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OBJECTIVE

In 1974, the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) initiated its four-phase Research Safety Vehicle (RSV) program. The program's motivation was to develop a technological data base to support formulation of U.S. Federal Motor Vehicle Safety Standards reasonable for the mid-1980's time period. The program objective was to generate the necessary research and test data by developing an integrated research vehicle. When conceptually introduced into the vehicle population, this RSV would maximize safety payoff consistent with meeting the Government's other automotive-related social goals. By safety payoff, we mean the dollar amount by which societal savings associated with injury reduction exceed the costs of safety system implementation.

The program emphasis on an integrated safety vehicle was especially challenging with respect to energy usage. A necessary trade-off was thought to exist between low-weight requirements for high fuel economy, and what have been perceived to be the safety advantages of heavy crashworthy structures. The first experimental safety vehicles were heavy tank-like structures. Their high life-time energy usage (including energy used in manufacture) and low fuel economy were particularly ill-suited to an energy-scarce operating environment. Minicars' RSV effort has sought to demonstrate that a reasonable weight trade-off compromise can be reached between energy usage and safety: The goal has been to develop an exceptionally lightweight vehicle with low life-time energy usage, that delivers high fuel economy but still offers outstanding occupant protection.

In addition, the other goals of the RSV program include reduced emissions, relative ease of repair, relative ease of cost-effective manufacture, and high marketability. All of the goals mentioned are generally character-

ABSTRACT

Mr. Donald Friedman was developing vehicle concepts at GM from 1960 to 1968 and has continued this research since then as president and founder of Minicars, Inc. He has participated in the development of urban electric cars, the DOT/AMF/ESV, passive restraints and structural energy management programs. Mr. Friedman is presently in charge of systems analysis and integration of the Minicars Research Safety Vehicle Program.

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ized as the "S3E" concept-Safety, Energy, Environment and Economy.

ANALYSIS

The safety requirements were established in Phase I by an analysis of accident data. Fig. 1 represents the number of annual injuries of broken bone type severity for each area of crash damage around the automobile. For 1975, these injuries totalled about 1.2 million. There are approximately 100,000 very severe injuries annually (Fig. 2) which involve temporary to partial to permanent disability. There are also some 27,000 annual fatalities (Fig. 3). From the frequency and severity of injuries in each damage position around the car, we can prioritize our occupant protection research efforts. Through the use of a vigorous methodology which weighs benefits and costs for alternative safety systems in a given operating environment, we can determine the degree of occupant protection necessary to maximize safety payoff for each crash mode. By extrapolating vehicle and vehicle-use schedules and trends, we can reasonably project our figures into the future, as we did to 1990 for the RSV program.

DEVELOPMENT METHODOLOGY

In this way, Minicars' RSV development program started with a fairly clear picture of what is going to be required of the industry in the 1985 time frame. This picture evolved into a preliminary vehicle mockup, which was used to adjust concepts of styling, structure, suspension, accommodations, and equipment. Sequences of tests were then conducted to refine and implement the conceptual ideas.

Implementation of RSV structural analysis and concepts required an assessment of the

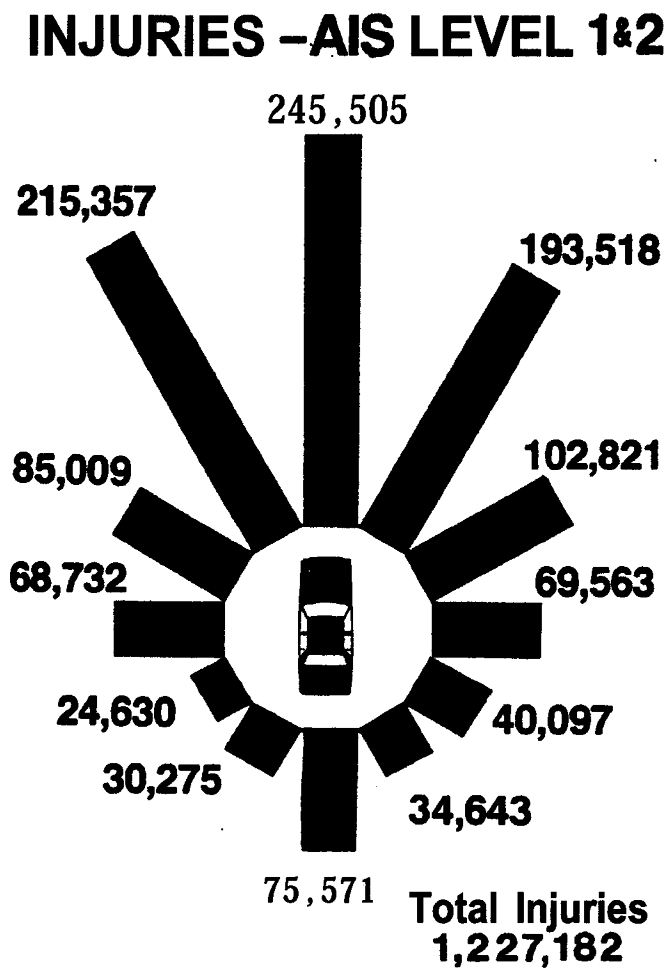

Fig. 1 - Moderate injuries

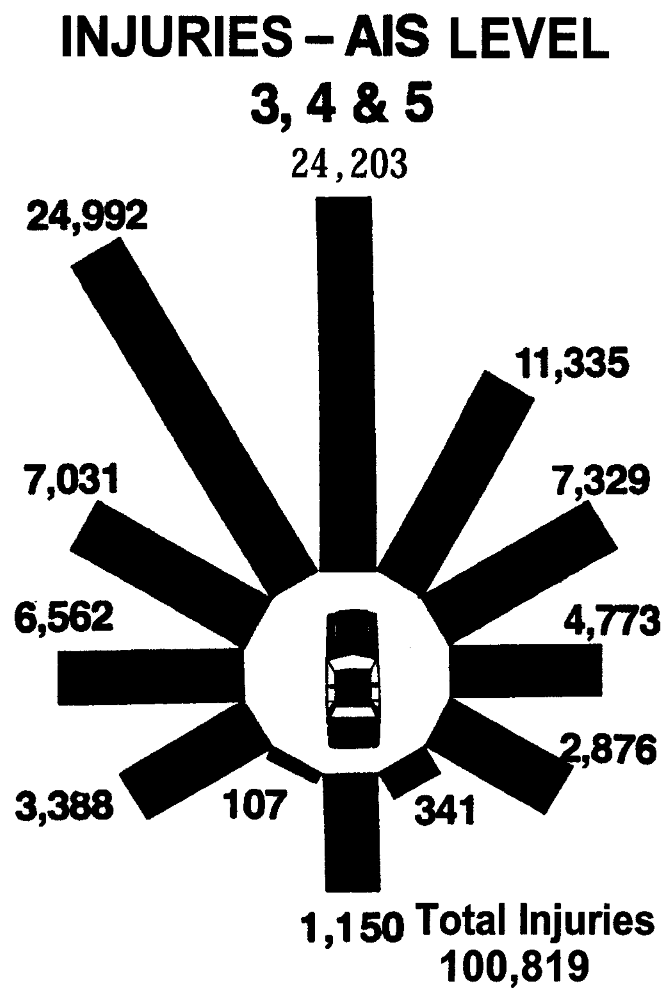

Fig. 2 - Severe injuries

front, rear, and side crush characteristics of conventional cars in order to ensure compatibility with the RSV (Fig. 4). Through these static tests and subsequent computer analysis and dynamic impact testing, the RSV structure was refined. Some twenty relatively identical structures were built to provide a base for integration and test of other subsystems — doors, exterior skin, suspension restraints, powertrain, brakes, interior accommodations, etc. Such subsystem integration and test efforts are relatively standard procedure for ground-up vehicle development efforts. In this case, however, the substance behind the procedure is quite innovative.

TECHNICAL DISCUSSION

The structure is sheet steel formed into closed volumes which are filled with a polyurethane foam. The foam reagents are mixed as a liquid, which is injected into the structure through holes in the closed sections. The foam then expands and becomes rigid. It, in turn, stiffens the thin sheet steel and stabilizes the structure surfaces. The entire resulting structure is exceptionally lightweight and easy to manufacture; yet, its energy absorbing properties provide improved occupant protection.

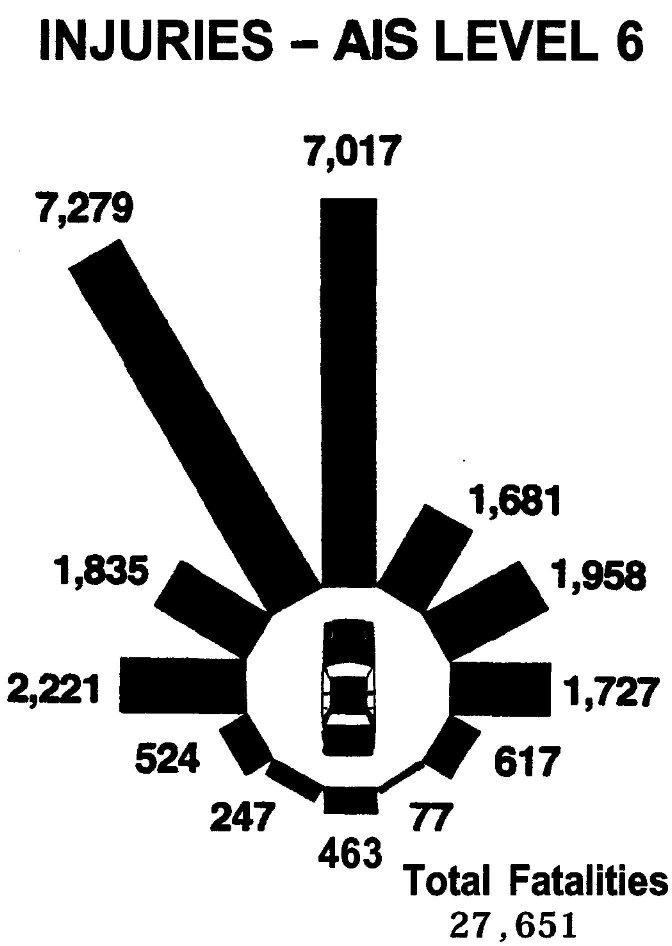

Fig. 3 - Fatalities

Fig. 5 shows the completed structure. The steel shell is the basic foam-filled sheet metal structure. The front and rear bumpers (#1) are formed of semi-flexible, high-density urethane foam. The front bumper is capable of absorbing barrier impacts of up to 10 mph while sustaining no damage at all. The structure just behind the front bumper (#2) is a bolt-on replaceable nose section which absorbs impacts up to 20 mph and leaves the steel shell behind it undamaged.

The engine (#3) is mounted in the vehicle's aft in order to allow maximum front-end crush space to optimize 11 to 1 o'clock occupant protection (refer to Fig. 3-6). The engine is the four-cylinder Honda CVCC 97.5-in^3 Accord, adapted to the RSV with Honda's guidance. It is an energy-efficient engine which achieves mid-30's range fuel economy in combined highway and urban driving.

The gas tank (#4) lies ahead of the engine on the vehicle's center line. It is thus located inside the safest portion of the structure, well-protected by cross-members to minimize the possibility of fire. It is made with a flexible urethane skin and filled with reticular foam to further reduce the likelihood of fire in a collision.

Fig. 4 - Compatability crush test

The four-wheel independent suspension (#5) utilizes McPherson/Chapman struts and is adapted from the Fiat X1/9. In the rear a brace was added between the "A" arms to provide improved crashworthiness. The four-wheel disc brake system is coupled with an anti-skid system developed by ITT-Teves.

The RSV uses "advanced concept tires" (ACT), which have been in development by Firestone since 1973. They maintain a run-flat capability: After a puncture, they can be driven at 50 mph for over 50 miles. This capability saves vehicle weight and adds significant storage space because it eliminates the need to carry a spare tire and associated equipment.

The vehicle systems were integrated in the ride and handling car shown in Fig. 6 and then road-tested. The car exhibited the basic dimensional characteristics of the final Phase II design: a stable wheelbase of 104 inches (260 cm), a track width of 62.5 inches (156.3 cm) front and rear, and an overall length of 173.5 inches (433.8 cm) and width of 70.5 inches (176.3 cm). The test weight (less passenger ballast) of 2240 pounds was distributed 58% in the rear, 42% in the front.

Aerodynamic testing without special refinement resulted in a 0.39 drag coefficient (Cd). With refinement, 1/4-scale model tests in the Cal Tech wind tunnel resulted in a Cd of 0.29.

The RSV's exterior parts are made of reaction-injection molded (RIM) urethane. The exterior plastic fits like a glove over the structure (Fig. 7). It is semi-rigid in the hood-fender section and flexible on the front fascia. This exterior skin is highly resistant to scrates and scrapes, a characteristic very attractive from the standpoint of marketability.

Fig. 8 is the completed vehicle at the end of Phase II in January of 1977. Two significant changes since have involved the rear-end styling and structure. A lo-inch thick foam urethane bumper, which provides a 10-mph no-damage capability in the rear, has replaced the 5-mph rear bumper of the Phase II car. Consequently, the vehicle has been lengthened, as in Fig. 9.

Easy entrance and exit into the RSV is achieved with gull-wing doors, which require only 17 inches of clearance next to an adjacent car to open completely. In the RSV's interior (Fig. 10), the seats have changed significantly in terms of added strength. The basic seat configuration, including the clear, mylar/polyvinyl butyrate headrest and the thin seat back, is essentially the same as in the final Phase II car.

There has been little structural change in the gull-wing door except for putting the latch assembly in the door and the striker plate on the sill. There is up to four inches of door padding in key anatomical locations. That much strategically placed padding obviates the need for seat belts to assist side-impact occupant protection. The gull-wing design (Fig. 11) acts to dissipate side impact crash energy leaving the occupant compartment intact. The doors remain closed in a severe crash or rollover, thus eliminating the cause of many very severe injuries. The overall result is

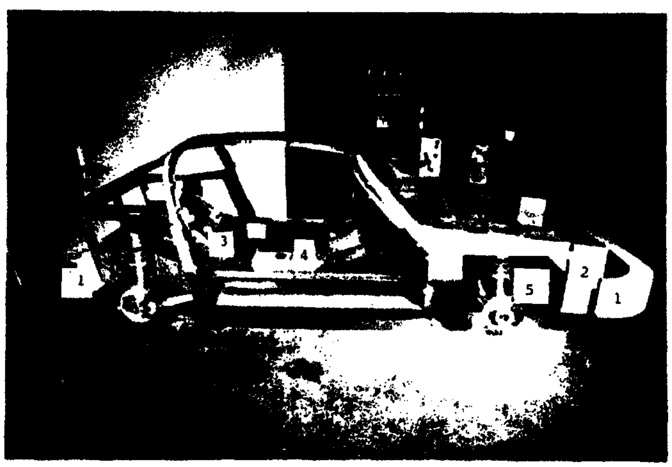

Fig. 5 - RSV structure

Fig. 6 - RSV ride and handling car

exceptional side impact and rollover occupant protection as demonstrated in tests described below.

In conjunction with the structural innovations described earlier, the RSV features high technology dual chamber airbag restraint systems to provide the best available frontal impact protection. In this system, the gas generator inflates a torso chamber. The head chamber is inflated by gas vented from the torso element. This allows fast deployment to restrain the torso, and relatively slower and softer deployment to cushion the head.

The basic driver restraint developed at the end of Phase II (Fig. 12) has been retained, although the wheel has been changed to a four-spoke assembly and a productionized column has replaced the prototype column used previously. The passenger restraint has been redesigned for production. The force-limited stroking feature of the Phase II design was eliminated because its benefits did not justify its associated costs. Extensive testing in a variety of impact modes in high velocity ranges has been accomplished in order to optimally tune the production-modified systems. A further

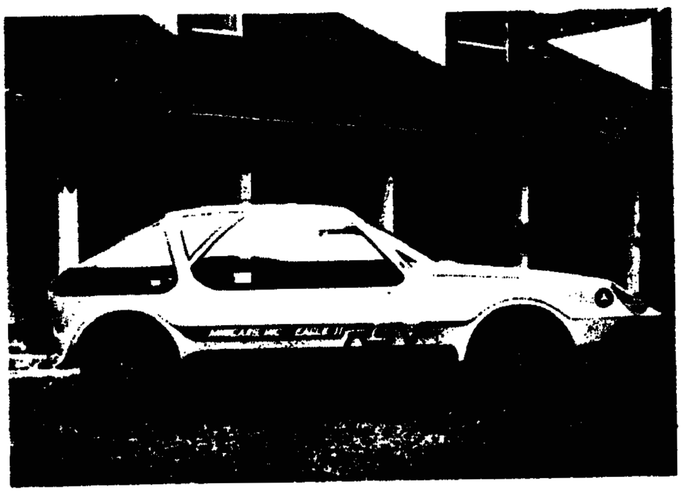

Fig. 8 - RSV Phase II final prototype

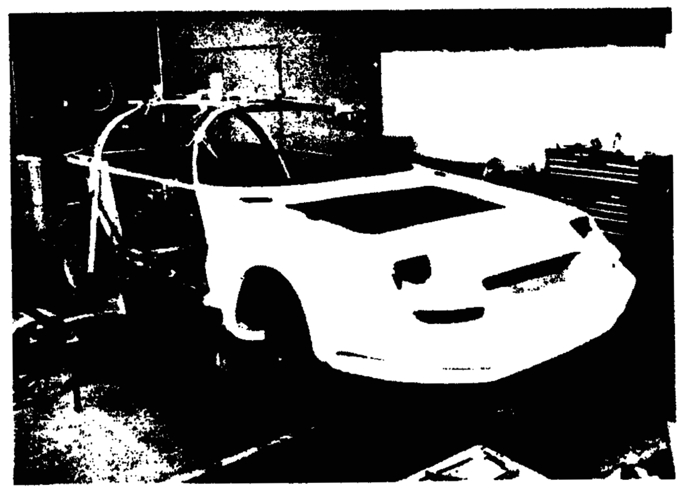

Fig. 7 - Flexible RIM urethane body glove

Fig. 9 - RSV with redesigned rear end

effort is continuing with respect to investigating circumstances such as out-of-position passengers.

The complete RSV occupant protection system has been tested in the following crashes:

- 50 mph frontal barrier (Fig. 13 and 14)
- 45 mph half offset barrier
- 80 mph half car frontal offset with a Volvo (Fig. 15)
- Volvo to RSV side with each moving 38 mph
- 1977 Chevrolet to RSV side at 60° (Chevrolet at 40 mph, RSV at 20 mph)
- 1977 Chevrolet to RSV side with each moving 38 mph
- 30 mph rollover

and other similar tests.

The high levels of occupant protection exhibited in these tests will be further assisted by the incorporation of sophisticated electronics in the RSV. The electronics described below are presently under development as part of the Phase III effort in conjunction with RCA Laboratories.

Fig. 16 is a mockup of the RSV's microcomputer. It processes signals from the radar located behind the front fascia and from sensors located throughout the vehicle. The man/machine interface is affected through an alphanumeric display adjacent to the driver's line of vision.

The solid state radar with printed circuit antennas (Fig. 17) operates in a bi-static mode at a 17.5-gigahertz frequency. It provides range and range rate information with excellent false target discrimination. Operating through the microcomputer, the radar:

- provides audible warning at ranges to 100 meters concerning targets whose relative range and range rate suggest a potentially dangerous but avoidable impact

Fig. 10 - RSV interior

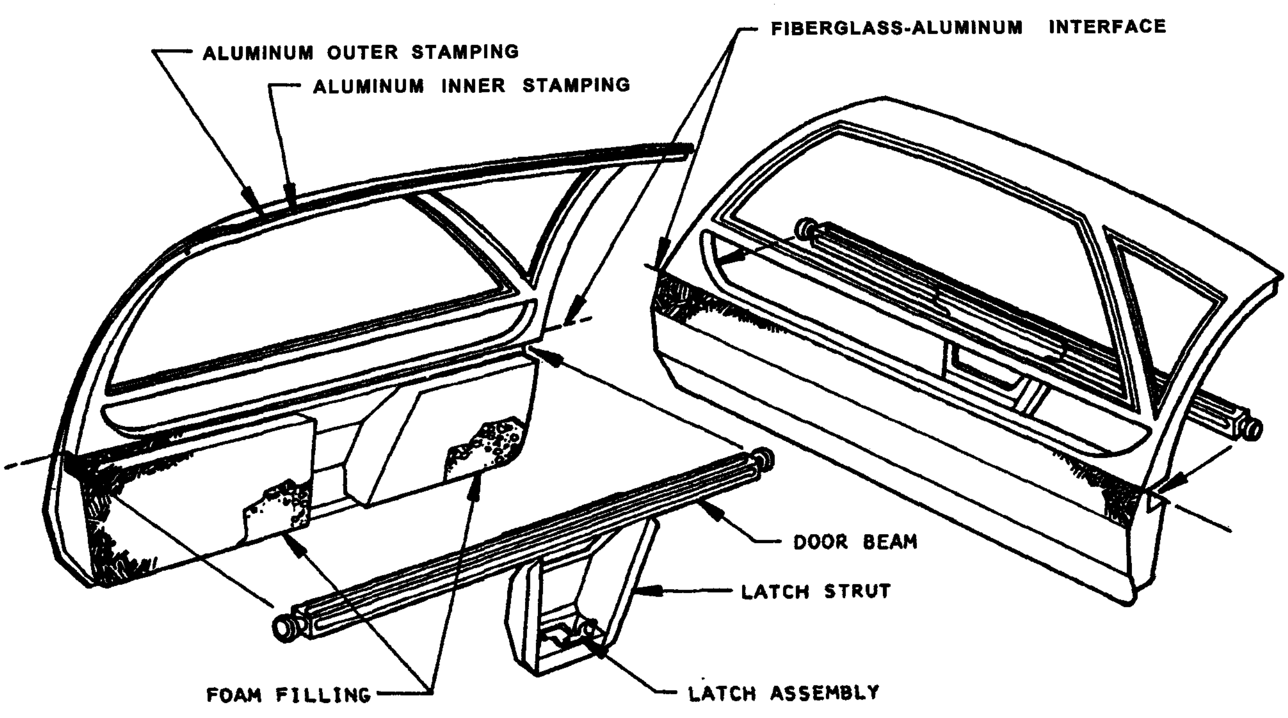

Fig. 11 - RSV gull-wing design

Fig. 12A - RSV passive restraints

Fig. 12B - RSV passive restraints

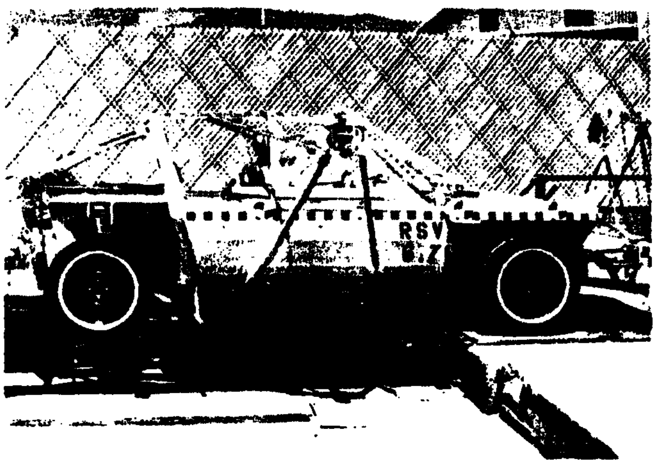

Fig. 13 - RSV before 50 mph frontal barrier crash

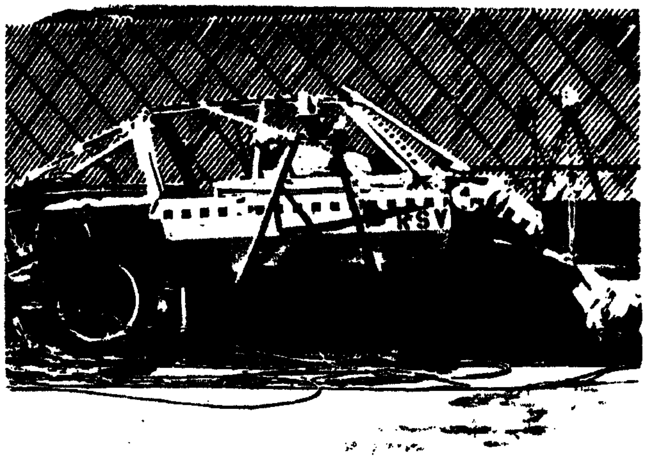

Fig. 14 - RSV after 50 mph frontal barrier crash

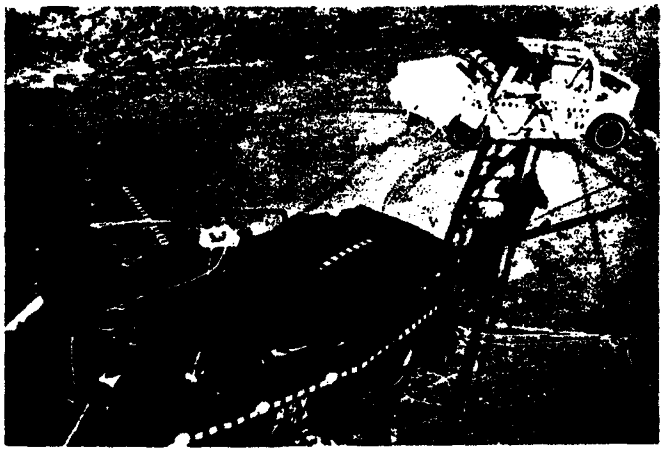

Fig. 15 - RSV-Volvo 90 mph half-car frontal offset crash

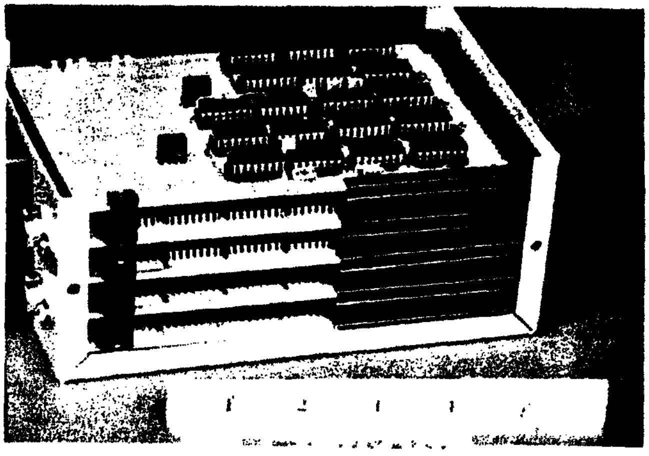

Fig. 16 - Microprocessor

- allows the cruise control system to operate in a car-following mode, and
- activates collision mitigation braking only when an impact is unavoidable.

Other sensors monitor a variety of vehicle and environmental factors to provide maintenance and failure diagnostics, vehicle status readings and analog operational read-outs through an alphanumeric display and two bezels (Fig. 18). That monitoring capability includes accurate read-out of such factors as ground, engine, and wheel speed, steering angle, fuel conditions, and temperature.

Among the program elements included as a research goal to demonstrate potential fuel economy and emissions improvements is the development of algorithms to control, through the microcomputer, the shifting of the five-speed Honda transmission. Fig. 19 presents a summary diagram of one of the computer programs developed to simulate performance, fuel economy, emissions, and shifting.

The program evaluates a control algorithm to automatically shift the manual transmission with a strategy that minimizes fuel consumption within the constraints of drivability. The fuel consumption map for the Honda engine is presented in Fig. 20. It shows that for a given torque, maximum engine speed results in the greatest fuel consumption. Similarly, for a given engine torque, minimum fuel consumption tends to be at the lowest attainable engine speed. This minimum for the Honda Accord is assumed to about 1500 rpm under load.

The shift algorithm is shown graphically in Fig. 21. It displays shift points as functions of pedal position and vehicle speed. It can be tailored to provide maximum fuel economy, by selecting the gear that provides minimum fuel consumption at any vehicle tractive force/speed condition, consistent with driver demands for acceleration.

Driver acceleration demands are satisfied by engaging a turbo-charger whenever required by high performance operation. The turbocharger increases engine power by 55%, providing approximately 100 brake-horsepower, but affects Federal Test Procedure fuel economy insignificantly: In this way, we meet the Government's fuel economy goals, yet sacrifice few consumer expectations.

The RSV is designed to be mass produced with a minimum of energy waste. As Fig. 22 indicates, significant energy savings are accrued throughout the life of the vehicle.* Total energy savings can be 45% over a vehicle with similar interior volume. In production quantities of 300,000, the complete car would retail for perhaps $1000.00 more than the Ford Pinto. Yet, benefits from Minicars' RSV concept can be realized in the near-term, even if the complete vehicle is not mass produced. As an example of what can be achieved with an existing production vehicle, Minicars has conceptually redesigned and converted a 1977

*It should be noted that these figures apply to the Phase II vehicle and do not incorporate energy figures for the powertrain innovations just described.

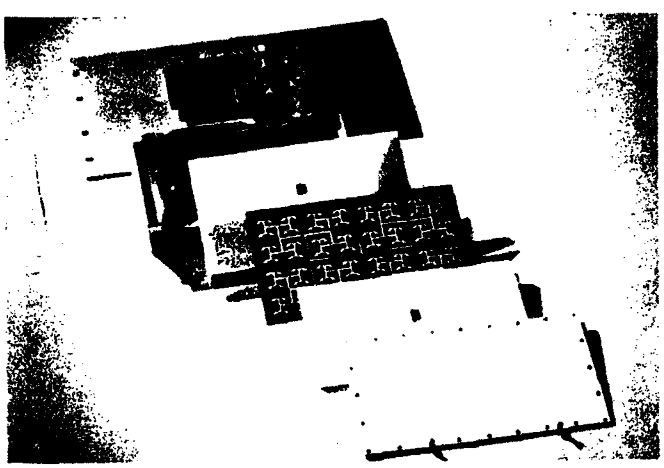

Fig. 17 - Solid state radar

Fig. 18 - Upper digital status, lower analog driving bezels

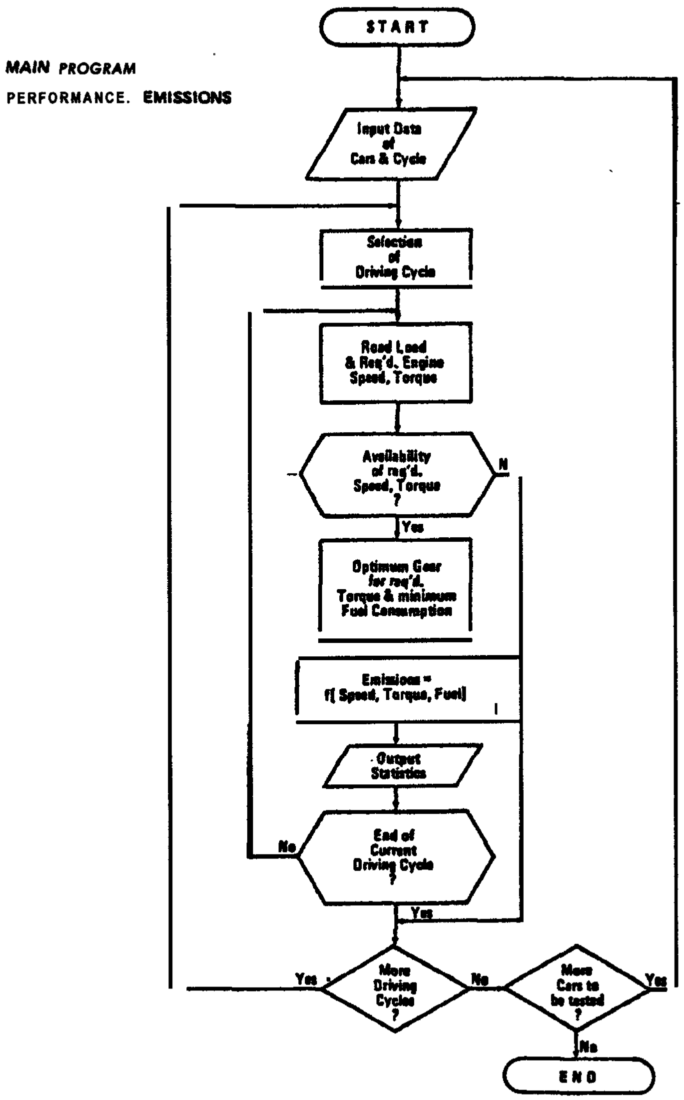

Fig. 19 - Simulation program

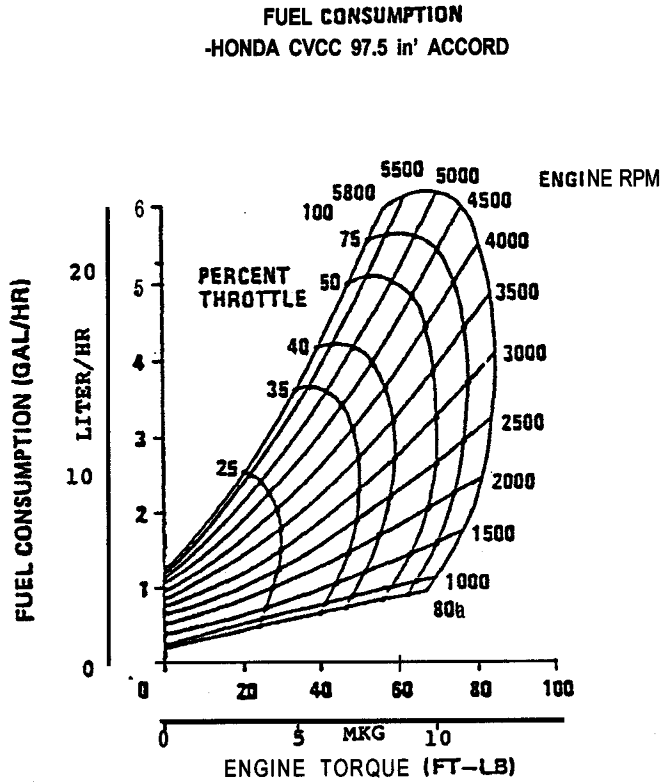

Fig. 20 - Torque versus fuel consumption

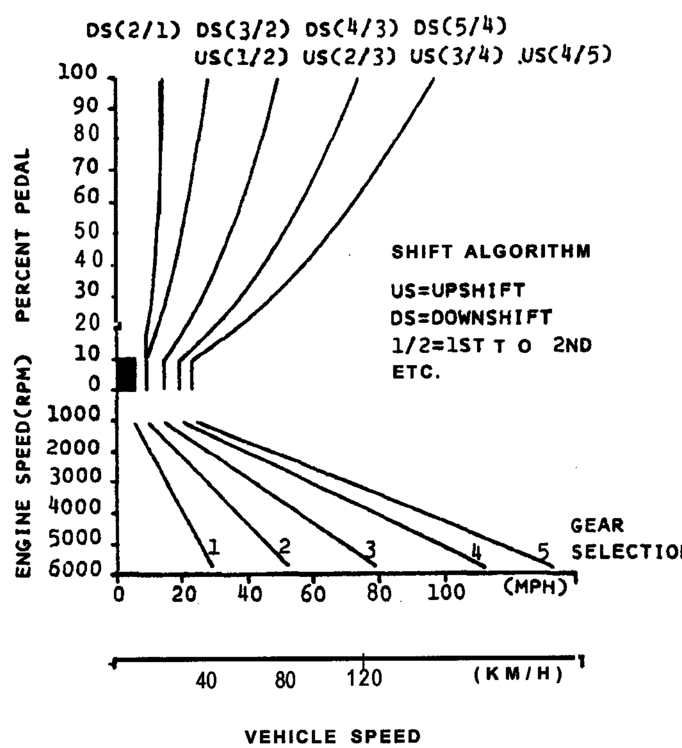

Fig. 21 - Shift algorithm

model year Chevrolet Impala (Fig. 23) into an operational mockup of a Large Research Safety Vehicle, the LRSV.

LARGE RESEARCH SAFETY VEHICLE

The LRSV (Fig. 24) is a task of the Phase IIIa RSV program. Its primary goal is to demonstrate that the advanced vehicle technology achieved in the compact-sized RSV's can be applied to full-sized sedans both to increase their fuel economy, and to improve their crashworthiness. The LRSV operational mockup is the first step in the evolutionary development Of a full-sized six-passenger sedan that provides Level II crashworthiness and offers 27.5 mpg combined city/highway fuel economy.

General Motors removed almost 800 pounds from the 1976 Impala to create the down-sized 1977 Impala. Through the application of RSV technology, we have been able to remove an additional 1000 pounds by extensively modifying the 1977 Impala — without sacrificing interior volume or comfort. (Fig, 25 gives a detailed weight comparison.) The result is a six-passenger vehicle that should achieve the 27.5 mpg goal.

The vehicle structure was redesigned by eliminating the 320-pound base Impala chassis and substituting the RSV type foam-filled sheet metal structure. The passenger compartment was retained except for the removal of the floor pan which was also replaced with a foam-filled sheet metal section with transverse members and larger door shutfaces (Fig. 26). Lightweight plastics were substituted where possible, without sacrifice of crash integrity. A modified version of General Motors' 1972 Air Cushion Restraint System and some additional padding was used for front seat occupant protection. These techniques should protect occupants in 40-mph frontal and 30-mph side crashes.

Five hundred pounds were saved, but the same power-weight ratio as the Impala was maintained, by replacing the stock Chevrolet propulsion system with a turbo-charged Volvo engine with Lambda Sond emission control (Fig. 27), coupled to a Lancia Beta transmission. The entire package was then mounted transversely and situated to drive through the front wheels. The Lancia Beta McPherson strut suspension package was used, saving further weight.

Additionally, lightweight lo-mph, no-damage, polyurethane bumpers have been used. The car's nose has also been redesigned to be less aggressive in pedestrian and vehicle-to-vehicle impacts. Fig. 28 shows the finished LRSV prototype.

CONCLUSION

The results, outlined above, of Minicars' participation in NHTSA's Research Safety Vehicle

VEHICLES WITH SIMILAR INTERIOR VOLUME	MANUFACTURING ENERGY (MILLION BTU'S)		LIFETIME ENERGY (MILLION BTU'S)		TOTAL
PLYMOUTH VALIANT	61		263		324
RSV	38		144		182
SAVINGS	23	(38%)	119	(45%)	142 (44%)

Fig. 22 - Energy requirements

Fig. 23 - 1977 Chevrolet Impala

Fig. 24 - Large Research Safety Vehicle (LRSV)

LRSV WEIGHT REDUCTION

Base Sedan Curb Weight*	3869 LB
LRSV Curb Weight **	2925 LB
Total Weight Difference	944 LB

Weight Savings by Systems and Components	Weight Change (LBS)
Engine Transmission, Differential and Accessories	-290
Body-in-White, Structure, Door and Glass	-157
Steering Front Suspension and Brakes	-109
Rear Suspension and Brakes	- 19
Front and Rear Body Panels	- 55
Front and Rear Bumpers	- 54
Hood	- 51
Other systems and Components	-149
	944

*Base Sedan Weight Taken From MVMA Specifications.
**Although the LRSV does not have a Heater/Air Conditioning System installed the System Weight has been included in the total.

Fig. 25 - LRSV/Impala detailed weight comparison

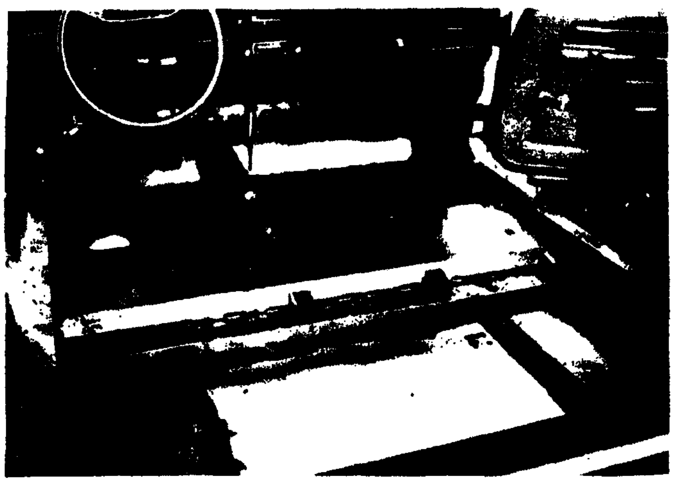

Fig. 26 - LRSV floor pan modification

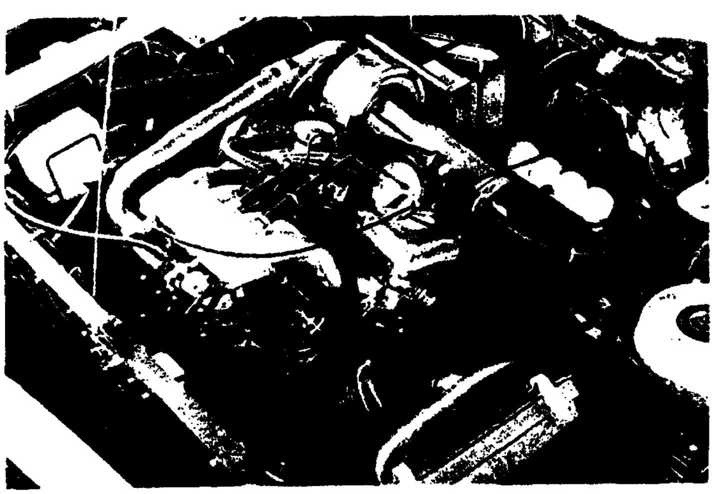

Fig. 27 - Volvo Lambda Sond engine

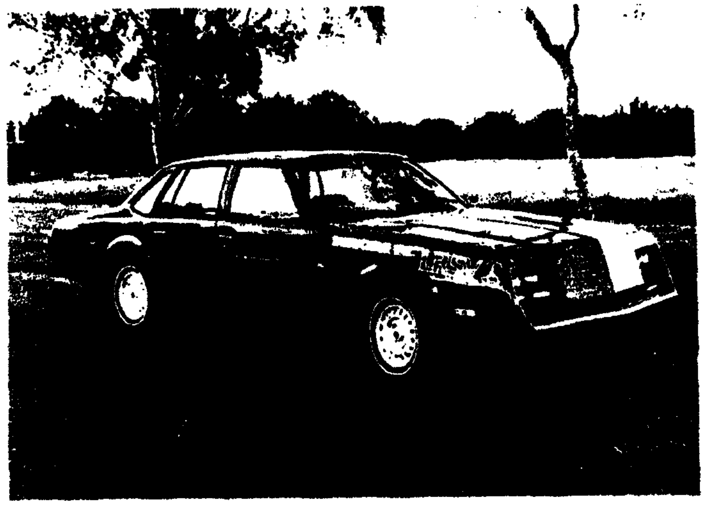

Fig. 28 - Finished LRSV prototype

program have shown that it is technically feasible to simultaneously meet the needs and goals of the Government, the industry and the consumer.

While consumer choice is manipulated to a significant degree by industry and Government, we can assume that the consumer will look out for his or her own interests in terms of vehicle costs, styling, and performance. On the other hand, the industry will concentrate, as it must, on the pursuit of profit. It will be limited by consumer preference and Government rulemaking, which is imposed to look after the interests of society as a whole. We must consequently be careful to ensure that the requirements we impose upon industry can be met in a cost-effective way.

In this context, the job to formulate socially beneficial goals falls to the Government. Its various studies have generated the following regulatory goals for the 1985/1990 time frame:

- for fuel economy, a manufacturer's fleet average of 27.5 mpg
- for safety, 43-45 mph frontal and 30 mph side impact protection
- for emissions, .4g/mi of HC, 3.4 g/mi CO, and less than 1.0 g/mi oxides of nitrogen.

Based on Minicars' RSV program effort, we conclude that such goals are technically feasible, socially worthy, industrially producible, and can be met without sacrificing consumer appeal.