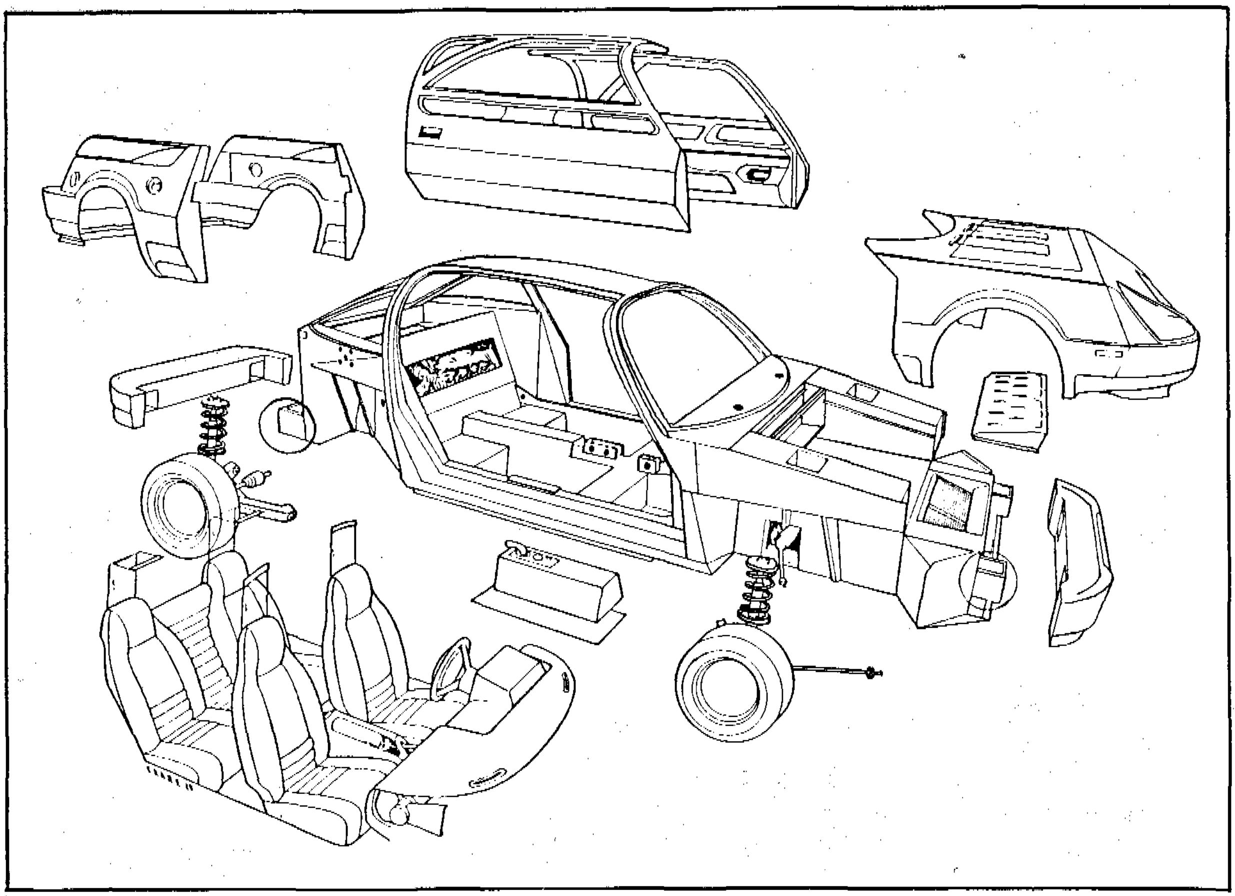

Figure 2. Explosion sketch of the Minicars RSV.

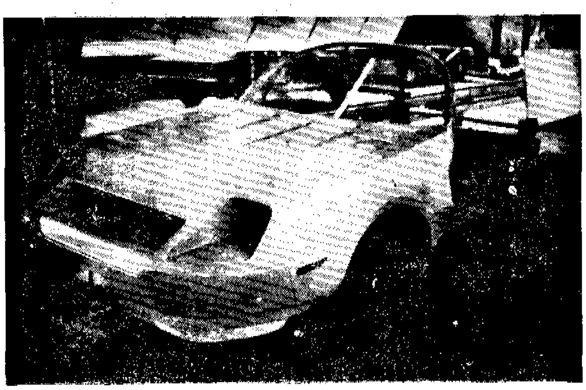

Figure 3. Minicars buck.

Table 1. Field of direct view.

Test nr.	Impact speed (mph) 15	20	25	Hood impact area hard	soft
Min 1	X			X	
Min 2		X		X	
Min 3		X		X	
Min 4		X			X
Min 5		X			X
Min 6			X	X	
Min 7			X		X

Minicars provided the BASt with a rollable buck for carrying out the car-to-pedestrian accident simulations (Figure 3).

Diving of a real car while braking was simulated by a corresponding fixation of the wheel suspension on the body of the car. The vehicle impacted the pedestrian in pitched position. Because the automatic braking system was activated not before the collision, it was possible, to keep the specified test speed within an average tolerance of ± 1 percent.

TESTING PROGRAM

On Table 1 the tests, including the various parameters for collisions with adult-dummies are listed. The ones applying to collisions with child-dummies are listed on Table 2.

Graphical representations of the various contact areas or locations of impact on the hood are found on Figure 4.

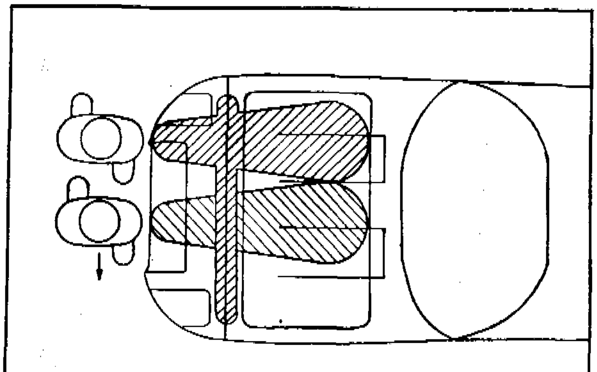

Figure 4. Hard and soft areas of impact on the hood.

TEST RESULTS

Table 3 shows the test results for the adult-dummy in tabular form; Table 4 shows the results for the child-dummy.

The curves in Figures 5–8 are an illustration of the test data, in which those data of interest to human survival, i.e. HIC, resulting chest acceleration, SI, and resulting pelvis acceleration

Table 2. Field of indirect view (rearview mirror systems).

Test nr.	Impact speed (mph) 15	20	25	Hood impact area hard	soft
Min 8	X			X	
Min 9		X		X	
Min 10		X			X
Min 11			X	X	
Min 12			X		X

Table 3. Results from the 50 percent male-dummy tests.

Test nr.	Impact speed (km/h)	Throwing distance (m)	Head: Max. res. accel. (g) Primary impact	Head: Max. res. accel. (g) Secondary impact	Head: HIC Primary impact	Head: HIC Secondary impact	Chest: Max. res. accel. (g) Primary impact	Chest: Max. res. accel. (g) Secondary impact	Chest: SI Primary impact	Chest: SI Secondary impact	Pelvis: Max. res. accel. (g) Primary impact	Pelvis: Max. res. accel. (g) Secondary impact	Knee — lateral — left: Max. accel. (g) Primary impact	Knee — lateral — left: Max. accel. (g) Secondary impact	Knee — lateral — right: Max. accel. (g) Primary impact	Knee — lateral — right: Max. accel. (g) Secondary impact	Foot — lateral — left: Max. accel. (g) Primary impact	Foot — lateral — left: Max. accel. (g) Secondary impact	Foot — lateral — right: Max. accel. (g) Primary impact	Foot — lateral — right: Max. accel. (g) Secondary impact
1	23.3	4.40	22	18	41	33	22	20	77	34	40	—	57	—	83	136	146	17	196	54
2	32.0	9.50	88	212	434	256	24	39	141	85	38	56	150	—	189	57	270	110	100	166
3	32.6	8.60	99	18	146	15	16	14	68	22	34	35	84	170	120	130	275	148	—	—
4	32.1	9.40	52	35	234	30	14	40	143	91	34	58	63	67	114	115	287	227	228	247
5	32.3	11.0	84	140	415	239	44	28	188	76	38	82	140	52	60	116	270	340	148	—
6	40.3	12.45	134	130	1593	256	40	130	673	531	48	96	114	36	140	74	273	88	253	23
7	38 7	13.30	168	362	1771	1677	44	126	671	445	64	74	120	—	96	—	278	200	253	—

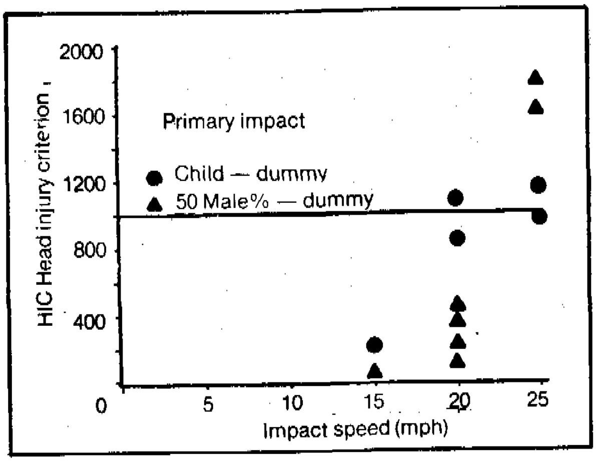

Figure 5. HIC vs. impact speed.

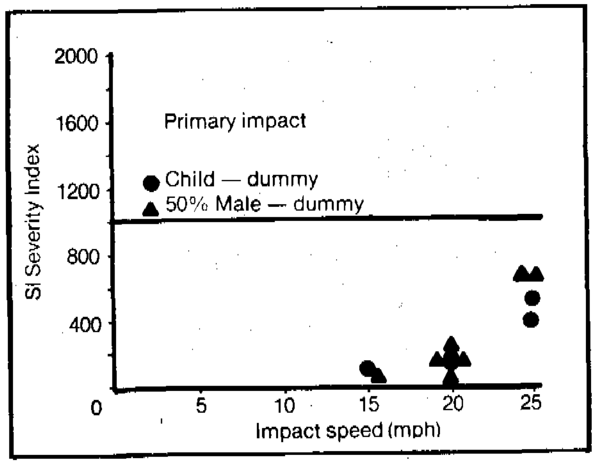

Figure 7. SI vs. impact speed.

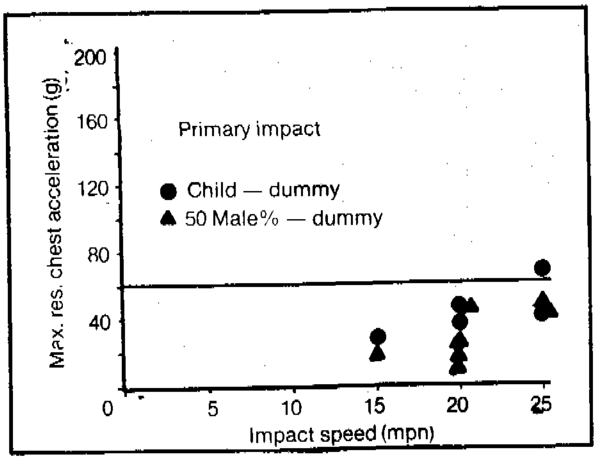

Figure 6. Max. res. chest acceleration vs. impact speed.

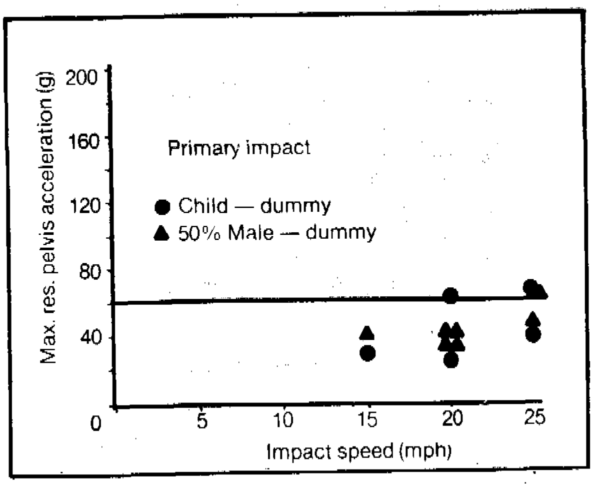

Figure 8. Max. res. pelvis acceleration vs. impact speed.

are plotted in relation to the speed of impact. The tests were focused primarily on the relationship between the design of the front end of the car and its stiffness and the load on the dummy, the data mentioned above are plotted only with respect to the primary impact between pedestrian-dummy and car.

In general, the data for the secondary impact between pedestrian-dummy and road are of about the same magnitude as for the primary impact in the case of the adult-dummy. In the case of the child-dummy the data from the secondary impact are clearly lower than those from the primary impact.

It can be seen that a child reaches the critical HIC limit of 1000 at an impact speed of 20 mph, an adult reaches this limit at 25 mph. The explanation is that the impact area of a child's head, independent from the contact area, is always found on the hard flange of the car's front facing, resulting in very high head acceleration values.

The area of impact of the head of an adult-dummy is generally found within the softer upper part of the car's hood. The windshield or its frame are generally not impacted, as is shown in Figure 9.

For this reason, only low acceleration peaks are reached in the primary impact between adult-dummy and car, Figure 10.

The points of head impact on the car were independent of the impact speed. The upper part of the adult-dummy's body did not crash through the lid of the trunk, which is built in a sandwich construction.

Table 4. Results from the 50 percent 6 years old child-dummy tests.

Test nr.	Impact speed (km/h)	Throwing distance (m)	Max. res. accel. (g) Primary impact	Max. res. accel. (g) Secondary impact	HIC Primary impact	HIC Secondary impact	Max. res. accel. (g) Primary impact	Max. res. accel. (g) Secondary impact	SI Primary impact	SI Secondary impact	Max. res. accel. (g) Primary impact	Max. res. accel. (g) Secondary impact
			Head				Chest				Pelvis	
8	24,1	5,70	87	—	201	—	26	24	96	29	28	26
9	32,0	6,70	240	—	1076	—	44	—	117	—	60	34
10	32,3	10,60	232	122	821	296	32	24	153	67	22	48
11	40,4	14,40	188	136	1121	293	65	66	387	120	64	28
12	39,8	16,35	256	—	956	—	40	110	515	314	36	34

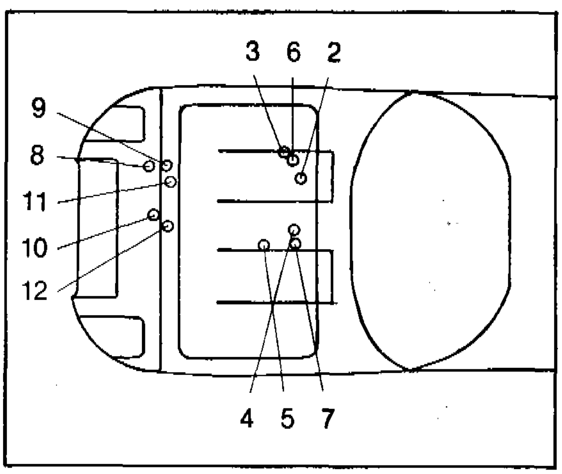

Figure 9. Points of impact on the Minicars RSV for the child-dummy and the adult-dummy.

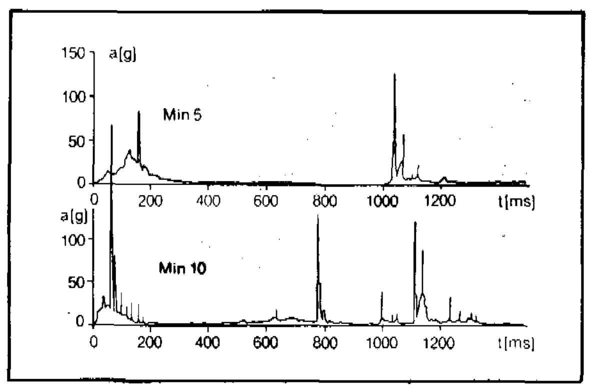

Figure 10. Resulting head acceleration for the adult-dummy and the child-dummy.

In the case of a car-pedestrian impact, the car's front impacts the area of an adult-dummy's knees or a child-dummy's hips. This results in different kinematics. The child-dummy bends around the car's front and is thrown off in a position parallel to the road. The adult-dummy, upon impact, gets a high rotation around its center of gravity. In the case of higher speeds, it can result in being turned over and in a dangerous secondary impact between head and road surface (Figure 10).

The resulting maximum chest acceleration and the SI value at 25 mph have been found to be lower than the biomechanical tolerance values, widely accepted up to now (Figures 6 and 7). The resulting maximum pelvis acceleration reaches for both dummy-types the 60 g-level at 25 mph.

Interesting is the kinematic of a pedestrian hit by the curvature of the Minicar's front to the car's side. He turns away and falls beside the car. Therefore the risk of severe injuries is low. The probability, to be hit by the right or left frontside in the area of the fender, amounts to 14.8 percent[4]. Therefore it can be said, that in 15 percent of the pedestrian accidents the injuries are lower by means of the curvatured Minicar's front than by means of the rectangular front-end design of common cars.

The throwing distances of the dummies are in about the same range as found in other simulated car-pedestrian impacts[3]. Plastic deformations of the car-structure to absorb energy did not take place. The lid of the trunk and the foam-bumper remained in fully elastic condition. The foam-bumper system showed a tendency to break at high forces.

The contact area of the car is not important for the loads of the child-dummy concerning head impact, but the values for the resulting chest and pelvis acceleration are a little bit higher for the hard impact area than for the soft.

There is no influence of the contact- or impact area to the measuring data for the adult-dummy.

CONCLUSION

The aim of this project was to examine the behaviour of the Minicars RSV in car-to-pedestrian collisions under special test conditions.

It is possible to get the following conclusions:

- The child-dummy reaches the critical HIC limit of 1000 at an impact speed of 20 mph because of the hard primary impact of the child's head.
- The high rotation of the adult-dummy at higher impact speeds can favour a dangerous secondary impact.
- There is no impact on hard parts of the windshield or its frame because of the long front-end.
- There is no plastic deformation of any part of the front end.
- Because of the curvature of the front face to the side of the car, the probability of severe injuries for a pedestrian in an accident is reduced.

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Side Collision on RSV Minicars

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Two side-collisions between a Renault 20 and the vehicle made by CALSPAN were conducted in FRANCE in 1979 within the framework of the RSV programme.

The results were communicated at the last ESV Conference in PARIS (ref. 1).

The same type of tests have been conducted in 1980, with the target vehicle being this time the MINICARS'-designed RSV.

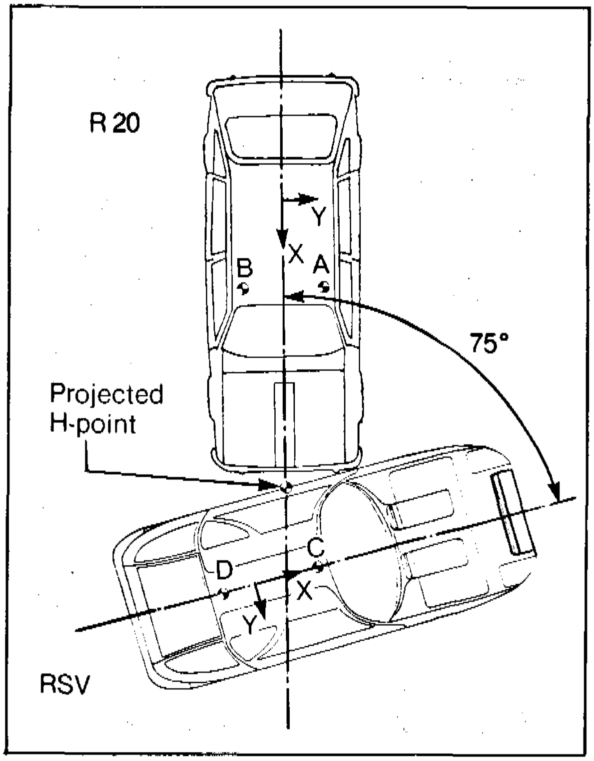
The results, analyses and conclusions of this programme are stated later and are compared with those obtained in identical collisions with a production vehicle, the Renault 30, which is similar in size and mass to both the above-mentioned RSV vehicles.

The test programme drawn up in accordance with the National Highway Traffic Safety Administration (NHTSA) provided for two collisions at different speeds. Both these tests were conducted by RENAULT at its LARDY technical centre.

The main points of the programme were as follows:

- Target vehicle: RSV (Research Safety Vehicle) developed by MINICARS by contract with NHTSA;
- Striking vehicle: RENAULT 20, model 1980;
- Point of impact: point R of front seat projected onto outer panel of target vehicle;
- Speed: the RSV was stationary, the RENAULT 20 was at 50 km/h for the first impact on left-hand side of RSV, and another R.20 at 65 km/h for the second test on the right-hand side of the same RSV;
- Trajectory: the R.20 trajectory formed an angle of 75° with the centreline of the RSV body (table 1);
- Occupants: 3 dummies fitted with instruments in the R.S.V. MINICARS—two in the front, one at the back on the impacted side, and two ballast dummies in the Renault 20.

Table 1. Vehicle orientation for Renault-20 TS into RSV, 75° left side impact test.



PREPARATION AND DESCRIPTION OF THE TWO TESTS

The preparation and test conditions were the same for each collision; only the impact velocity and, of course, the impacted side of the RSV were different.

In both cases (cf. photo 1) the RSV MINICARS was positioned above a wide, glass-covered pit permitting the structural behaviour to be filmed from underneath.

It was positioned in such a way that the centrelines of both the vehicles formed an angle of 75°, and the centreline of the R.20 passed through the projection of front point R on the R.S.V. door panel.

Only the R.S.V. hatchback was removed to facilitate the fitting of a camera inboard. As the side windows and the windscreen are glued to the structure, the other views of the dummy behaviour were taken through the windows.

With the in-board equipment and the three dummies, for each test the R.S.V. MINICARS weighed 1415 kg. The R.20 with two dummies weighed 1405 kg. In table 2, the breakdown is

Photo 1. RSV and R 20 positioned in the impact configuration.

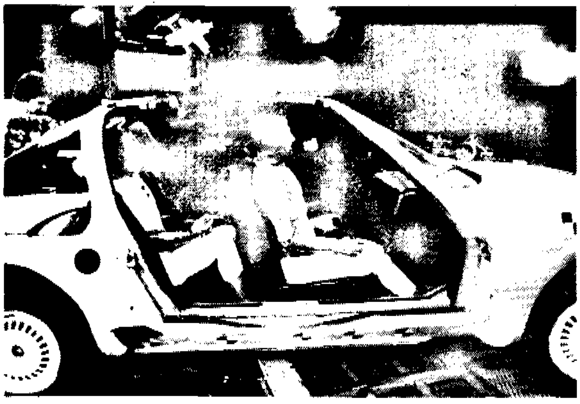
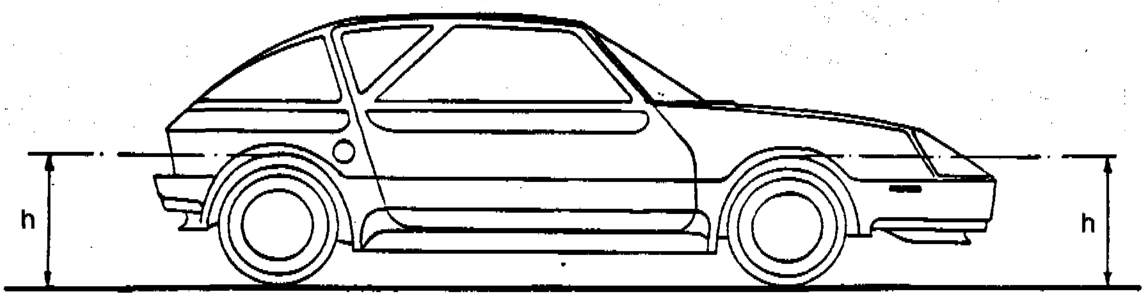


Photo 2. Passengers in RSV side impact test.

Table 2. Table of weight and attitude.



			Front	Rear	Total
Test 50 km/h	RSV	Weight (kg)	619	796	1415
		h right side	720	730	
		h left side	730	728	
	R 20	Weight (kg)	825	580	1405
		h right side	650	555	
		h left side	640	545	
Test 65 km/h	RSV	Weight	619	796	1415
		h right side	720	715	
		h left side	720	720	
	R 20	Weight	800	606	1406
		h right side	655	555	
		h left side	645	550	

shown of the masses as well as the vehicle attitude heights measured on centreline of front and rear wheels.

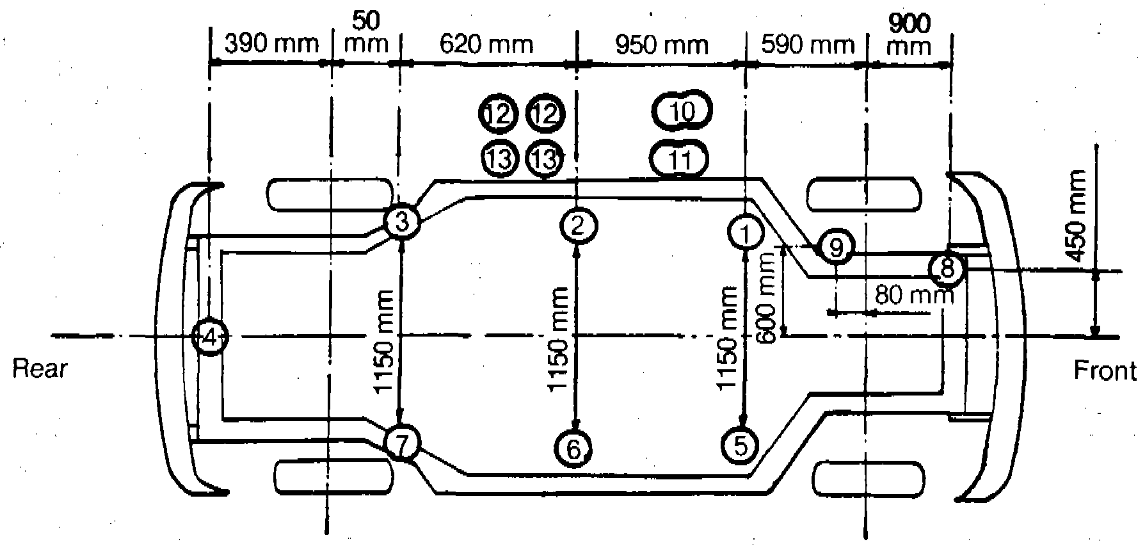
The two dummies in the Renault 20 were Hybrid II's, not fitted with instruments, acting as ballast. They were restrained by standard reel belts.

Three dummies fitted with instruments were positioned in the R.S.V. They were previously calibrated and verified in accordance with PART 572. They were fitted with triaxial accelerometers in the head, thorax and pelvis, and a load sensor in each femur. In order to prevent any failures, two transversal accelerometers were fitted in the thorax and pelvis.

Furthermore, several electrical switches were fitted to the shoulders and pelvis of the dummies in order to accurately determine the moment of impact.

Many accelerometers (table 3) were positioned in different points of the R.S.V. and Renault 20 structures, namely in the door on the impact side

Table 3. Table of sensor position for the struck vehicle.



No.	Description of location	X	Y	Z
1	Left A pillar	✓	✓	✓
2	Left B pillar		✓	
3	Left C pillar	✓	✓	✓
4	Rear cross member	✓	✓	✓
5	Right A pillar	✓	✓	
6	Right B pillar		✓	
7	Right C pillar	✓	✓	
8	Next to air bag sensor	✓	✓	
9	Next to rearmost crash sensor	✓	✓	
10	Left front door thorax level (2)		✓	
11	Left front door pelvis level (2)		✓	
12	Left rear door thorax level (2)		✓	
13	Left rear door pelvis level (2)		✓	

at pelvis and thorax levels of the dummies (table 4). By double integration, it is possible for the different phases of crushing in to be appreciated.

This point is interesting, for in this vehicle, side protection is provided to a great extent by the resistance to penetration afforded by a large door comprising metal compartments filled with foam. This door is supported by the rear pillar, the door sill and the front pillar. The door sills are solidly reinforced with large cross members which are located under the front and rear seats.

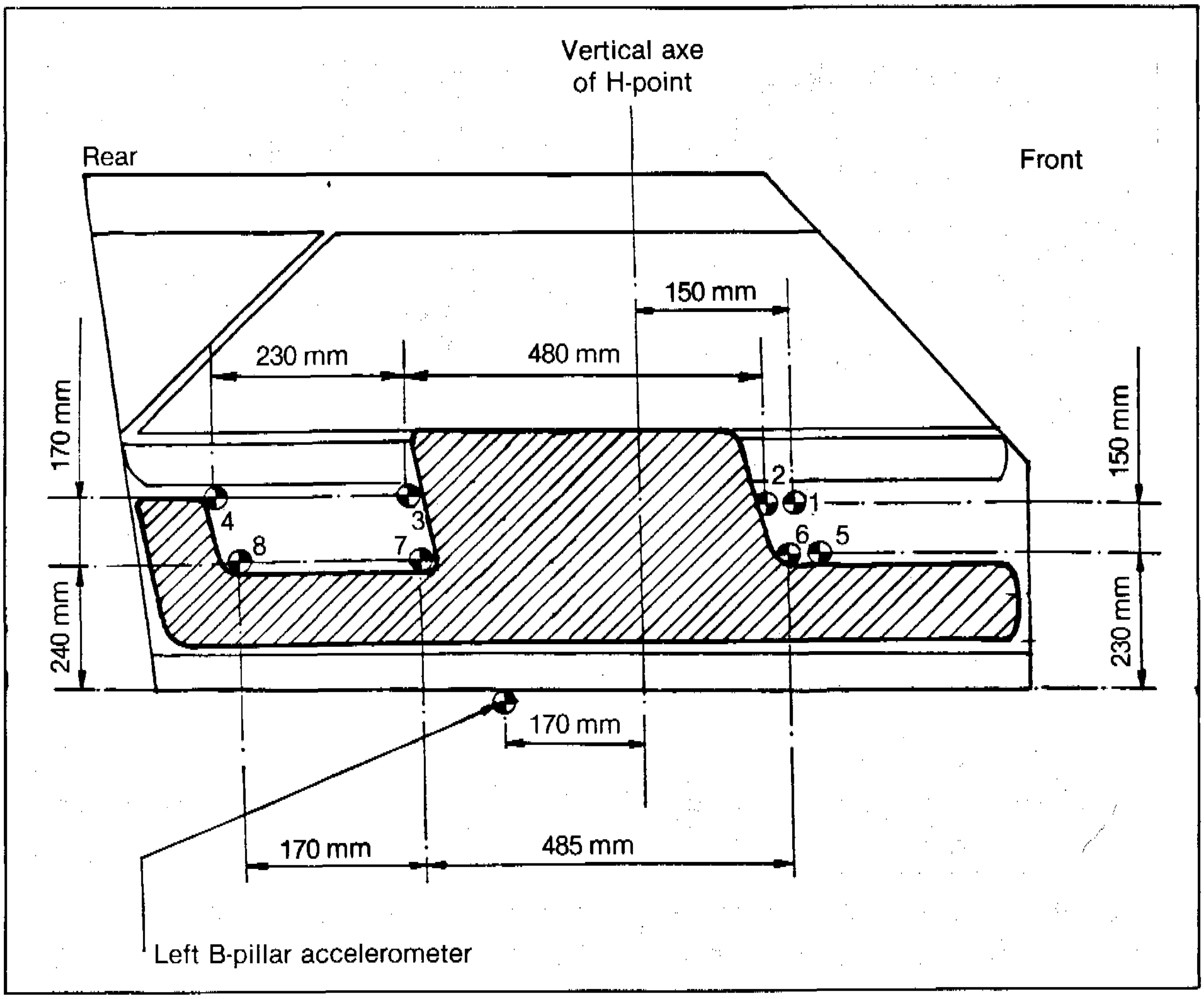
All these units use the same technique of hollow members filled with foam.

The doors are connected to the structure with three locks positioned on the front pillar, the door sill and the rear pillar.

For occupant safety, thick padding should be provided at thorax and pelvis level on the reinforced body side and door structure. It should consist of plastic-covered foam strengthened with glass fibres.

Although they are of less importance in this

Table 4. Position of the door accelerometer (RSV).



type of side collision, the other systems of protection are:

- for the driver: an inflatable, two-chamber bag in the steering wheel, and a foam-filled knee bar;
- for the passenger: an inflatable bag also with two chambers, and a foam-filled knee bar;
- for the rear passengers: three-point reel belts located on the parcel shelf.

The inflatable bag trigger system is checked prior to each test, and the ignition is switched on for the time the shot lasts.

Just before the collision, white powder is sprinkled on the different parts of the vehicle that the dummies are liable to contact, such as padding, instrument panel, etc. This method enables the dummy impact points to be accurately located.

The same powder applied to the belts enables belt movement during the collision to be known.

Results of the Test at 50 KM/H (table 5)

The actual impact speed of the RENAULT 20 was 50.4 km/h. Trajectory precision was excellent as testified by the marks on the ground and examining the film.

The two vehicles came to rest locked together at 4.5 m from the point of impact (photo 3). At the end of the crushing phase (83 ms) both vehicles had a common velocity of 7 m/s; the change in transversal velocity of the R.S.V. was identical to the change in longitudinal velocity of the Renault 20.

Table 5. Summary of two collision test.

R 20 against R.S.V.
R 20 against R 30
Velocity 50.4 km/h

Parameter	Crash R 20-R.S.V.		Crash R 20-R 30	
	R 20	R.S.V.	R 20	R 30
Test weight (kg)	1405	1415	1495	1570
Impact velocity (km/h)	50.4	0	50.7	0
(m/s)	14	0	14.08	0
Final velocity (m/s)	6	8	5.5	6.5
Velocity change (m/s)	8	8	8.58	6.5
Initial kinetic energy (kJ)	137.7	0	148.2	0
Energy dissipated (kJ)	69.1		75.9	
Max. compartment acceleration (g)	15	15	13	14
Max. compartment intrusion (mm)	300	240	315	440

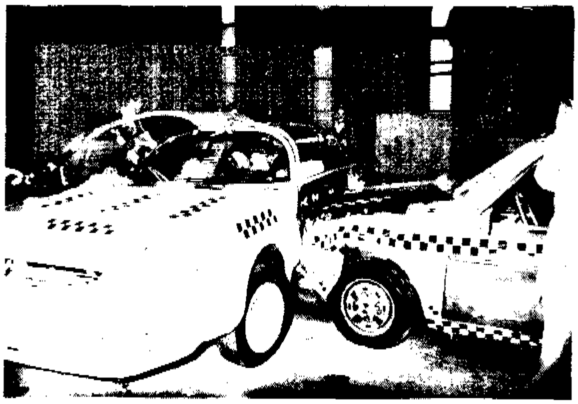


Photo 3. Post test RSV and R 20 vehicle.

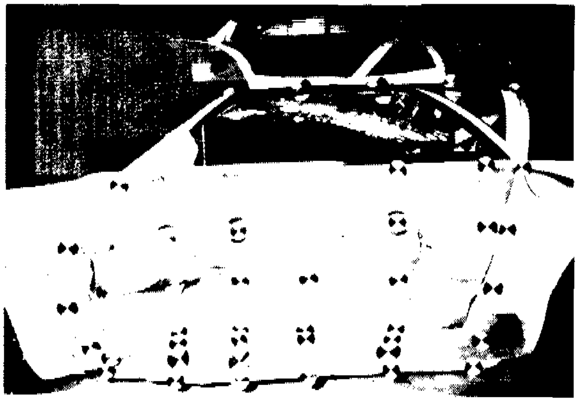


Photo 4. Test at 50.4 km/h — lateral view of RSV minicars.

Examination of the Renault 20

No impact of the occupants of the R.20 with the internal or external parts of the vehicle was observed.

Maximum deformation of the R.20 on the structure was 300 mm; furthermore, the bonnet was unlocked, the windscreen stayed in position and the four doors could be opened after the collision.

Examination of the RSV Minicars' Structure

The aspect of the vehicle was generally satisfactory. Maximum intrusion recorded after the collision was 240 mm and 200 mm at point R (photo 4). The left-hand door suffered most from the collision, but the locking points withstood the collision perfectly. The side window was split.

The door sill tended to pivot inwards. A slight bend was formed at the junction between the rear seat cross-member and the door sill.

Protection of RSV Occupants (Tables 6–7)

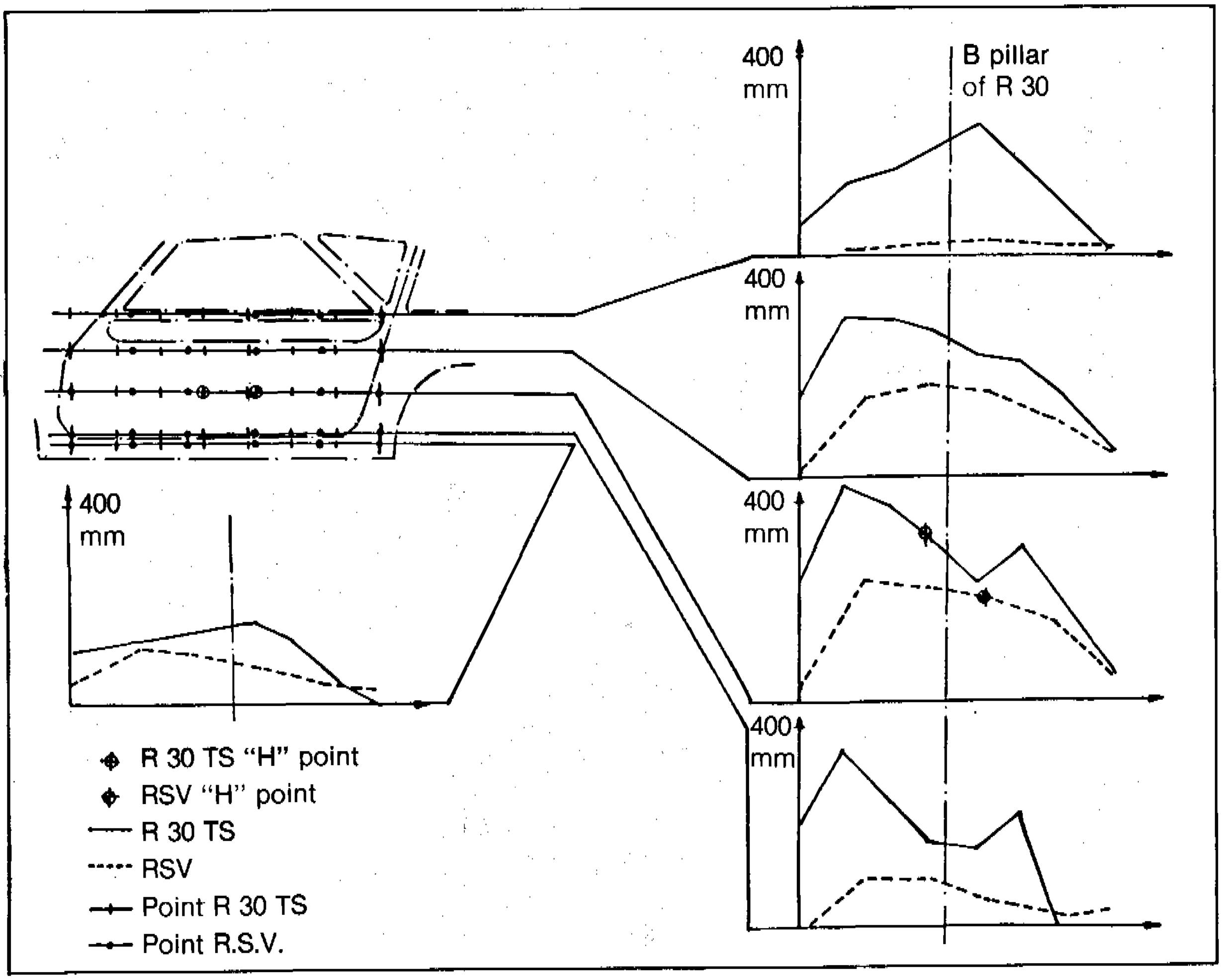
The air bags were not used in this collision. (Photos 5–6)

The driver, seated on the impact side, remained still up to the moment the door padding hit his arm at thorax level and the pelvis (26 ms). Although the head did start moving towards the door, there was no impact.

Pelvis acceleration over 3 ms was 28 g with a maximum of 42 g (55 ms).

Thoracic acceleration over 3 ms was 37 g with a maximum of 51 g probably due to the stiffness of the fibre-glass padding skin prior to breaking.

Table 6. R 30 and RSV impacted side deformation. v = 50.4 km/h



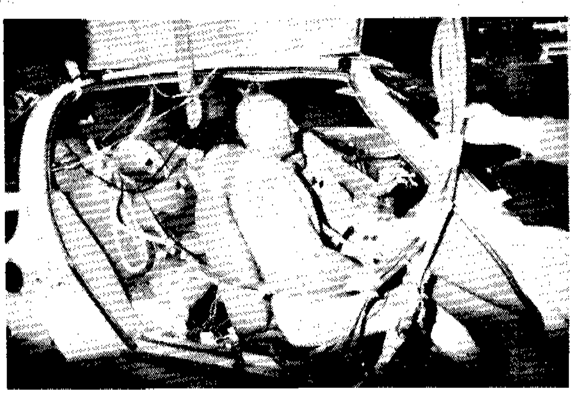


Photo 5. Test at 50.4 km/h – passengers in RSV.

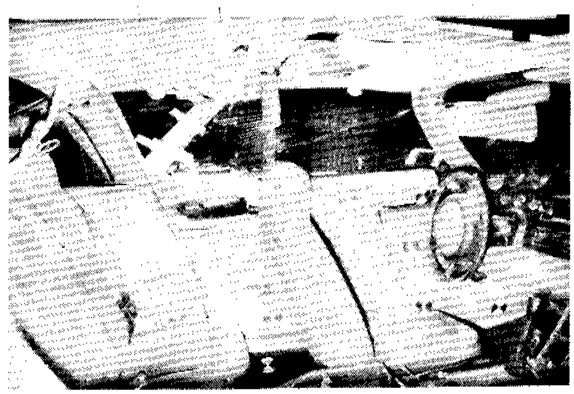


Photo 6. Test at 50.4 km/h – compartment intrusion in RSV.

Another peak of 31.5 g with an opposite sign was the impact between passengers in the front seats (70 ms).

The front passenger struck the driver mainly on the shoulder with a maximum of 44 g. Pelvis contact was light with maximum acceleration of

Table 7. Dummy responses in two collision tests.

R20 against R30
R20 against R.S.V.
Velocity 50.4 km/h

Dummy Responses		Pelvis				Thorax				Head		
		γmax res.	$\gamma 3ms$ res.	SI	ΔV trans.	γmax res.	$\gamma 3ms$ res.	SI	ΔV trans.	γmax res.	SI	HIC
Impacted side (driver)	R.S.V.	42	28	78	7.23 m/s	51	37	146	8.12 m/s	24	62	46
	R30	129	96	1089		94	76	471		190	879	440
Opposite side (front passenger)	R.S.V.	15	15	39	9.84 m/s	44	41	78	6.87 m/s	29	71	57
	R30	34	32	80		51	43	72		182	436	334
Impacted side (rear left passenger)	R.S.V.	41	38	120	8.88 m/s	48	46	127	9.45 m/s	25	54	42
	R30	55	53	236		50	47	139		55	173	116

15 g. Impacting the driver deflected the passenger trajectory upwards; passenger head contact with the roof did not however exceed 29 g.

Rear passenger thorax and head remained motionless up to time the left arm came into contact with the padding (32 ms). Thorax acceleration was 46 g over 3 ms; pelvis acceleration was 38 g. No head impact was recorded.

Test Results At 65 KM/H (Table 8)

Impact speed of the RENAULT 20 was 65.3 km/h. Test conditions were the same as those for the previous crash.

The two vehicles came to rest at a distance of 8.5 m from the point of impact. At the end of the crushing phase (82 ms), both vehicles had a common velocity of 9 m/s. (Photo 7)

Examination of the Renault 20

No impact of occupants in the R.20 was recorded. (Photo 8)

Maximum vehicle deformation was 390 mm. As in the previous test, the windscreen stayed in position and the four doors could be opened normally after the collision.

Examination of the RSV Minicars Structure

Vehicle aspect was satisfactory. Maximum intrusion was 350 mm at projection of point R. (Photo 9)

The right-hand door sustained the whole collision.

It made the rear pillar pivot inwards (240 mm of crushing at rear point R) as well as the door

Table 8. Summary of two collision test.

R 20 against R.S.V.
R 20 against R 30
Velocity 65.3 km/h

Parameter	Crash R 20-R.S.V.		Crash R 20–R 30	
	R 20	R.S.V.	R 20	R 30
Test weight (kg)	1405	1415	1405	1510
Impact velocity (km/h)	65.3	0	64.4	0
(m/s)	18.13	0	17.94	0
Final velocity (m/s)	10.33	9.5	7.5	9
Velocity change (m/s)	7.8	9.5	10.44	9
Initial kinetic energy (kJ)	231	0	226	0
Energy dissipated (kJ)	124.6		125.4	
Max. compartment acceleration (g)	22	28	25	31
Max. compartment intrusion (mm)	390	350	480	240

sill (210 mm of crushing maximum). The front pillar was hardly touched (30 mm of deformation) because of the lock being pulled out of the door (Photo 10). The side window was broken.

The windscreen remained intact. The left-hand wheel had its fixing studs pulled out due to its sliding sideways. The under-seat cross-members were crushed locally at their junction with the door sill.

Protection of RSV Occupants (Tables 9–10)

As with the previous collision, the air bags were not used.

The front passenger seated on the impact side remained still up to the time the door padding hit the pelvis (70 g maximum at 11 ms) and the arm (44 g maximum at 16 ms). Due to inertia, the head started rotating towards the door.

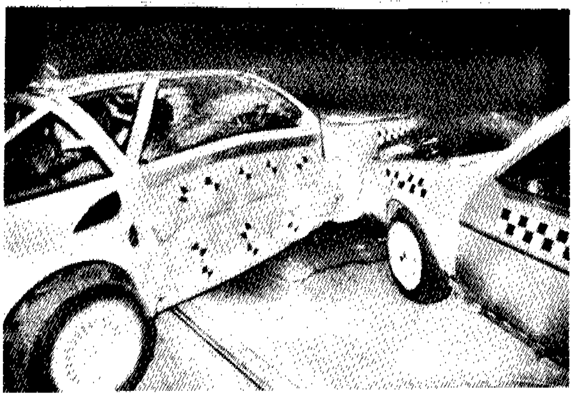


Photo 7. Post test at 65.3 km/h — RSV and R 20 vehicle.

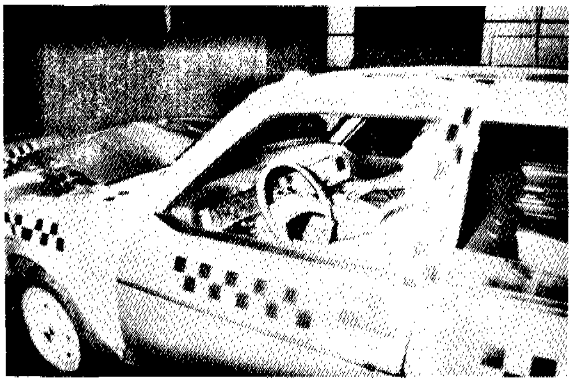


Photo 8. Post test view — front passengers in R 20.

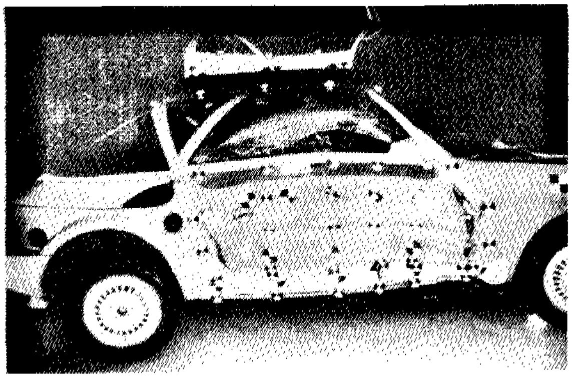


Photo 9. Test at 65.3 km/h — lateral view of RSV minicars.

The kinematics of the passenger were further affected by impacting the driver (61 ms), thus leading to another peak of 60 g on the thorax deceleration curve, 70 g on the pelvis curve, and a head-window impact (36 g maximum at 79 ms).

Table 9. R 30 and RSV impacted side deformation. v = 65.3 km/h.

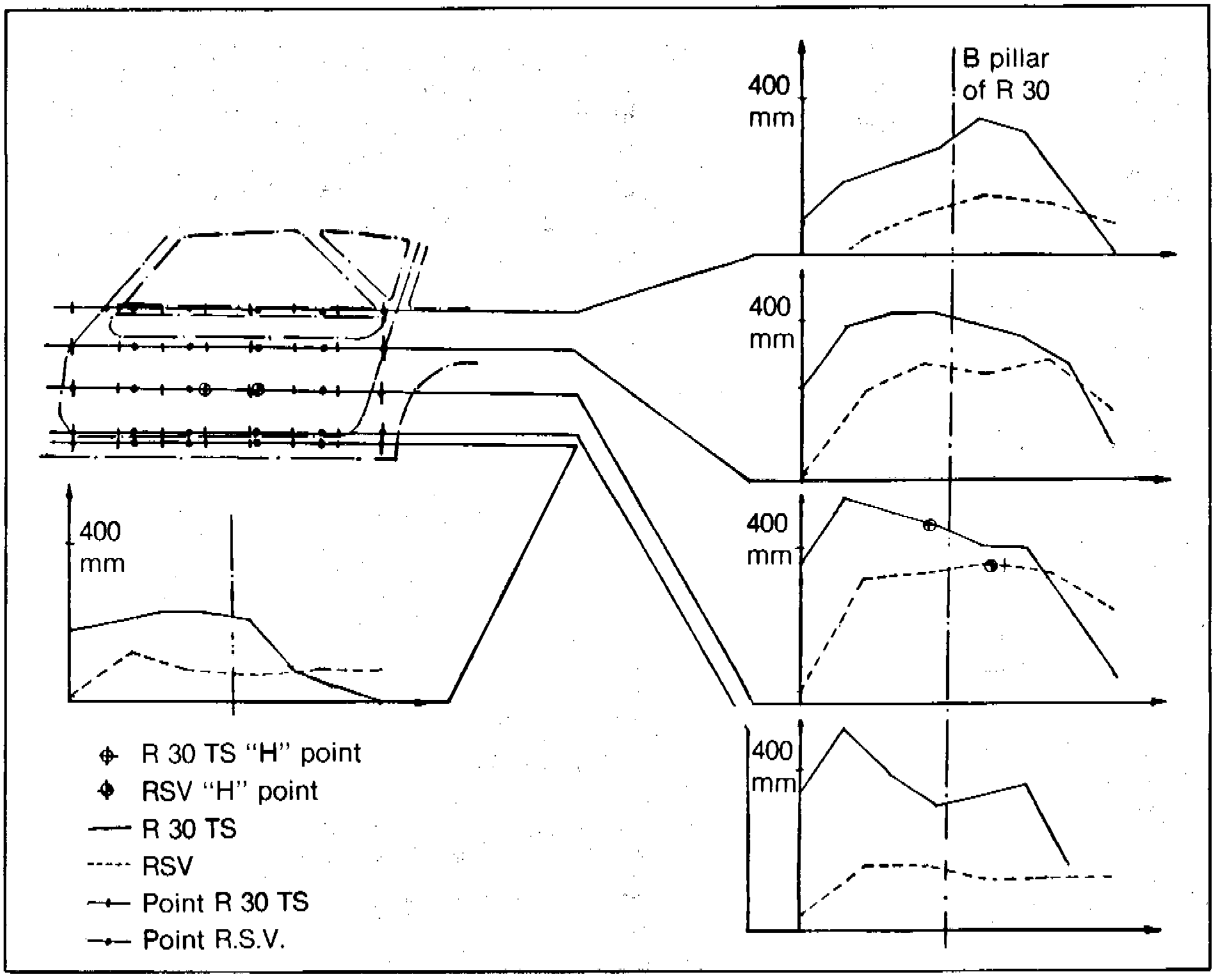


Photo 10. Test at 65.3 km/h — front lock of RSV.

As far as the driver is concerned, contact with the passenger caused a maximum deceleration of 42 g on the pelvis, 84 g on the thorax, and indirectly 52 g on the head when it struck the roof.

The rear dummy restrained by a 3-point belt was impacted on the arm by the padding (83 g maximum at 33 ms), and on the pelvis (85 g maximum at 41 ms).

Impacting the arm caused the head to rotate and strike the upright of the rear bow.

DISCUSSION

The above-stated results can be compared with those obtained with a production vehicle tested in the same collision conditions. This was a Renault 30 struck on the side by a Renault 20 at 50 and 65 km/h.

The values recorded in the tables show that the deformations of the side structures were lower by about 130 mm in the case of the RSV (collision at 50 km/h).

There was also a difference of 100 mm in the 65 km/h collision. Furthermore, the shape of the deformation was considerably different.

Table 10. Dummy responses in two collision tests.

R20 against R30
R20 against R.S.V.
Velocity 65.3 km/h

Dummy Responses		Pelvis				Thorax				Head		
		γmax res.	γ3ms res.	SI	ΔV trans.	γmax res.	γ3ms res.	SI	ΔV trans.	γmax res.	SI	HIC
Impacted side	R.S.V. (front passenger)	70	65	479	11.42 m/s	44	42	432	11.47 m/s	45	222	172
	R30 (driver)	246	150	3102	14.5 m/s	75	64	588	12 m/s	76	529	338
Opposite side	R.S.V. (driver)	42	38	185	10.04 m/s	84	68	325	8.84 m/s	52	282	175
	R30 (front passenger)	137	120	1088	10 m/s	63	51	239	10 m/s	87	332	231
Impacted side	R.S.V. (rear passenger)	85	72	538	11.52 m/s	83	76	418	10.24 m/s	57	388	310
	R30 (rear passenger)	233	220	4266	19 m/s	65	60	232	8 m/s	222	5123	3508

These differences in behaviour were due mainly to:

- no similarity between the vehicle structures (2 doors for the RSV-4 for the R.30);
- the difference in height of the rigid units of the target vehicle's side with relation to the front end of the striking vehicle.

However the main point in the comparison are the values measured on the dummies positioned on collision side. The uncertain trajectories of the occupants positioned on the opposite side do not allow valid conclusions to be drawn.

As far as the front occupants are concerned, the largest saving was obtained on the pelvis. At 65 km/h 246 g were recorded at this point (150 g/3 ms, SI = 3102) for the R.30, compared with 70 g (65 g/3 ms, SI = 479) for the RSV.

The experimental vehicle and the production vehicle however differ much less from each other when it is a question of values recorded on the thorax (centre of frequent serious injury in real side collisions). This body area is not located in line with the stiff parts of the striking vehicle's front end, and it is probable that the deformability of the upper part of the production vehicle door behaves, in this case, in a similar manner to the padding used in the RSV.

Furthermore, the bad representativeness of the arm-shoulder-thorax assembly in the HYBRID II dummy considerably limits the benefit of measuring at this level.

However, the positive facet of the padding thickness can be seen in the case of the RSV which tends to minimize and even annul the head impact on the side sections of the roof.

In this case once again, the lack of realism in sideways tilting of dummy head-thorax did not enable the above-mentioned potential advantage to be totally appreciated.

The results obtained for the rear passenger do not highlight any important differences in the first collision at 50 km/h. The values recorded at 65 km/hr should be compared in order to see the improvements afforded by the RSV design. In this case once again, there is a considerable improvement for the pelvis, no or a few differences for the thorax, and less risk of head impact.

CONCLUSIONS

The results of the experimental collisions analysed above highlight the improvement brought about in this type of impact by the RSV MINICARS. Moreover, they confirm the conclusions previously obtained in tests conducted in the same conditions on the CALSPAN-made RSV.

The strengthening of the body side and, to some extent, the change in height of these strong units, together with the fitting of padding of suitable stiffness enable the values recorded on the occupants' pelvis on the collision side to be notably reduced.

The improvements are less perceptible for the thorax, but as the HYBRID II dummy is not representative, no valid conclusion can be made in this case.

Finally, it is clear that the strength of the padding units to be provided in the vehicle can be effectively determined only when the difficulty relating to the dummy has been removed.

The High Technology Research Safety Vehicle

JEROME M. KOSSAR
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ABSTRACT

This effort has provided a five speed automatic transmission which eliminates fluid coupling losses of conventional automatics and offers the fuel economy benefits of a manual five speed transmission. It incorporates a cruise control which offers conventional set speed control, but additionally provides a button which will automatically accelerate the car through its gear shifts to 55 mph and then maintain that speed. Further, under cruise control it will automatically reduce throttle on the RSV in attempt to maintain a safe headway clearance should the traveling lane become blocked by a slower moving vehicle. The same radar system that detects vehicles ahead to slow the RSV will also apply severe braking to reduce crash speed should an accident no longer be avoidable. The vehicle also provides adaptive braking to the four wheel disk brakes to avoid loss of control from wheel lockup. A top of the dash mounted driver information display replaces conventional dials and meters with a digital and analogue system which, in addition to normal car status information, will provide emergency messages should a hazard be detected by any of the sensors with which the RSV is equipped. All of these features are the result of current technology applications. The systems employed require further development, then miniaturization and production engineering, but their functional feasibility has now been demonstrated.

INTRODUCTION

This effort employs the RSV to demonstrate the feasibility of advanced state-of-the-art electronics to provide additional utility, convenience, safety and fuel economy. The basic RSV, of itself, has been demonstrated to provide exceptional crash protection to its four occupants in the various modes of crash common to real life accidents. This crash protection has been accomplished in the basic RSV weighing 2560 pounds (1161 kg) and providing an urban mileage of 28.9 mpg (12.3 km/L), and highway mileage of 41.2 mpg (17.5 km/L) when tested using EPA dynamometer test procedures on a low mileage RSV employing a 1980 1.5 liter Honda engine and Michelin tires. The combined city/highway mileage is, therefore, 33.4 mpg (14.2 km/L). The emissions measured in this low mileage vehicle satisfy U.S. statutory requirements of 1981, if the assumption is made that they are representative of 50,000 mile performance.

The High Technology RSV, as seen in Figure 1, incorporates experimental systems developed under contract with the National Highway Traffic Safety Administration of the U.S. Department of Transportation. These systems include an RCA developed on-board radar system, seen in Figure 2, with associated microprocessors to provide interpretation and command to other systems, and a high mounted digital and analogue driver information display, seen in Figure 3. To provide an automatic transmission, Minicars, Inc., has modified the shifting mechanisms of a Honda manual five speed transmission, eliminating the foot pedal for clutch operation, and providing solenoid value operation of pneumatic cylinders, to automate shifting into the five forward gears, neutral and reverse. Dubner Computer Systems, Inc., has developed the microcomputer system and software which directs automatic gear shifts and provides a cruise control logic and function. It also utilizes range information from the on-board radar to provide automatic throttle cut back, slowing the RSV to provide safe clearance when following another vehicle traveling at a speed below that set by the RSV driver on the automatic cruise control. In Figure 4 the cruise control stalk is seen and Figure 5 shows the automatic transmission drive selector. The Bendix Automotive Control Systems Group has adapted an experimental anti-skid brake system to function with the four wheel disk

Figure 1. The high technology RSV

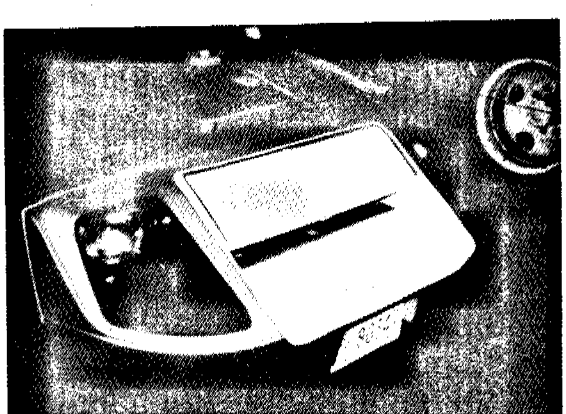
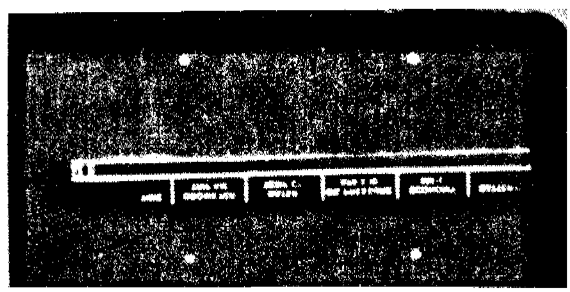
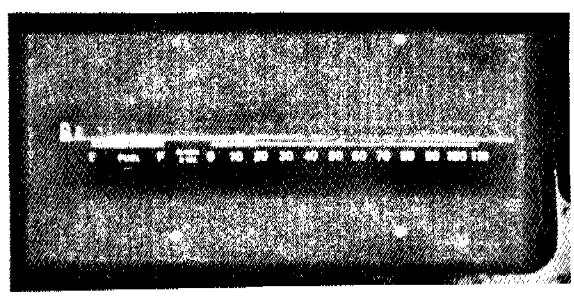


Figure 2. The radome for on-board radar

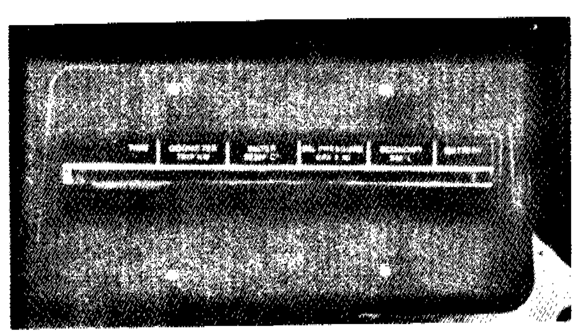
Figure 3. The driver information display



Digital information display



Analogue information display



Typical emergency message on information display

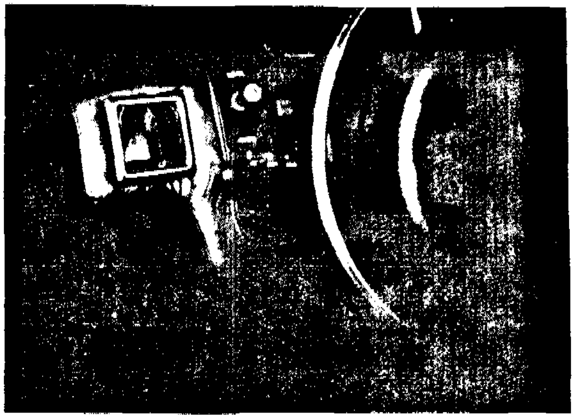


Figure 4. Control stalk for cruise control.

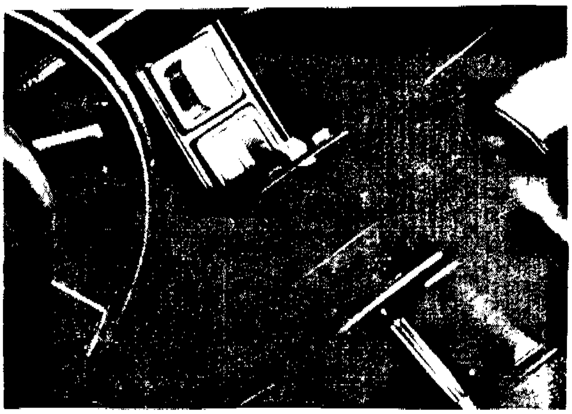


Figure 5. Automatic transmission reverse, neutral and drive selection buttons.

brakes of the RSV. Minicars, Inc., then introduced an additional high pressure brake fluid accumulator and associated solenoid valves to automatically activate the brakes upon command from the RCA crash mitigation system (CMS) microprocessor. The CMS microprocessor utilizes range and range rate information from the radar in its decision to command automatic severe brake application.

The marriage of these experimental systems into the RSV has demonstrated the feasibility of current electronic technology to provide significant advances in car safety, utility, convenience and fuel economy. Each of the systems employed is experimental and requires additional development before miniaturization and production design can be accomplished. It is hoped that the success of this feasibility demonstration program will encourage industry to continue development of systems such as these to enhance the performance of future cars.

The following sections will provide further description of the High Technology RSV advanced systems.

Automatically Shifted Five Speed Transmission

Conventional automatic transmissions have provided drivers with a reliable convenience commonly available as a new car option at time of purchase. Their popularity has been universal, having been provided in 89 percent of 1979 U.S. car models. There are, however, some inherent power transfer inefficiencies in common automatic transmissions. Sources for these inefficiencies are torque converter viscous friction losses, hydraulic pumping losses and band and seal friction losses. Transmission speed ratio is an important variable in vehicle fuel economy. Ideally gear ratios should be selected to optimize engine efficiency as a function of load and car speed. The lower number of gear ratios provided in older automatic designs, therefore, further restricted achievement of fuel economy. Recent technical advances in automatic transmissions have reduced some of the above inefficiencies and the advent of infinitely variable transmissions, with further development, portends significant fuel economy improvement.

The purpose of this automatic transmission effort is to provide the driver with the convenience of an automatic and the fuel economy achievable from a five-speed manual. We demonstrate the feasibility of utilizing available electronic technology to gain improvement in fuel economy without denying the driver's freedom to obtain the varying engine power outputs dictated by driving situations. In this system the driver perceived power requirement is provided by the degree to which the accelerator pedal is depressed. The automation utilizes a micro computer and closed loop servo systems with pneumatic actuators.

A five-speed transmission with conventional clutch has been modified to operate automatically under computer control. The computer is programmed to identify gear shift points providing best fuel economy consistent with the five discrete forward speed transmission gear ratios available, the car speed and the driver's power level demand. The transmission is designed to be operated like an automatic, there is no clutch pedal or manual shift lever. To start the car moving, the driver depresses the accelerator to the degree commensurate with the acceleration desired. The computer selects first gear; the clutch release pneumatic actuator is energized by a solenoid value thereby disengaging the clutch; the gear selector pneumatic cylinders are activated engaging first gear; the clutch engagement commences. Clutch engagement pressure is regulated by engine speed and accelerator pedal position. At small accelerator depressions the computer regulates engine speed to a low value by throttle control and by clutch engagement loading. At larger accelerator depressions the computer regulated engine speed is higher. If the actual engine speed becomes less than the computer demand during the clutch engagement, the clutch is allowed more slip by increasing the clutch release actuator pressure. Conversely, if the engine speed is too great the clutch engagement is increased by faster venting of the clutch release actuator. To prevent stalls and excessive clutch plate wear, the computer determines and controls engine acceleration during clutch engagement. High engine acceleration, even when engine rpm is below computer demand, will cause an increase in clutch engagement load. A high engine deceleration will cause clutch release to prevent stall. Once clutch lockup is sensed, the clutch release actuator is fully vented.

The first gear algorithm, therefore, attempts to keep the engine speed constant, at the value selected from accelerator pedal depression, by controlling the clutch. Third, fourth and fifth gear engagement is controlled by a second algorithm in the computer software. The high gear algorithm uses the computer to control the throttle plate to attempt to match engine rpm to ground speed while the clutch is engaged by the computer at a rate determined by the error between rmp's and ground speed—the larger the error, the slower the rate of clutch engagement. The algorithm for the second gear shift is a hybrid of the first gear and high gear algorithms. The high gear throttle algorithm is employed to match engine speed to ground speed and the first gear algorithm attempts to keep engine speed constant through clutch pressure modulation during engagement.

Two subroutines are present in the computer software to override normal shift routine under special conditions. When the computer attempts to match engine speed to ground speed during a shift sequence, the throttle opening percentage is not permitted to exceed the accelerator pedal depression percentage. This rule prevents the engine rpm algorithm from powering the car when the driver's foot is off the accelerator as might occur when the car is being intentionally decelerated by motor drag. In order to avoid engine lugging during brake application another computer routine will disengage the clutch when the engine speed slows to less than 1200 rpm.

The automatic transmission computer also provides an effective cruise control. The cruise control can be activated by buttons on the end of the directional signal stalk after car speed exceeds five mph (8 km/hr). The "SET CRUISE" button will maintain car speed existing when this button is pressed. The "SET 55" button will accelerate the car and produce automatic shifting to attain a 55 mph (88.5 km/hr) road speed and will then maintain that maximum U.S. legal car speed. The "RESUME" button will return the car to cruise control at the last speed entered by the "SET CRUISE" button even if the "SET 55" button had been employed since having entered a speed on the "SET CRUISE." The cruise set speed may be exceeded by the driver at any time by depression of the accelerator pedal. Driver brake application will immediately return the car speed to accelerator pedal control.

When the vehicle is in the cruise control mode the transmission computer receives the range output information from the on-board radar which is aimed along the lane of traffic directly ahead. When the vehicle is in a cruise control mode and either overtakes a car in its traveling lane, or a car ahead cuts into the traveling lane, the computer will automatically reduce the throttle and will thereby attempt to maintain a safe following distance. The RSV will then automatically further adjust throttle opening should the car ahead speed up or slow down. Should throttle adjustment be insufficient to decelerate the RSV adequately for maintaining the calculated safe clearance, as might be the case following down a hill, the driver must apply the brakes. Although a brake closed loop servo system could be added to the headway control function in the future, it has not been implemented in this program. When the RSV travel lane is cleared by lane change of either the RSV or the car ahead, or by speed up of the lead car to velocity higher than the cruise control set speed, the RSV will automatically again attain and maintain its set speed.

The headway clearance algorithn calculates safe clearance to be 2.2 feet per mile per hour (0.42 m/km/hr) traveling speed and the RSV throttle close down occurs when the range of the car ahead is 1.1 times the calculated safe distance.

On-Board Radar System

The radar installed in the High Technology RSV was designed at the Microwave Technology Center of RCA Laboratories, Princeton, New Jersey. The radar is a frequency modulated continuous wave system (FM/CW) employing separate flat, printed circuit, phased array, antennas to transmit and receive. The carrier frequency is 17.5 GH_z with a deviation frequency of $\pm$ 50 MH_z, and power output is 10mW. The two radar antennas are mounted side by side in one assembly located behind the attachment plane of the RSV front fascia. The dimensions of this bistatic antenna assembly are 30.3 in. $\times$ 8.0 in. $\times$ 1.0 in. (77 cm $\times$ 20.5 cm $\times$ 2.5 cm). Horizontal antenna beam width is 3° and vertical beam width is 5° as defined by the 3-db points of the antenna gain pattern.

The radar serves two functions in the RSV. It provides range information to the Dubner Computer Systems developed micro-computer controlling the automatic transmission and "smart" cruise control which provides automatic safe headway control for the RSV. In this function the radar range is 23 ft. to 164 ft. (7 m to 50 m). The radar also feeds range and range rate information to the RCA microprocessor controlling activation of the Crash Mitigation System (CMS) which automatically applies the RSV brakes to reduce impact speed in the event of an unavoidable frontal collision. In the CMS function the radar range is 23 ft. to 98 ft. (7 m to 30 m). The shorter radar range employed for the crash mitigation brake function was selected on the basis of assured elimination of false alarms in consideration of the increased hazard of being struck in the rear by a following car in the event of unwarranted extreme braking caused by a false alarm from the radar. The beam pattern of the radar is tapered and, therefore, is narrower at closer range, thereby reducing the possibility of the radar return being from objects not actually in the RSV travel path.

The aspect of avoiding automatic brake application caused by radar false alarms was given much attention during system development. An effective technique for developing algorithms eliminating radar false alarms was developed. A video camera and recorder was employed in the radar vehicle which recorded actual roadway situations while simultaneous recordings were made of the beat frequency return from the radar along with speed and steering information. By use of this recording system a tape of a variety of traffic situations was acquired. Playback of the recording system through the microprocessor would thus give perfect repetition of events. Hardware and software changes could be made in the signal processor and microprocessor and the effect of these changes could reproducibly be observed when the tapes were played back. The use of this recording system greatly helped in the systematic evaluation and optimization of the radar system. Changes in the crash mitigation software to eliminate a radar false alarm resulting from any particular source would then be tried on reruns of all the tapes to ensure that the correction did not destroy the sensitivity of the system.

In view of growing concerns with nonionizing radiation effects, the microwave power radiated from the radar was investigated theoretically, as well as by measurement. This Ku-band radar emits a power of 10 mW. In the far field of the antenna, the power density decreases inversely with the square of the distance from the antenna. Near field, or the Fresnel region of the antenna is a more complex region where the field pattern undergoes various spatial maxima and minima due to interference in the near field. The maximum power density has been calculated to be 20 micro Watts per square centimeter occurring at a distance of 23.6 inches (0.6 m) from the antenna. Actual measurements have indicated a maximum power density of 15 micro Watts per square centimeter which occurs at 39.4 inches

(1 m) from the antenna. The measurements are not considered very accurate since the presence of the measuring wave guide antenna used distorts the existing field pattern, however, a good order of magnitude is provided.

At present, the U.S. microwave radiation limit is $10 mW/cm^2$, which is based on the onset of thermal effects in the human body. The Soviet Union, on the other extreme, maintains a limit for continuous exposure as low as $10 \, uW/cm^2$ to avoid possible neurological and physiological effects. Substantial controversy exists as to where a realistic safe limit should be drawn. In any case, radiation from this radar is very low and for distances above a few meters is even below Russia's very stringent standards. Although not presently implemented, a simple solid state switch could be introduced to prohibit radar function below a set low speed which would further reduce the radiation exposure of humans in actual traffic situations.

Driver Information Display

The High Technology RSV provides the driver with a high mounted computer controlled display of car operating conditions and information concerning malfunctions or safety hazards. Its location above the dash board requires only minimal diversion of the driver's eyes from the roadway ahead for observation and its viewing angle may be driver adjusted to accommodate seating height.

By switch selection, the driver of the RSV has a choice of two normal modes of information display with respect to the performance of the car. In one mode, fuel level and speed are shown by analogue bars whose lengths are proportioned to magnitude of actual value read on an illuminated scale below. In that same mode, engine rpm is digitally displayed in multiples of 100. The second mode which the driver may select by switch presents digitally displayed time, trip mileage, coolant temperature, oil pressure, present fuel economy and status of battery charging.

If one of the sensors detects a malfunction, the normal display mode is interrupted by an emergency message. The message interrupts the normal display every 30 seconds until the malfunction is corrected. Emergency messages may be "service brake on," "door open," "restraint system out," "anti skid out," "brake fluid low," "oil pressure low," "water temperature high," "hazard" and if radar indicates dangerous headway clearance, "radar warn—slow down."

Adaptive Braking And Crash Mitigation System

The High Technology RSV employs the 4-wheel disk brake system of the Fiat X-1/9 vehicle with an adaptive brake system designed by the Bendix Automotive Control Systems Group. The adaptive brake system prevents wheel lockup during severe braking and thereby increases directional control of the vehicle and on slippery road surfaces reduces required stopping distance. This brake system has been adapted by Minicars to be automatically activated by signal from the RCA radar system when collision is no longer avoidable. The braking will not prevent collision, but will reduce the impact speed and, thereby, the collision severity.

Adaptive Braking

The adaptive braking system employs four reluctor wheel speed sensors, each independently picking signals from teeth cut on the outside diameter of the brake rotor on each wheel. Each wheel speed sensor is wired to the electronic control unit which converts the alternating voltage from the sensors to individual wheel speeds. When the brakes are heavily applied the electronic control unit determines the rate at which each wheel is decelerating. If the rate of deceleration of either front wheel is great enough to produce excessive wheel slippage or wheel lockup, the electronic control unit sends commands to the pressure modulator controlling that wheel's brake caliper pressure. The pressure modulator closes the fluid path from the master cylinder by energizing an isolation valve and opens a pressure decay valve. As the caliper pressure decreases the wheel speed stops decreasing and starts to increase back toward vehicle speed. The electronic control unit then de-energizes the decay valve and the still energized isolation valve then provides the caliper with pressurized fluid from a pressurized accumulator through a regulator at master cylinder pressure. This cycle of brake caliper pressure will repeat until lockup is no longer threatened or the car speed is reduced below 5 mph (8 km/hr), where wheel speed resolution is no longer possible. Since both rear wheel brakes are controlled thru a single pressure modulator imminent lockup of either rear wheel will cause brake pressure modulation to occur on both rear wheels simultaneously. A pump which is part of the adaptive brake system replenishes the front brake and rear brake accumulators when their pressures drop below 1500 psi pressure.

Crash Mitigation System

The crash mitigation system employs the radar and Crash Mitigation System (CMS) microprocessor units developed by RCA to signal release of pressurized hydraulic brake fluid from an accumulator, added by Minicars, to the vehicle front and rear brake lines. Accumulator backflow to the master cylinder is prevented by solenoid operated check valves. Programming of the RCA system prevents this automatic braking from occurring until crash avoidance is no longer possible or if the driver is taking evasive action. When the brakes are automatically applied, the crash will normally not be avoided, but its severity will be reduced. This logic provides assurance that automatic braking will not interfere with the guidance of the most potent microprocessor aboard the vehicle, the driver's brain. It also reduces probability of false alarms from the radar, thereby reducing possibility of needless severe braking, which in itself, may subject the vehicle to the hazard of being struck from the rear by a following vehicle.

The programming of the Crash Mitigation System microprocessor is such that automatic braking will occur only when four conditions are each satisfied. The first condition requires that the RSV speed be greater than 22.4 mph (10 m/sec) and the second condition requires that the closing speed between the RSV and radar detected threatening target be greater than 35 mph (16 m/sec). These two conditions prevent automatic braking unless a crash of significant severity, threatening vehicle occupants, will otherwise occur. The threat of rear impact by a following car, common at low speeds in an urban environment, is therefore reduced.

The third condition requires that the driver is not already applying brakes and that the front wheels are turned no more than 1½ degrees. This prevents the severe automatic braking from interfering with a crash avoidance strategy already implemented by the driver. The 1½ degree wheel limitation serves also as a radar false alarm prevention, since at wheel angles greater than this, in turns, targets which are not on the path to be traveled by the RSV could appear to be so because of the orientation of the RSV axis relative to its travel path.

The fourth condition requires that the target range be less than 82 feet (25 m), since at these lower distances driver evasion of crash is improbable.

Final tests of the crash mitigation system in the High Technology RSV were conducted on September 26, 1980, by RCA and Minicars on an airport runway at Princeton, New Jersey. The RSV was driven at several speeds towards a string suspended corner reflector target. Speed traps measured car velocity prior to automatic CMS operation and at the target reflector. Results are presented below:

Test Speed	Speed At Target	Reduction of Crash Energy
38.9 mph (62.2 km/hr)	0	100%
46.1 mph (74.2 km/hr)	31.0 mph (49.9 km/hr)	54.8%
50.5 mph (81.3 km/hr)	35.9 mph (57.8 km/hr)	49.5%

Two higher speed tests were also attempted but the braking results were substantially inferior to those above. Reduced battery power from heavy prior drains was a possible cause of slower solenoid valve function in these tests. Also suspect are the large wind blown motions of the target reflector during these tests. Such reflector motions may delay CMS activation due to the CMS microprocessor screening subroutines which are employed to eliminate false alarms. Analysis of data from these and earlier tests indicate that improvements in brake plumbing and radar in-