Section 3: Results of ESV/RSV Development

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Results of the United States Research Safety Vehicle Program

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ABSTRACT

The United States Research Safety Vehicle Program has been completed. Technical data on safety performance of two RSV designs is available. These data shows that the crash performance of these vehicles exceeded the performance of cars available on the market and that the aggressiveness of these RSVs to other road users was less than production cars. Steering and handling performance was not improved over production cars although some other advanced crash avoidance features were superior. Consumer interest in "safe" cars was evident in marketing studies. Program management problems were mainly associated with the technical specification of crash avoidance requirements, the lack of resources for a full demonstration program, and the inability to transfer technology to the market place.

INTRODUCTION

The United States Research Safety Vehicle (RSV) Program has been completed with fabrication and evaluation testing of complete RSV vehicles. Results, or products, of this seven-year program include an extensive amount of engineering data from a large number and variety of tests, design information on materials properties and processes, structural and mechanical component performance data, and systems integration data. Participants in the program also developed analytical methodologies as part of their specification and design studies. In addition to these technical outputs the RSV Program also compiled data on public attitudes towards automobiles emphasizing safety features.

This paper provides an overview of these results at the Program level for the Minicars and Calspan RSV projects. The evolution of the overall program plan and technical goals is briefly reviewed and the two RSV designs are summarized. Results are summarized for safety performance and design integration and the response of the general public to the RSV designs is presented as a market factor. Comments are offered on some of the major issues relevant to government sponsorship of such programs.

RSV PROGRAM

A project for an RSV-class passenger car was included in the original U.S. Experimental Safety Vehicle Program presented at the First ESV Conference (1)*. Described as an "Intermediate Sedan—3,000 pound class" the preliminary technical performance specifications for this project were distributed in 1973 prior to the Fourth ESV Conference. At that Conference the overall plan was reviewed (2) and many of the participants commented on the specification and on the program. In the implementation of the program many of these suggestions were accepted and incorporated either into the program or into one of the specific projects. The General Motors comments, for example, on the major issue of trading off crash protection against other design parameters and on the minor issue of lighting systems (3), were recognized and essentially adopted.

The Program objectives can be divided into two major areas (Figure 1). The first effort was the design and fabrication of experimental vehicles which would demonstrate improved levels of safety performance without negative effects on fuel economy or emissions, and, hopefully, with some enhancement of this performance. These vehicles were then used to assess the market acceptability

*Numbers in parenthesis are references.

- **Develop Experimental Vehicles To:**
  - **Demonstrate Improved Safety Performance**
  - **Improve Fuel Economy and Emissions Performance**
  - **Assess Market Acceptance of Safe Cars**
  - **Identify System Integration Problems**
- **Test Vehicles To:**
  - **Acquire Engineering Data for Rulemaking**
  - **Guide and Support Added R&D**

Figure 1. Research safety vehicle program—objectives.

of "safe" cars. The second major objective was to test these vehicles to acquire data for rulemaking support and to direct or assist other R&D efforts. This was done both at the total vehicle level and at the subsystem/component level (e.g., single beam headlights, soft bumpers). Throughout both areas, but primarily in the development work, a number of system trade-off and integration problems were identified and analyzed. This need to reconcile the frequently conflicting design demands of improved safety, better fuel economy, emission control, and economic feasibility in the market place was a key factor in initiation of the RSV Program.

Some of the underlying philosophy of the Program was that:

a. there should be continuous dissemination of information from the contractors involved,
b. industry should be substantially involved in order to assist in the technology transfer, whether voluntary or through regulation, and
c. safety was not viewed as a competitive selling feature and unless this could be changed voluntary improvement was unlikely.

Major phases or stages of the Program are shown in Figure 2. Five parallel studies were made in 1974 to define the broad concepts of the RSV and to further develop the performance specifications first proposed by NHTSA. As noted earlier, extensive review of the proposed specifications led to a number of changes in requirements. Two contractors, Calspan and Minicars, were then competitively selected to proceed with the design and development phase and subsequently moved on to systems integration and fabrication.

Frequent reports on the Program were presented as shown in Figure 2. These conferences were keyed to completion of major phases or milestones. References 4, 5, and 6 present results through the second phase and References 7 and 8 provide the contractors' status midway through the fabrication phase.

Evaluating testing began early in 1979 and was sup-

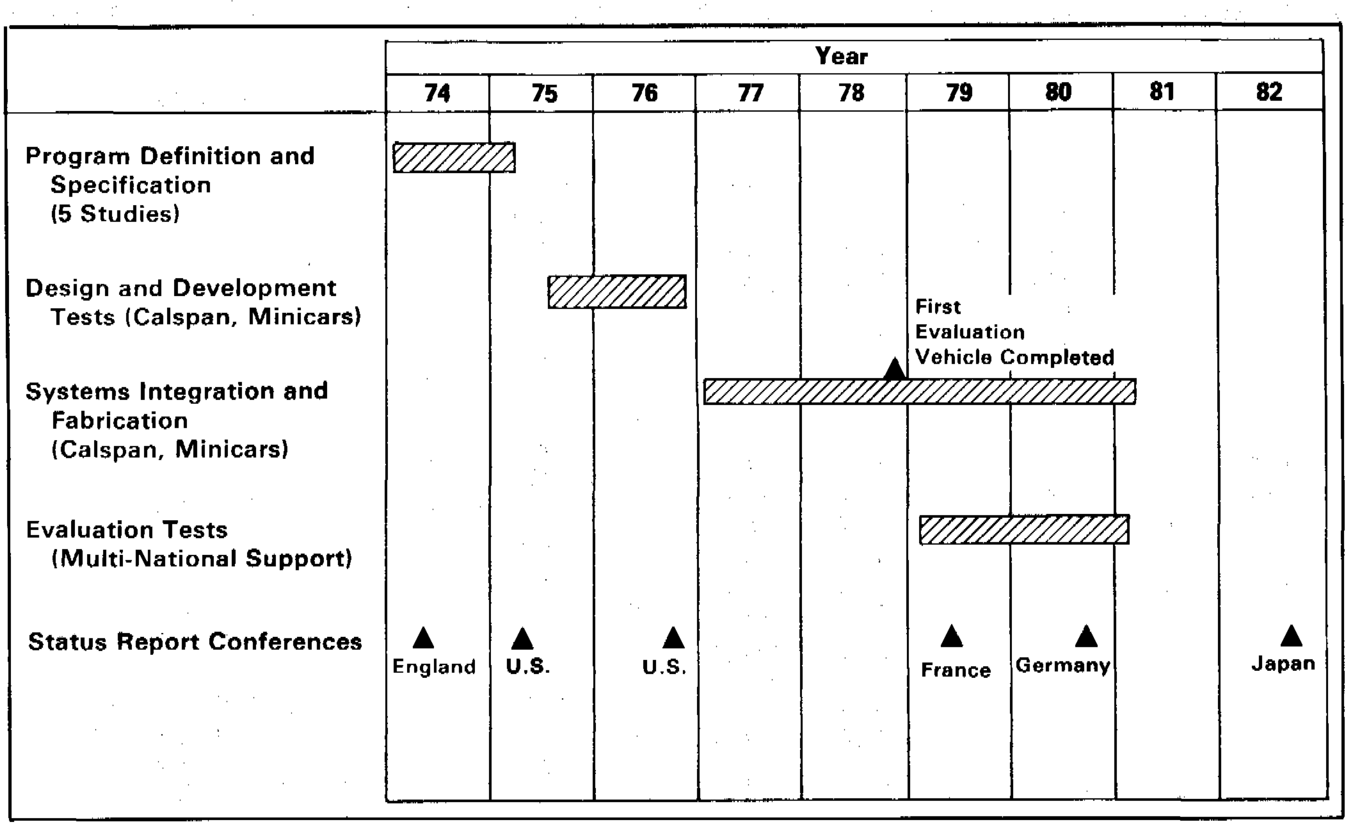

Figure 2. Research safety vehicle program—activity schedule.

	(U.S. $000's)
• Program Definition and Specification (5 Studies)	2,200
• Design and Development Tests (Calspan, Minicars)	7,000
• Systems Integration and Fabrication (Calspan, Minicars)	18,000
• Evaluation Tests	*2,900
Total	30,100

* Does Not Include Extensive Test Costs Incurred by Germany, Italy, France, United Kingdom, Netherlands, and Japan

Figure 3. Research safety vehicle program—program costs.

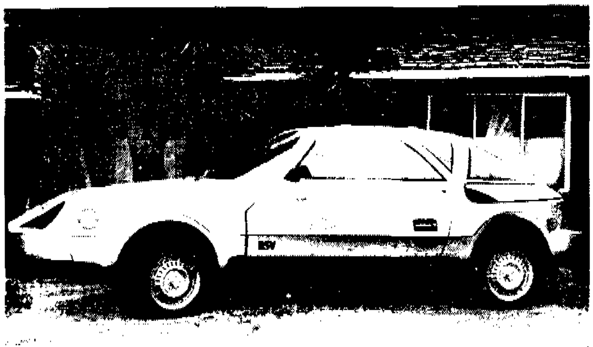

Figure 5. Minicar RSV.

ported extensively by most of the countries and many of the manufacturers participating in the International ESV work. France, Italy, Germany, The Netherlands, the United Kingdom, and Japan all performed significant evaluation tests and reported on these tests beginning with the Seventh International ESV Conference in Paris in June 1979.

Costs of the RSV Program incurred by the United States are shown in Figure 3. Note that the total cost of $30 million does not include costs to other countries or the manufacturers who participated in the evaluation testing phase. For comparison, the cost of the U.S. Family Sedan ESV program was $15 million.

DESIGN SUMMARY

The design features of the Minicars and Calspan/Chrysler RSVs have been extensively reported earlier (5, 6, 7, 8, 9). Briefly, the Minicars approach, as shown in Figure 4, was to develop an all new body structure applying an innovative fabrication technology of foam-filled, thin gauge sheet metal sections for body structure. Designed from the basis of reducing societal cost from crashes, the design ended up at 2,550 pounds curb weight and achieved 50 mph barrier crashworthiness. Fuel economy achieved with the modified Honda engine was 29 mpg (City) and 41 mpg (Highway). The Minicar RSV is shown in Figure 5.

The approach for the Calspan/Chrysler RSV is shown in Figure 6. This RSV was evolved from a 1976 Model Year Chrysler Simca and thereby represents a conventional, near-term State-of-Art technology. Extensive use was made of simulation analyses in the structural design process. The RSV, as shown in Figure 7, weighed 2,675 pounds. Major crash performance levels achieved were 40 mph Frontal Car-to-Car protection and 34 mph Side protection. The turbocharged engine with 5-speed gearbox and feedback carburetor installed by Volkswagen provided 26 mpg (City) and 42 mpg (Highway) and reduced emissions significantly over the standard Omni/Horizon engine installation.

PERFORMANCE RESULTS SUMMARY

Nearly 60 complete RSV test vehicles of various types were built and tested throughout all phases of the RSV Program. Many different types of tests were performed—aerodynamic drag, handling, braking, crash repairability, low speed damage protection, and others, as well as high-

- All New Vehicle
- Innovative, Near-to-Midterm Technology
- Societal Benefit Basis for Design
- 2,550 Lb. Curb Weight
- Crashworthiness
  - Frontal: 50 MPH Barrier
  - Side: (Impact by Large Car) 35 MPH Each Car (90°)
- Fuel Economy
  - 29/41/33 MPG
  - 0.4/2.5/0.7 HC/CO/NO_X GPM

Figure 4. Research safety vehicle program—minicars approach and performance.

- Modification of Production Vehicle (Chrysler Simca)
- Conservative, Near-Term Technology
- Analytical Basis for Design
- 2675 Lb. Curb Weight
- Crashworthiness (Car-to-Car)
  - Frontal: 40 MPH (Each Car)
  - Side: 35 MPH (Each Car, 90°)
- Fuel Economy/Emissions
  - STD Engine: 23/34/27 MPG; 0.5/4.87/1.03 HC/CO/NO_X GPM
  - T/C Engine: 26/42/32 MPG; 0.13/2.1/0.9 HC/CO/NO_X GPM

Figure 6. Research safety vehicle program—Calspan/Chrysler approach and performance.

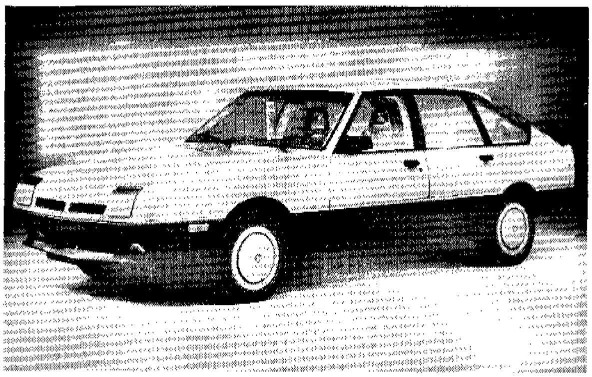

Figure 7. Calspan RSV

speed car-to-barrier and car-to-car crash tests. Detailed results of these tests have been reported at previous International Technical Conferences on Experimental Safety Vehicles beginning with the Sixth. This report summarizes these results at the Program Level.

OCCUPANT PROTECTION

Both RSVs developed crashworthy structure and integrated these structures with automatic restraints, padding, seating systems, and other body and chassis elements to provide safety performance as shown in Figure 8. Using either conventional (Calspan/Chrysler) or innovative (Minicars) technology as described earlier, these vehicles were able to demonstrate occupant protection in various crash modes.

Both RSV designs integrated automatic restraint systems for drivers and front seat passengers. Two distinctly different air bag designs were developed for the drivers. The Calspan/Chrysler RSV driver restraint incorporates a steering wheel-mounted air bag with a pyrotechnic inflator, porous nylon bag, primary and back-up crash sensors, and a dash-mounted diagnostic box. Knee blockers are used but an active lap belt is available. The Minicars RSV driver restraint system has a dual air bag configuration mounted in the steering wheel assembly. The inner and outer bags are cylindrical and are constructed of low permeability nylon. Venting in these bags is accomplished by the fabric porosity. This system also has inflators, primary and back-up crash sensors, and a diagnostic system. The system generally works with a collapsible steering column and additional knee restraints. Satisfactory structural integrity, controlled collapse of the front end, and adequate energy dissipation are achieved through proper design of the frontal structure.

It was in matching front structure performance with restraint performance and in integration into the RSVs that most effort was required.

The Calspan RSV system has demonstrated protection up to 80 mph closing speed in head-on crashes against equal weight cars. The Minicars RSV system users will be protected in frontal impacts as severe as a 50 mph barrier crash. Of approximately 9,500 driver fatalities that occur annually, in the U.S., it is estimated that almost 6,200 of these could be eliminated if all cars were equipped with similar systems.

The Minicars RSV also uses a dual bag concept for automatic passenger restraints. Two bags separated by a thin membrane serve as a torso and head cushioning device. The torso bag is smaller than the head bag and the volume and design features of each are tailored to meet chest and head loading requirements. The system consists of dual chamber bag, solid propellant inflator, crash sensors, energy absorbing dash, and knee pad. In the event of a crash the torso bag fills very quickly and maintains a high pressure. As the torso comes in contact with the bag, the gas is forced into the bag for the head through a vent in the membrane. Then the upper bag inflates and retards the head as it starts to move. The system includes passenger knee restraints.

The Calspan/Chrysler RSV uses an inflatable torso belt system for passenger protection. The belt uses an auxiliary drive system to automatically position the belt on the passenger. Knee blockers or an active lap belt are used in conjunction with the belt.

An inflatable belt distributes the crash loads on the occupant torso over a large area thereby reducing chest injuries. It also cushions the head and restrains occupant forward motion. The same system functions as a conventional shoulder belt system when low-level crash forces are encountered as in minor accidents which do not deploy the air belt. A pyrotechnic inflator automatically inflates the belt to an 8-inch-round bag during crashes. Force limiting webbing is used on the ends of the belt to limit the belt loads to 2,000 pounds. An advantage of this type of system is that it is not unique for any particular model and therefore can be used in a full line of production car models, thereby reducing costs. The air belt is obviously more susceptible to consumer complaints about discomfort, inconvenience, and appearance than are air bags.

The RSV Side Impact Occupant Protection Systems

- **Developed Both Conventional and Innovative Structures for Front, Side, Rear, and Rollover Crash Protection**
- **Demonstrated Automatic Protection For:**
  - **80 MPH Car-to-Car Frontal Crashes With Conventional Structures Technology**
  - **50 MPH Frontal Barrier Crashes With Innovative Structures Technology**
- **Demonstrated Car-to-Car Side Crash Protection at 50 MPH Closing Speeds**
- **Demonstrated Rear Crash Protection at 45 MPH With Conventional Technology — No Fuel Leakage**

Figure 8. RSV results summary—occupant protection.

utilize improved door structure, strengthened pillars, interlocks between the door and the vehicle structure, door beams, and interior padding. The purpose of these components is, first, to reduce the gross deformation of the passenger compartment caused by an impacting vehicle, and secondly, to control the impact forces on the crash victim.

The Calspan RSV Side Structure utilizes conventional design combined with application of high-strength materials to prevent the intrusion into the occupant compartment. Having reduced the intrusion, the occupant impact forces are controlled by utilizing foam door trim pads which enclose aluminum honeycomb. As the door is moved inwards towards the occupant, the honeycomb and padding deform to limit and control the forces imposed on the occupant.

In addition to the design features of the Calspan RSV, the Minicars RSV embodies a heightened door sill. The purpose of this sill is to interact with a striking vehicle's front structure, thereby reducing the magnitude of collision force applied to the door itself.

The Calspan and Minicars RSV Side Impact tests have demonstrated that front seat dummies could survive in a car-to-car crash at up to 50 mph closing velocities with each vehicle traveling at 35 mph. Survival is defined as injury measures on the dummies being less than those required by Federal Motor Vehicle Safety Standard 208. If all vehicles in the U.S. car fleet provided front seat occupant protection in side impact accidents at speeds of 50 mph, fatalities would be reduced by approximately 40%, assuming no change in the accident pattern. This is based on an analysis of the side impact test data of the Calspan RSV.

Rear crash protection of the Calspan RSV was gained not only by modest strengthening of the rear structure but also through careful redesign of the fuel tank and fuel filler systems. The tank was strengthened and moved forward on the vehicle and attached with wrap-around straps. The fuel filler neck was also moved forward over the rear wheel and out of the impact zone. These steps were essential to reducing fuel leakage in rear impacts.

AGGRESSIVENESS

A principal requirement of all Experimental Safety Vehicle research has been the reduction of aggressiveness toward other road users—pedestrians, bicyclists, and cars. RSV results in this respect are summarized in Figure 9.

- **Demonstrated Technology To Reduce Pedestrian Injury Levels at Impact Speeds Up to 25 MPH**
- **Demonstrated Low Speed Damage Protection to Struck Cars up to 8 MPH**
- **Demonstrated Technology To Reduce Injury Levels of Struck Car Occupants in Side Crash Tests at 50 MPH Closing Speeds**

Figure 9. RSV results summary—aggressiveness.

Low speed aggressivity toward pedestrians or other cars was achieved by designing a "soft nose." This soft nose design developed for the RSVs consists of a high density reaction injection molded (RIM) skin which encloses a low density foam. Engine cooling air slots are provided, together with cut outs for headlamps and parking lamps. The shape of the unit, and the foam properties, can be tailored to meet specific design requirements. With this concept, vehicle aggressivity toward both pedestrians and other vehicles is simultaneously reduced. This front end design provides clear cut reduction of pedestrian injuries compared to current front-end designs. It is also less aggressive in low speed (less then 10 mph) impacts with other cars. The weight of the unit, as designed for the Calspan RSV, for example, is approximately 35 pounds; one half that of a conventional bumper, grill, valance, etc., which it replaces.

The National Highway Traffic Safety Administration has estimated that up to 13,000 pedestrian injuries would be reduced in severity and up to 340 pedestrian fatalities per year would be eliminated if the entire U.S. car fleet was equipped with soft bumpers.

High speed crash aggressivity reduction, of course, involves front end structural design rather than just the soft nose. In a series of paired car-to-car tests the RSVs showed the ability to reduce the level of dummy measurements in the car struck in the side by the RSV as compared to the paired car. Such benefits in reduced aggressiveness are, of course, gained at the expense of occupant protection and the RSV design development and evaluation tests provide valuable data for understanding this concept.

In the paired tests the reduction in front seat dummy measures was significant. Chest and pelvic accelerations were reduced 30 to 40%. Rear seat dummy measures were not improved, however, to the same degree and this behavior has not yet been explained.

ACCIDENT AVOIDANCE

A number of well-established concepts related to accident avoidance were integrated into the RSVs. Some of these are noted in Figure 10. Anti-lock brake systems, flat-proof tires, low tire pressure warning systems, and high level rear lighting were used but were not specifically evaluated under this program. A light-weight, single beam headlight system was developed by CIBIE for the Calspan RSV and was evaluated under a separate NHTSA project

- **Integrated Crash Avoidance Subsystems:**
  - **Anti-Lock Brakes**
  - **Advanced Lighting**
  - **Conspicuity Stripes**
  - **Tires**
- **Developed Radar-Activated Crash Mitigation System**
- **Identified Issues With Crash Avoidance Performance Specifications**

Figure 10. RSV results summary—accident avoidance.

(10). A radar-activated Crash Mitigation System was developed for the Minicars RSV but was not extensively evaluated beyond the design development phase.

Probably the most important contribution of the RSV Program to Accident Avoidance was to focus attention on the problems of crash avoidance specifications. While the RSVs met the technical specifications for steering, handling, and braking performance that had been proposed and accepted at the beginning of the Program, they were considered by many to be inadequate in this performance category (11). The quantified RSV performance requirements were not sufficient or complete enough to avoid this negative judgment. Further definition of these requirements must be made in future R&D work.

SYSTEMS INTEGRATION

A prominent feature of the planning for the RSV Program was the broad objective of examining the tradeoffs and integration demands of the various subsystems or requirements. Indeed, early descriptions of the Program focused on the so-called "S3E" concept of balancing *S*afety, *E*nergy conservation, *E*nvironmental protection, and *E*conomy of purchase and operation for the consumer. The principal focus of these efforts became the development of weight efficient body structures using either conventional production processes with new applications of materials, or the development of the innovative Minicars structure. Very limited engine, drive line, and emissions control development was carried out in this Program and so the tradeoffs and integration were limited to packaging the various power plant components and subsystems.

Some other integration efforts were made on Safety/Fuel Economy issues as shown in Figure 11. Aerodynamic tests were carried out on the RSVs not only to explore external shapes but also to investigate specific details of front dams, external mirror size and shape, wheel covers and wheel parts, etc. It was on the basis of such data for example, that decisions were made to use headlight covers

- **Designed Weight Efficient Conventional and Innovative Structures — 2500 to 2700 Lbs.**
- **Identified Aerodynamics Benefits/Tradeoffs**
  - **External Shapes**
  - **Design Details: Front Dam, Mirrors, Glazing, Spoilers**
- **Methodology for Systems Optimization**

Figure 11. RSV results summary—systems integration.

and small external mirrors that failed to show FMVSS compliance, in order to enhance fuel economy at the expense of some *possible* degradation of safety performance.

Finally, the development of analytical methodologies for design optimization were initiated in the RSV Program. Simulation methodologies for vehicle level and fleet level analyses were started in the first phase of the Program and continued expansion of some of these is continuing. Other methodologies were developed for projecting vehicle engineering characteristics and for cost-benefit assessments.

MARKET FACTORS

A summary of RSV work in the general area of market factors—price to the consumer, safety benefits, and acceptance of the concepts—is given in Figure 12. Throughout all phases of the Program an attempt was made to estimate the MSRP (Manufacturer's Suggested Retail Price) for the RSV designs. In some cases, automatic restraints for example, alternate price estimates were obtained from sources other than the RSV designs. As expected, the cost estimates for some systems varied by as much as 3 to 1. Obviously, the baseline for price estimates varied, different technological assumptions were made, and in fact, technology has changed over the course of the Program. Slight variations in performance could be accepted for reduced price. In fact, simplified versions of

- **Estimated MSRP for RSV Designs**
  - **Range of Price Estimates**
  - **Evolving Technology (Materials, Designs)**
- **Estimated Crashworthiness Benefits**
  - **Evaluation Technology (Dummy, Test Modes)**
- **Assessed Consumer Reaction to RSV Concepts**
  - **Market Research (Focus Groups)**
  - **Safety Valued at $300 to $1500**

Figure 12. RSV results summary—market factors.

such RSV concepts as side door interlocks and secondary hood latches are now appearing in production cars.

Similarly, various estimates of crash benefits were made. These are obviously heavily dependent on the human surrogates and test modes utilized in the evaluations. The improved designs for dummies now being utilized in side crashes would probably alter both the RSV designs and the anticipated benefits. It is NHTSA's judgment that substantial reductions of fatalities and serious injuries could be achieved with RSV-type structures and restraint/padding systems.

The RSVs were widely exhibited to the general public and to technical audiences. Media interest was high and, in fact, TV and magazines are still reporting on the Program. Public response covered a wide range of issues ranging from technical details to practical considerations of ownership to the philosophy of U.S. Government sponsorship of such programs. While classification of the responses is difficult, they signify a broad interest in highway safety and 95% of respondents who commented on market availability indicated a desire to purchase such safe cars. Such response obviously correlates closely with expected price.

A more concentrated marketing survey was made with the Minicars RSV using focus group discussions (12). Twenty-three such groups were assembled in 10 cities across the U.S. While results are not statistically valid the research did show an increased value of safety features after some education on automobile safety performance. Price and fuel economy (the study was conducted in 1980) were the strongest factors in purchase decisions.

A conclusion might well be that consumers are much less informed on safety than on fuel economy, comfort, or styling and that increased awareness of safety could alter these priorities.

PROGRAM MANAGEMENT

Finally, a number of program management issues became apparent during the eight-year span of the program. These are listed on Figure 13. One major issue was the incompatibility of goals and objectives with the resources available, and the variation in some objectives with changing administrations. Funding and schedules were clearly not compatible with the ambitious goals for emissions and fuel economy performance.

Similarly, as the emphasis changed from one of technical evaluation of advanced safety concepts to total demonstration, resources were insufficient. For example, a major problem in the Calspan/Chrysler RSV active safety or handling performance was the "cramped" driver environment. This occurred because resources were not available to widen the base Simca when side crash padding protection was added and the interior space was reduced.

RSV design reviews were lacking in two important areas. There was insufficient emphasis on production technology projected by the RSV designers and there was a failure to explore necessary parallel changes in operational requirements for such things or license plates, tax or inspection stickers. The soft front bumpers and modified windshields would necessitate changes that, while considered feasible, were not explored or widely recognized and acknowledged.

- **Ambitious Goals, Objectives**
  - **Fuel Economy, Emissions Goals**
  - **Demonstration vs Evaluation**
  - **Inadequate Resources**
- **Inadequate Design Assessments**
  - **Production Technology**
  - **Operational Requirements**
- **Wide Dissemination of Information**
  - **Technical Conferences**
  - **Media**
- **Inadequate Technology Transfer**

Figure 13. RSV results summary—program management.

These deficiencies in design reviews were partly overcome, however, by the frequent wide dissemination of program information to the technical community. In the U.S. the SAE included papers on the RSVs and technical displays in almost all of their national meetings from 1976 through 1980. Internationally, the ESV conferences and displays continued to provide the means for technical data exchange. General dissemination of data to the nontechnical public in the U.S. has been discussed earlier.

And, finally, a disappointment of the RSV Program Management has been the inability to transfer the technical results either to the market place or even to the NHTSA rulemaking engineers. Only one element unique to the RSV design—the St. Gobain "Securiflex" (TM) windshield—has been considered for rulemaking action. None of the fuel economy/safety tradeoff issues (e.g., headlight covers, external mirrors) are being considered for change. Utilization of the vast amount of engineering data has been minimal.

CONCLUSION

The RSV Program was responsible for acquiring a great deal of technical data on the safety performance of complete integrated vehicles in a wide range of crash conditions. The crash performance of these test vehicles exceeded the performance of cars available on the market. Similarly, the aggressiveness of these RSVs to other road users—cars and pedestrians—was less than production cars. Crash avoidance performance was not improved over production cars and in some aspects was considered less satisfactory. In the U.S. there would appear to be some consumer demand for "safe" cars as determined through market assessments with the RSVs. Transfer of improved safety technology to production cars is not being accomplished.

REFERENCES

1. "The United States ESV Program—Overview," John A. Edwards, Report on the First International Technical Conference on Experimental Safety Vehicles, January 1971.
2. "The Optimized ESV Performance Specifications," William E. Scott, Report on the Fourth International Technical Conference on Experimental Safety Vehicles, March 1973.
3. "Conclusions and Projections on ESV Development," Louis C. Lundstrom, Report on the Fourth International Technical Conference on Experimental Safety Vehicles, March 1973.
4. "U.S. Status Report on ESV Programs," John W. Snow, Report on the Sixth International Technical Conference on Experimental Safety Vehicles, October 1976.
5. "A Status Report on the Calspan/Chrysler RSV," Dr. Patrick M. Miller, Report on the Sixth International Technical Conference on Experimental Safety Vehicles, October 1976.
6. "A Summary of the Minicars RSV Program," Donald E. Struble, Report on the Sixth International Technical Conference on Experimental Safety Vehicles, October 1976.
7. "Status Report on Minicars Research Safety Vehicle," Dr. Donald Struble, Report on the Seventh International Technical Conference on Experimental Safety Vehicles, June 1979.
8. "Status Report on Calspan/Chrysler Research Safety Vehicle," G. J. Fabian and G. Frig, Report on the Seventh International Technical Conference on Experimental Safety Vehicles, June 1979.
9. "The Minicars Research Safety Vehicle," D. Friedman, Report on the Eighth International Technical Conference on Experimental Safety Vehicles, October 1980.
10. "Evaluation of the Feasibility of a Single-Beam Headlighting System," DOT-HS-805-219, December 1979.
11. "Results of Handling, Stability and Braking Tests of the Minicars RSV," Dr. A. Zomotor, Report on the Eighth International Technical Conference on Experimental Safety Vehicles, October 1980.
12. "Consumer Acceptance of RSV Features," DOT-HS-805-454, June 1980.

Minicars RSV: Results of Angled Barrier and Headform Impact Tests and a Comparison with Those of the Calspan RSV and Chrysler Alpine

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ABSTRACT

A Minicars RSV was impacted into a 30° wood-faced angled barrier at a speed of 60 km/h and subsequently its interior was impact tested using a free flight headform. The results of these tests are compared with those from similar tests on the Calspan RSV and a Chrysler Alpine car which was the baseline production car used to develop the Calspan RSV. All the tests were carried out at MIRA.

In the angled barrier test the Minicars RSV met the requirement of ECE Regulation 33 with regard to occupant survival space. There were two Part 572 dummies in the front seats. Despite a delay in the deployment of the drivers airbag, all the dummy acceleration and femur loads complied with the requirements of FMVSS 208. The car met the full system integrity requirement of FMVSS 301 with regard to the 30° angled barrier impact but failed to meet the static rollover requirements because of a minor design error in the fuel filler.

The headform tests showed the need for more protection in secondary vehicle impacts when the occupants are not fully restrained.

The comparison of the results from the different cars showed an improvement in survival space and occupant injury criteria of the RSV designs over the production car.

INTRODUCTION

This is a report of a frontal angled barrier crash test of the Minicars Research Safety Vehicle (RSV) (Ref 1) followed by a series of interior headform impacts. The tests were carried out at the Motor Industry Research Association (MIRA) (Project officers Messrs. B F Smith and K Clemo) upon instructions from the Transport and

Road Research Laboratory (TRRL). The tests are part of the continuing co-operation between the USA and the UK in the field of vehicle safety.

The testing procedures were similar to those used for the Calspan/Chrysler RSV test (Ref 2). The results of the two sets of RSV tests and those from a standard Chrysler Alpine upon which the Calspan RSV design was based are compared and highlight some of the differences in design concepts.

Object

To assess the performance of the Minicars RSV in the context of crashworthiness, with particular attention being paid to occupant protection. Detailed objectives were:

a) To subject the Minicars RSV to a 60 km/h, 30° angled wood-faced barrier crash test, primarily to check its performance with regard to FMVSS 208 occupant protection and FMVSS 301 fuel integrity.
b) To measure the noise generated by the airbags of the passive restraint systems.
c) To subject the front of the Minicars RSV passenger compartment to impacts by an instrumented aluminium headform and analyse to FMVSS 208 with regard to the head injury criteria.
d) To compare the results with the Calspan RSV and Chrysler Alpine tests.

The Test Vehicle

The test vehicle was a Minicars Research Safety Vehicle, (Fig 1) and was identified by the figures M5-10. The vehicle structure consisted of a frame that was built of large thin-walled box sections, most of which were foam filled. The outer skin was manufactured from a non-reinforced plastic, except for the luggage compartment lid and its surrounding panel, which were manufactured from glass-reinforced plastic, (GRP). Some of the inner wing weather covers were also produced from a thin GRP. Minicars have aimed at providing for the needs of pedestrian safety and the reduction of low speed impact vehicle damage. To achieve this both the front and rear bumpers had been manufactured from urethane foam covered with a soft plastic skin. Access to the passenger compartment was by means of two gull wing doors that were hinged at the roof line. To allow the doors to reinforce the structures during a frontal impact, loads were transmitted between the door and the frame by location pins attached to the front and rear of the doors, which picked up on striker plates on the A-post and B-post.

The vehicle had a rear-mounted engine and transmission unit, giving rear-wheel drive. The road wheels were fitted with Dunlop Denova run flat tyres, that were inflated to 2.07 bar (30 psi) for the front wheels and 2.41 bar (35 psi) for the rear wheels. There was no spare wheel supplied with the vehicle. The windshield was of the

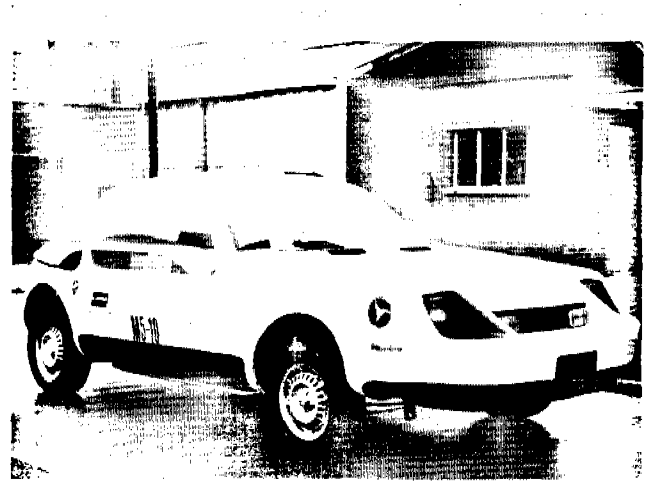


Figure 1. The vehicle on arrival for testing.

laminated type, and was bonded to the vehicle. The fuel storage tank was located inside the central spinal box section, just forward of the rear seats.

The driver's side restraint system incorporated a steering-wheel mounted airbag that consisted of non-porous nylon bag vented into the outer bag. The inner bag was inflated by a sodium azide squib. Also, the system incorporated a urethane foam energy-absorbing knee bolster. The front passenger restrains system incorporated a double non-porous airbag. The lower bag was vented into the upper bag, which in turn was vented to the atmosphere by two 62.5 mm diameter holes. The bags were inflated by a sodium azide inflator. Again a urethane foam energy-absorbing knee bolster was used. Both these systems were activated by three parallel crash sensors, two of which were mounted on the port and starboard sides at the front of the body structure, and one on the top of the left front suspension strut tower. The system also incorporated a diagnostic box to warn of any malfunction in the squib firing circuitry. In addition to the primary crash sensors a contact switch was located on the bumper blade at the point of first contact. This switch, combined with an electronic time delay circuit, was built and installed by MIRA staff to activate the restraint system in event of the primary system not firing.

Vehicle Preparation

The vehicle was painted in contrasting colours to assist in the analysis of the high speed colour films. Markers 250 mm apart, were fixed along the side of the body at the waist line and along the bonnet and roof on the vehicle centre line. Before the test the vehicle was drained of all fluids and, in compliance with FMVSS 301, the petrol tank was completely filled with 32 litres of stoddard solvent fuel substitute; then 5% was removed leaving 30.4 litres. The vehicle was fitted with contact event switches and 23 unbonded accelerometers. The vehicle complete with onboard camera and two 50th percentile dummies

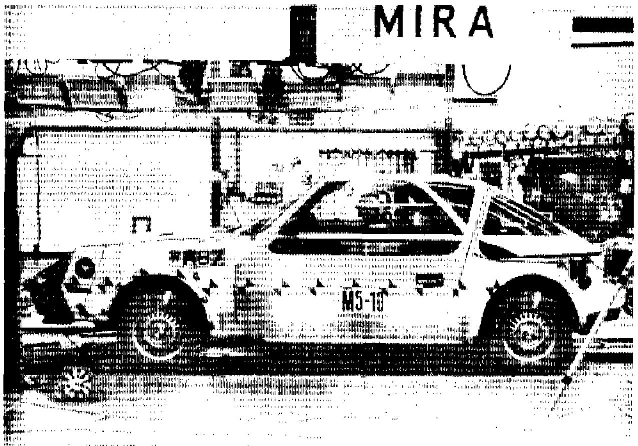


Figure 2. Port side of the vehicle pre-test.

Figure 3. The microphone installation.

in the front seats was weighed before the test (Fig 2). The loads on the wheels were:

Port front	295 kg (651 lb)
Port rear	363 kg (800 lb)
Starboard front	298 kg (657 lb)
Starboard rear	372 kg (820 lb)

This gives a total of 1328 kg (2929 lb) distributed with 45% on the front wheels.

Before the crash test the front seats were put in their most rearward latched position and an SAE three-dimensional seat deflection manikin was used to determine the front seat H-point, so that ECE 33 pre-test dimensions could be taken. Then the seats were repositioned to the instructions of Minicars Inc., Report No. 5010 FI (Check-out procedures in RSV Frontal Impact Crash Testing, Figures 3-1 and 3-2), and left in this position for the crash test.

BARRIER IMPACT TEST

Test Method

Using the MIRA linear induction motor crash facility the vehicle was impacted into a steel barrier set at 60° to the vehicles axis of motion and faced with a sheet of 20 mm plywood. The vehicle's and the dummies' instrumentation was to SAE Recommended Practice J211a. Fourteen high speed cameras were used to give colour film coverage of the impact.

Noise measurements were recorded during the impact to determine the noise level generated during the inflation of the restraint systems. For this purpose two condenser microphones, Type 4136, mounted in a foam block were fixed to the rear of the drivers seat head rest. The microphones were positioned so as to be adjacent to the driver's ears (Fig 3). The signal from each microphone was fed to an FM tape recorder via two channels with gains differing by 20 dB. This ensured a high signal to noise ratio for the test. Two forms of analysis were carried out on the recorded signals. The pressure waveform versus time was plotted to show the instantaneous peak pressure measured during the crash test. Repeated analysis showed that the essential detail of the waveform was obtained with a bandwidth of 6.4 kHz. The frequency content of the signature was obtained in octave bands from 2.5 Hz to 10 kHz using a Gen-rad 1995 integrating real time analyser set to "max hold." The "max hold" facility enables a spectrum to be obtained of the maximum level (with a time constant of 0.125 s) in each octave band over the record length. It should be noted that the sum of the octave band levels will generally exceed that of the maximum overall level because the maxima in the octave bands do not occur at the same time as the overall maximum.

Two FMVSS Part 572 dummies fitted with additional back up accelerometers in the head and chest were installed in the front seats following the procedures as defined in FMVSS 208 (Figs 4 and 5).

At the request of Minicars Inc., a squib firing circuit was fitted as backup to the existing air bag inertia switch

Figure 4. Starboard dummy pre-test.

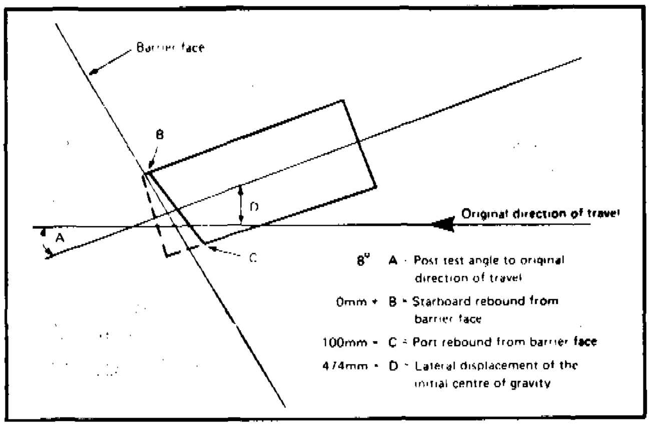
Figure 5. Port dummy pre-test.

circuit. The requirement was for squib firing current to be provided by the circuit 15 ms after impact.

The barrier test was followed by a static rollover test. The vehicle was rotated on its longitudinal axis to each successive increment of 90° (Fig 6).

Test Results

The vehicle speed just prior to impact was measured to be 60.3 km/h. The position of the vehicle after the test is showed in the diagram below and in Figure 7.



The Vehicle Structure

A measurement of the static crush showed a shortening of 235 mm on the starboard side and 1135 mm on the port side. These dimensions were taken from the metalwork as there was some considerable recovery of the urethane foam front of the vehicle.

The wheel base had lengthened by 14 mm on the starboard side and shortened by 262 mm on the port side. This was due mainly to the displacement of the front wheels. The rear wheels were still free to rotate.

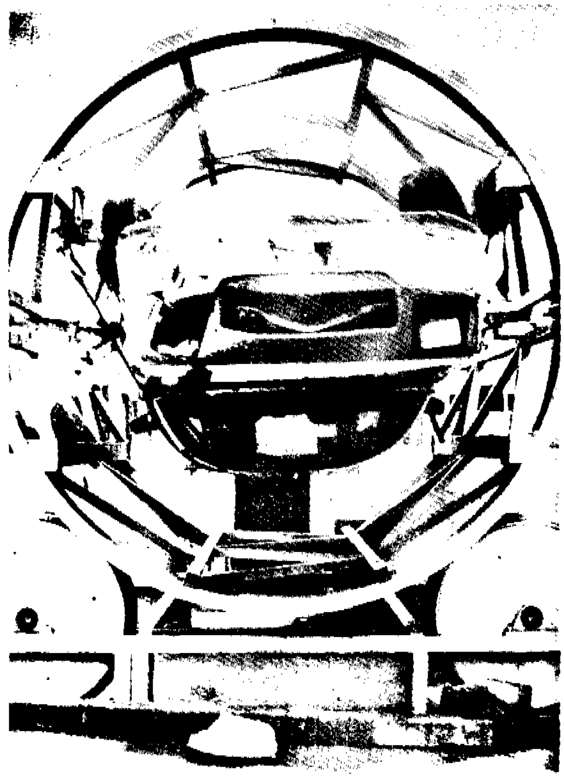


Figure 6. The vehicle installed in the static rollover rig in the second increment position.

The laminated windshield that was bonded to the vehicle was 100% retained, but examination showed that there were some cracks that radiated from the lower edge immediately behind the port side air intake. This appeared to be due to being hit from the inside by the left hand front corner of the dashboard instrument console.

Both of the gull wing doors remained closed and unlocked during the impact. The starboard door could be opened by using the normal force required for this operation. The port door catch released by using the normal force, but the door was partially jammed by the overlap-

Figure 7. Port side of the vehicle post-test.

ping of the rear edge of the front wing. However, the door could be forced open by using a snatch force to overcome the resistance of the obstruction.

Before the test it was thought that the fire extinguisher might break from its fixing and fly into the front passenger compartment during the impact. The first precaution was to have it weighed and then discharged and re-filled with water until it was back to its original weight. It was then anchored to one of the rear seat belt anchorage points by a cord with 200 mm of slack, so as to allow the fire extinguisher to break free if it was going to, but then to restrain it from entering the front passenger compartment. However, the fire extinguisher did not leave its fixing during the impact, and therefore did not present a hazard to the front seat occupants.

The Passenger Compartment

Both front seats were retained in position during the impact, and their displacement mechanisms were still operational after the test.

The resultant accelerations at the base of the port and starboard A-posts are shown in Figures 8 and 9 as examples of vehicle accelerometer outputs.

The survival space that remained available in the passenger compartment could be assessed against the requirements of the proposed ECE Regulation 33, although the test was an angled barrier impact and performed at a higher impact speed. The regulation specifies the minimum dimensions of the passenger compartment which must remain after a 48.3 km/h perpendicular frontal barrier impact. Paragraph 5.2 of the regulation relates to the horizontal distance between the R-point and the instrument panel; paragraph 5.3 relates to the horizontal distance (through the brake pedal) between the front of the passenger compartment and the R-point; paragraph 5.4 relates to the width of the footwell (through the brake pedal); and paragraph 5.5 relates to the floor to roof dimensions through the R-point. The numerical values of

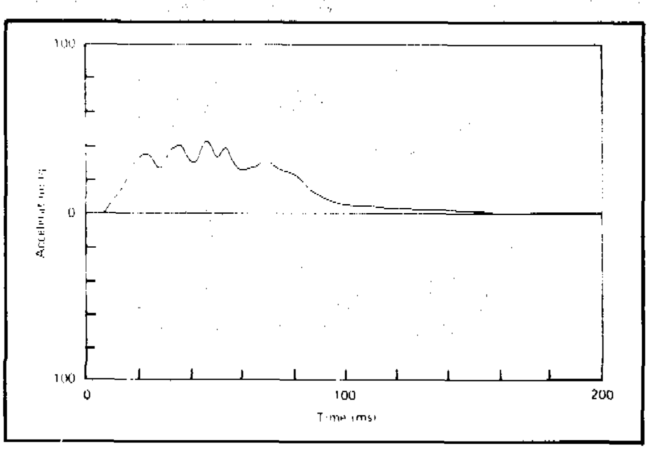


Figure 8. Resultant acceleration of the base of the port A-post.

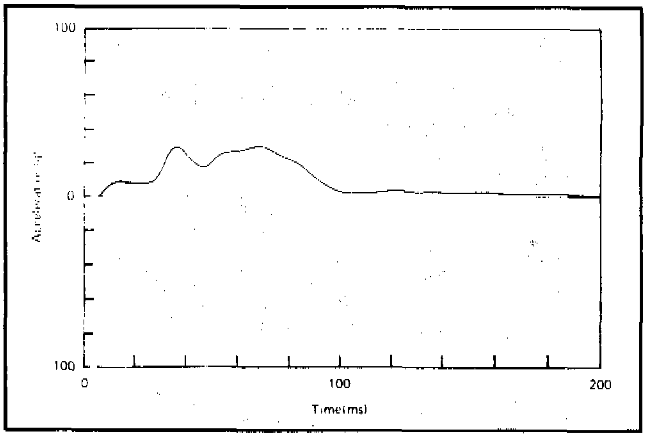


Figure 9. Resultant acceleration of the base of the starboard A-post.

the requirements and the results are shown as part of Table 1 which compares the vehicle measurements of the three cars tested. The figures show that the Minicars RSV meets the requirements of ECE Regulation 33 with regard to front occupant survival space.

Dummy Analysis

The signals from the transducers in the dummies' heads, chests, and femurs were analyzed to the requirements of FMVSS 208. The analysis results are given in Table 2 and Figures 10 to 17 and show that both dummies pass the requirements of FMVSS 208. It should also be noted that the femur loads pass the levels as defined in Reference 3 (12 kN may not be exceeded, 10 kN may not be exceeded except for duration of less than 3 ms, and 7 kN may not be exceeded except for durations of less than 10 ms).

The head of each dummy in the Minicars RSV was fitted with a chamois leather mask, so as to assess any lacerations that might occur in the test. The masks were painted just prior to impact, the left sides red and the right sides blue. This was to give witness to any head contact during the test. The post-test examination showed that there was no evidence of lacerations on either of the masks. The paint witness showed that both heads made contact with the airbags only. The driver's mask showed evidence of the steering wheel airbag rotating clockwise during the head contact which is confirmed by the high speed films, and the post-test position of the steering wheel. During the impact both dummies slid to the left of the centreline of their airbags, the driver sliding towards the A-post and the passenger sliding towards the space between the two airbag systems. The post-test examination found the driver dummy back in its seat more or less in its normal sitting position with the passenger dummy leaning towards the driver, shoulder to shoulder but with the passenger dummy slightly forward.

The impulse to the drivers head at 122.5 ms as shown

Table 1. RSV and Chrysler Alpine Vehicle Results.

Vehicle		Mini cars RSV	Calspan Chrysler RSV	Chrysler Alpine
Test date		21.1.81	10.7.80	14.2.77
Impact speed	km/h	60.3	60.3	59.4
Test weight	kg	1328	1436	1188
Weight distribution	% front	45	55	56.4
Steering wheel side		Port	Port	Starboard
Barrier face angle		30°	30°	30°
Side of first contact		Driver	Driver	Driver
Static crush. driver's side	mm	1135	800	900
Static crush. passenger's side	mm	235	60	115
Rebound driver's side	mm	100	150	380
Rebound passenger's side	mm	0	0	0
Lateral displacement of the centre of gravity	mm	474	825	135
Final yaw attitude (from original line of travel)		8°	20°	12°
Fuel leakage during impact		None	None	10 ml/min from fuel tank filler tube
Fuel leakage during static roll		200 ml/min (see text)	1 ml/min from fuel filler cap	Not rolled

ECE Regulation 33 Survival Space			Mini cars RSV		Calspan Chrysler RSV		Chrysler Alpine	
Parameter	Requirement	Position	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
5.2 Instrument panel to R-point*	>450 mm	Driver	560	550	462	460	521	390
		passenger	590	590	460	480	521	490
5.3 Front of compartment to R-point*	>650 mm	Driver	1118	1115	950	822	1003	630
		passenger	1120	1120	940	940	991	935
5.4 Width of footwell	>250 mm	Driver	480	475	705	690	597	0
		passenger	480	480	705	750	597	598
5.5 Floor to roof height	<10% reduction	Driver	1210	1205	1972	1970	1041	984
		passenger	1210	1215	1970	1970	1041	1027

*No R-point was specified for the RSV vehicles, so the pre-test H-points were used.

in Figure 10 was entirely from the head vertical accelerometer. At this moment the head was nearly horizontal and the top of the head was in the steering wheel airbag near the wheel structure. There was no evidence of wheel deformation due to a head impact. The chest accelerometers showed no impulse at this time but the pelvis lateral accelerometer had a pulse of over 100 g for 20 ms. The exact dummy kinematics cannot be determined. It is possible that the dummy while rotating round the partially inflated airbag with its knees held by the foam restraints started to slide sideways out of the seat and was hit back by an impulse from the door padding.

Airbag Deployment

Airbag firing time evidence was provided by two electronic circuits, one monitoring the current in the squib circuit at a point inside the primary system diagnostic box, and one monitoring the voltage output of the secondary (back-up) system. The signals showed that the primary system gave a current approximately 0.001 s in duration of 6 a at 0.017 s after first contact and this coincided with the film evidence of the start of deployment of the passenger's airbag. The primary system then gave a current approximately 0.003 s in duration of 2 a at 0.045 s after the first contact and this coincided with the deployment of the driver's airbag. It appears from film evidence that the driver's airbag was not fully deployed at the time of the dummy making contact with it, which was due to the delay in the start of deployment. This delay is also evident in the difference in the times of the deceleration of the two dummies after the start of the impact. The secondary (back-up) system showed that a voltage was switched to the squib circuit at 0.07 s after first contact, but at this time both squibs had already been fired by the primary system. Therefore, the secondary (back-up) system was not involved in the firing of the squibs. After consultation with the Engineering Staff of

Table 2. RSV and Chrysler Alpine Dummy Results.

	Normal Criteria to FMVSS 208	Minicars RSV		Calspan Chrysler RSV		Chrysler Alpine	
		Driver	Passenger	Driver	Passenger	Driver	Passenger
Type of dummy	Part 572	Part 572	Part 572	Part 572	Part 572	OPAT	OPAT
Head							
HIC over 250 m sec.	<1000	638	222	289	591	665	1744
HIC during contact	<1000	638+	222+	289+	No contact	665	1697
Gadd SI.	<1000	745	278	341	813	881	2279
Chest	<1000	367	177	488	402	463	315
SI over 250 m sec.							
Acceleration over 3 m sec.	<60 g.	46	35	51.5	44.5	55	40
Time over 60 g.	>0.003 sec.	0	0	0	0	0.001	0
Peak g.	—	48.5	33.3	54.3	49	63	44
Femurs load	2250 lbf (10 kN)						
Left (kN)		6.32	3.48	8.84	3.54	2.7	0.6
Right (kN)		8.52	4.55	5.72	5.75	1.8*	2.9
Pelvis resultant acceleration	—	133.5	36	67.3	67.8	54	55
Seat belt loads							
Shoulder (kN)	—	Airbag	Airbag	Airbag	8.4	4.8	7.3
Lap (kN)	—	No lap belt	Airbag	Airbag	No lap belt	4.4	8.4
Peak resultant**							
Acceleration at A-post g.	—	69	35	109	49	175	44
Time sec.	—	0.062	0.037	0.06	0.059	0.062	0.057

+ Contact with airbag.
* 1.8 kN was measured just prior to the load cell being damaged.
** Filtered at 180 Hz.

Minicars Inc., they conclude "that the driver's inflator did indeed receive current at the same time as the passenger's inflator, but that due to some inflator malfunction, the gas generator did not ignite until 0.03 second later." The post-test examination of the airbags revealed a small hole burnt in the passenger side airbag, approximately two cm. long and one cm wide. This would have had no significant effect on the restraint performance of the airbag as this hole is small compared with the airbag vent hole. However, the hot material that caused the burn could injure the passenger, and may present a fire hazard.

Fuel Integrity

The vehicle was assessed with regard to the requirements of FMVSS 301 in the 30° angled frontal barrier impact. The requirements of this standard are intended to apply to lower speeds of up to 48.3 km/h. The fuel spillage rates allowed by the standard are 1 oz. by weight from impact until cessation of motion and a total of 5 oz. by weight in the 5-min. period following cessation of motion. For the subsequent 25-min. period fuel spillage during any 1-min. interval shall not exceed 1 oz. by weight. The post-test examination showed that there was no fuel spillage during or after the impact.

The crash test was followed by a static rollover test as specified in FMVSS 301; the vehicle was rotated on its longitudinal axis to each successive increment of 90°. The vehicle was rotated first in the anti-clockwise direction looking from the front, which was with the fuel filler pipe down first. Immediately the fuel level was raised above the fuel filler pipe, fuel started leaking at a rate of 200 ml per minute (5.25 oz.), which exceeded the limit set in this standard.

At this point it was decided to abandon the test. On examination it was found that the leak was due to an inadequate seal between the metal fuel filler neck and the flexible rubber hose that leads to the fuel tank. The rubber hose was of the type that has a steel wire reinforcing wrapped spirally around its outer surface; this caused the inner seal to have a spiral indent, which made it difficult to make a good seal. First of all, the hose clip around this joint was tightened, but this did not stop the leak. It should be pointed out at this stage that when the fuel

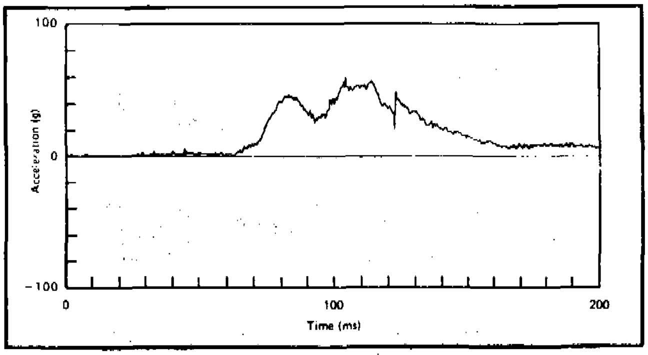


Figure 10. Resultant acceleration of the driver's head.

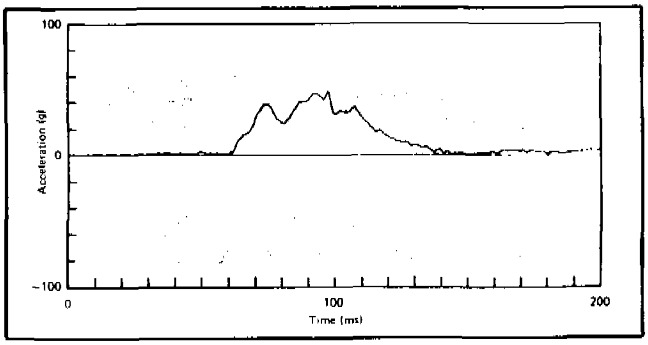


Figure 11. Resultant acceleration of the driver's chest.

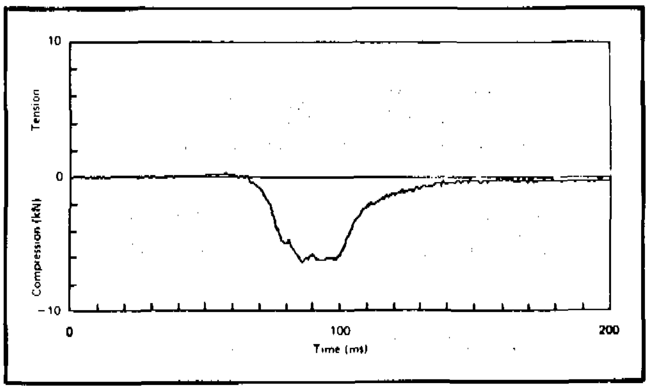


Figure 12. Axial force in the driver's left femur.

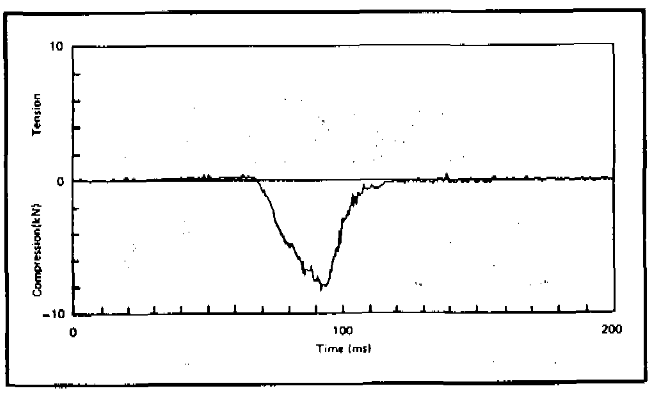


Figure 13. Axial force in the driver's right femur.

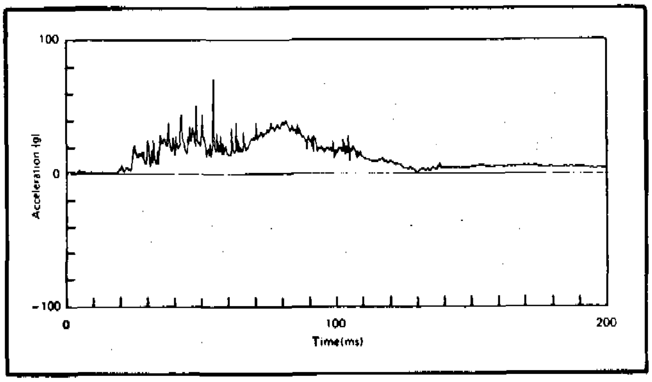


Figure 14. Resultant acceleration of the passenger's head.

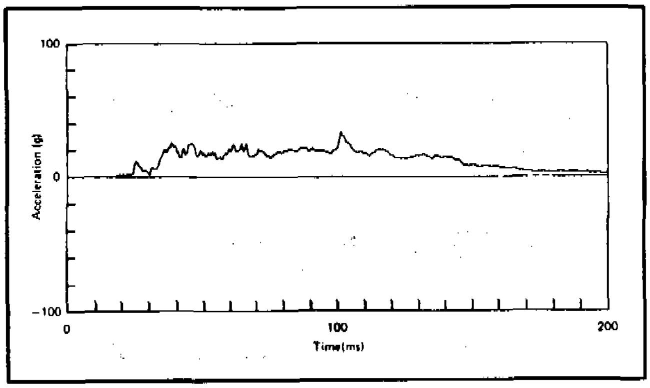


Figure 15. Resultant acceleration of the passenger's chest.

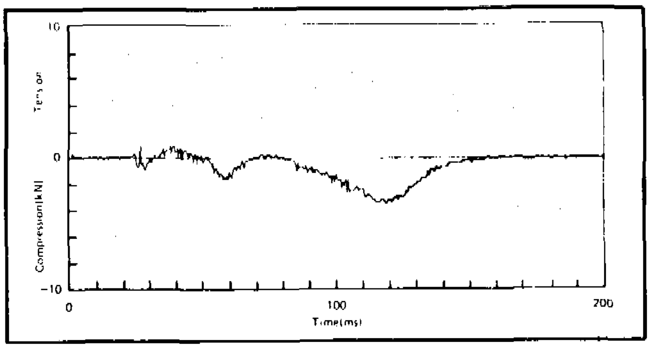


Figure 16. Axial force in the passenger's left femur.

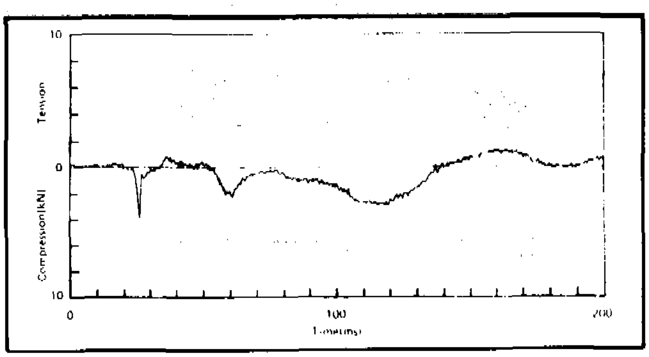


Figure 17. Axial force in the passenger's right femur.

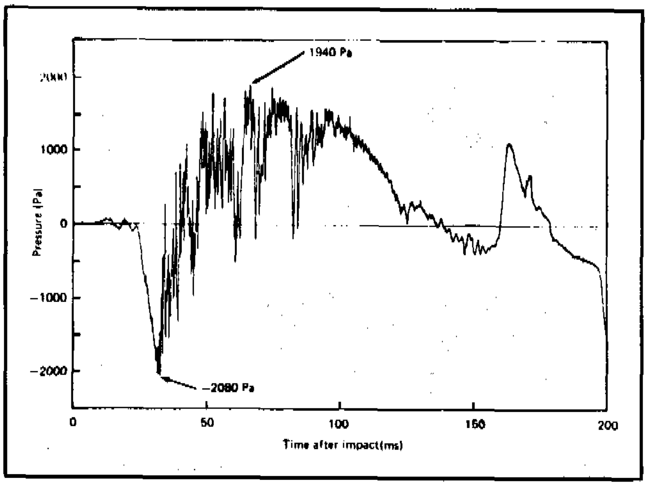


Figure18. Pressure vs time: microphone on left side of driver head position.

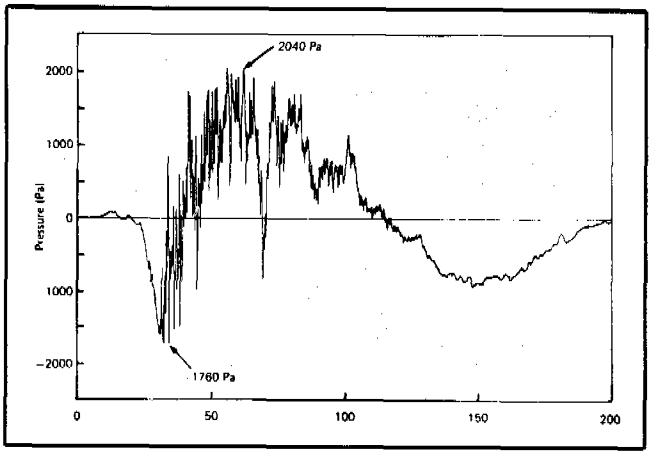


Figure 19. Pressure vs time: microphone on right side of driver head position.

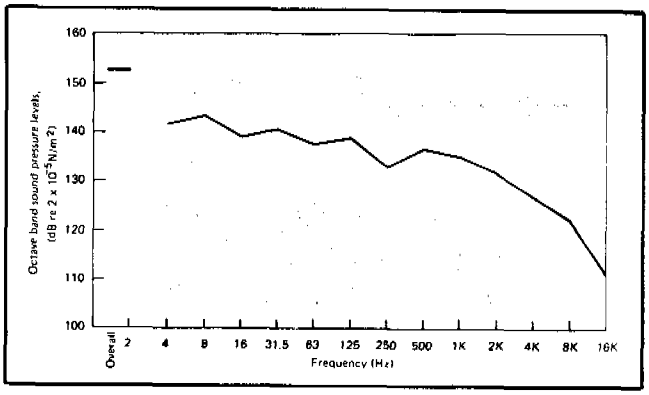


Figure 20. Maximum octave band sound pressure levels occuring during first 150 ms after impact (0.125 s time constant) left hand microphone.

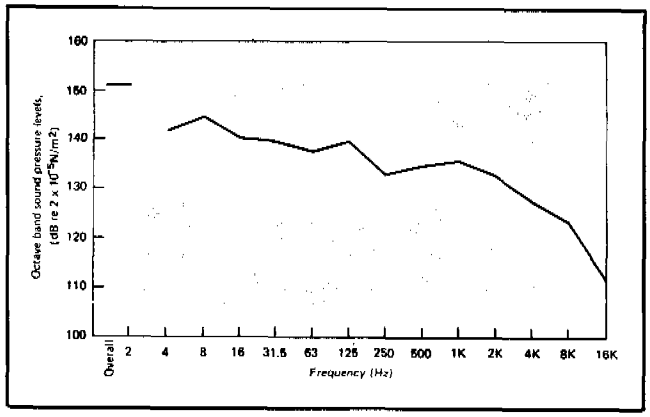


Figure 21. Maximum octave band sound pressure levels occurring during first 150 ms after impact (0.125 s time constant) right hand microphone.

filler pipe was below the level of the fuel, there were no fuel leaks from the filler cap or its interface with the filler neck, only from the connection of the rubber hose to the filler neck. It was then decided to insert a rubber bung into the end of the rubber hose and retest. In this repeat test there were no fuel leaks. The test was also carried out in the opposite direction of rotation and again there were no fuel leaks. Therefore if a better seal can be made at the fuel filler neck to the rubber hose connection, the vehicle would meet the requirements of the standard in this crash test mode.

Noise Measurements

The sound pressure levels are shown in Figures 18 and 19, the results of the octave band analysis are shown in Figures 20 and 21, and the 'A'-weighted octave band levels are shown in Figures 22 and 23. The instantaneous positive peak pressure of 1940 Pa for the left side of the driver's head and 2040 Pa for the right side of the driver's head is equivalent to an instantaneous sound pressure of

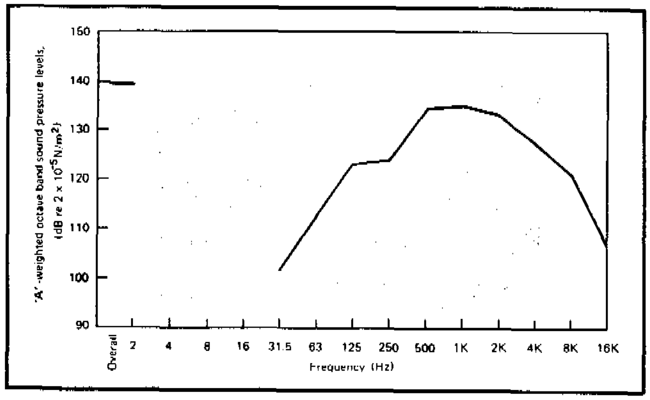


Figure 22. Maximum 'A'-weighted octave band levels occurring during first 150 ms after impact (0.125 s time constant) left hand microphone.

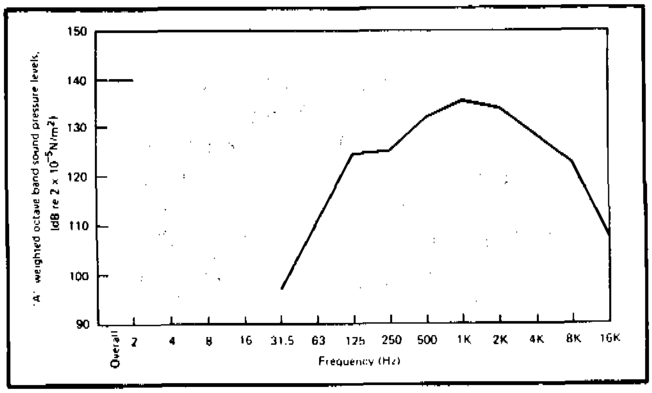


Figure 23. Maximum 'A'-weighted octave band levels occurring during first 150 ms after impact (0.125 s time constant) right hand microphone.

159.7 dB and 160 dB respectively. The figures were recorded with all of the windows closed.

This result can be compared with the over-riding limit of 150 dB of an instantaneous sound pressure in an impulse noise as quoted in the U.K. Code of Practice for reducing the exposure of employed persons to noise. (Ref 4).

HEADFORM IMPACT TESTS

Test Method

The crash test was followed by a series of impact tests on the interior surface, using a modified form of the test specified in Annex 4 of Regulation ECE 21 (Procedure for testing energy-dissipating materials). These tests were conducted at 14 specified points on the vehicle, distributed over the upper and lower facias, the header rail, and the windscreen pillars. The impact tests were carried out using an unrestrained spherical headform containing three accelerometers aligned with the impact direction and two other mutually perpendicular axes. This was fired at the impact point by a pneumatic launcher. The system incorporates two major advances over the normal ECE 21 pendulum test in matching more closely the conditions of a real accident:

1) The headform is capable of absorbing energy in rotation as well as translation when a glancing impact is made. A pendulum mounted headform is capable of absorbing energy only in translation.
2) The test is performed on a whole vehicle incorporating the damage resulting from the impact test, whereas the ECE 21 is normally conducted on segments cut from an undamaged car.

The impact speed of the headform was 6.7 m/sec and the impacts were aimed either in a direction originating from the area of the front seat occupants' heads for the header rail and upper facia or in a longitudinal direction for the lower facia tests. The signals were filtered to Channel Class 1000 to SAE J211b.

Headform Impact Test Results

The results of the tests are given as part of Table 3 the severity of the headform acceleration being expressed in terms of the peak magnitude of the Resultant Acceleration vector, the Gadd Severity Index, and the Head Injury Criteria. The points impacted are given in Figure 24 and may be divided into two groups. The first group are contactable in the initial or primary vehicle impact. Examples of this are the upper surface and underside of the facia which generally give rise to impacts of low severity as a result of their energy-absorbing characteristics. The second group are protected by the airbags during the primary impact but then might be contacted in a secondary vehicle impact when the airbag has deflated.

In some cases, the latter produce more severe accel-

Table 3. Headform impact tests—impact speed 6.7 metres/sec (15 mile/h)

Impact Position (Figure 24)	Minicars RSV			Calspan RSV		Chrysler Alpine	
	Peak g	Gadd SI	HIC	Peak g	Gadd SI	Peak g	Gadd SI
A	275	1134	893	47	161	94	—
B	46	178	157	59	206	57	100
C	34	95	87	45	321	47	140
D	33	61	51	40	141	88	292
E	59	111	79	—	—	—	—
F	170	961	820	61	227	61	176
G	112	423	354	79	305	88	239
H	30	83	76	—	—	—	—
I	123	440	369	58	210	58	151
J	24	59	53	—	—	—	—
K	*114/221	467/376	378/339	35	85	69	186
L	89	372	344	—	—	—	—
M	27	48	41	—	—	—	—
N	44	112	103	167	576	63	192
Belt anchorage	—	—	—	235	1621	104	524

* The second figure refers to a secondary impact of the headform on the inside of the windscreen, which it struck in rebounding from the impact point.

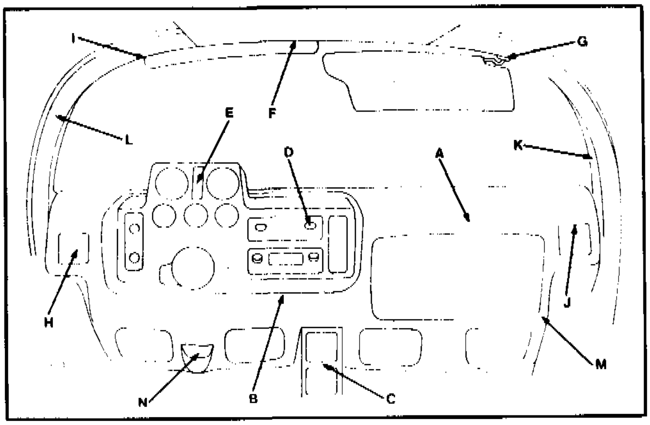


Figure 24. Headform impact position code.

erations of the headform, as for example at point A (see Fig 25), where the edge of the airbag container lies inside the facia covering material, and at point F near the centre of the header rail. Some impact areas resulted in sharp fragments of material being produced which could cause lacerations to an occupant. This occurred at points D and E on the instrument panel and to a limited extent at point C on the centre console.

DISCUSSION

The Minicars RSV Crash Test

The RSV impacted the 30° wood faced angled barrier at a speed of 60.3 km/h. The driver's (port) side of the vehicle made first contact.

The vehicle structure met the intrusion requirements of ECE Regulation 33 with regard to front occupant survival space.

Two Part 572 dummies were positioned in the front seats. Analysis of the signals from the dummy instrumentation showed that they met the requirements of FMVSS 208.

Both the restraint systems functioned; but whereas the passenger's system started to deploy 0.017 after first contact, the driver's system did not start until 0.045 sec.

The 30° angled port side barrier impact requirements of FMVSS 301 were met, there being no fuel leakage during the impact or the 30-min. period following impact. However, when the vehicle was subjected to the static rollover test required in the regulation, a fuel leak that exceeded the limit set in the regulation was observed. After the fuel leak had been stopped by removing a hose from the filler pipe and sealing it off, the test was repeated. This time there was no fuel leakage. Therefore, if a fuel-tight joint had been made to the filler pipe, the vehicle could have met the static rollover test requirements of FMVSS 301.

The peak noise pressure levels were measured to be 159.7 dB for the left side of the driver's head and 160 dB for the right side of the driver's head with all of the windows closed. These exceed the 150 dB level recommended in the Code of Practice for Reducing Exposure of Employed Persons to Noise.

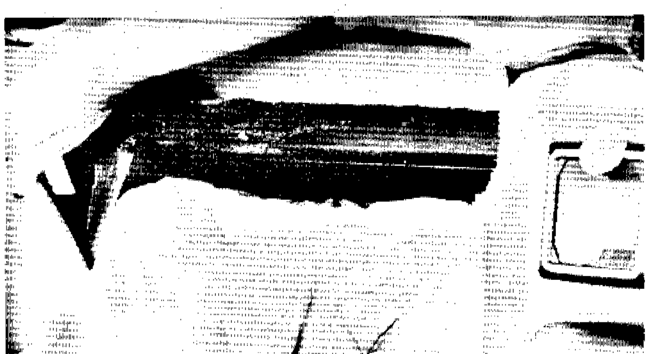


Figure 25. The metal work of the passenger's airbag container.

The Minicars Headform Impact Tests

The results of the headform impact test show that although the areas in the front of the car which might be contacted in the primary impact are well protected, there are points which may be contacted in the secondary impacts which require additional protection. This would be in the form of improved energy-absorbing material on the facia and header rail (at points A and F, Fig 24) and a change to a material that does not produce sharp fragments when impacted on the instrument panel and data console (points C, D, and E, Fig 24).

Comparison of the Minicar's RSV with the Calspan/Chrysler RSV and a Standard Production Chrysler Alpine

The combined results of the three cars are given in Tables 1, 2, and 3. The Chrysler Alpine car was the baseline production car used to develop the Calspan RSV. Although the Minicars RSV had the greatest overall static crush, the survival space as defined by ECE Regulation 33 was greatest for this car with only the Alpine production car being less than is required for different conditions in the regulation. The increased crush in the Minicars RSV is reflected in a lower vehicle deceleration pulse measured at the A-post on the impacted scale, with a corresponding increase in duration.

With a minor design modification to the Minicars fuel filler system, both RSVs would have passed the static rollover test of FMVSS 301. The Chrysler Alpine production car was not tested to the standard.

As the occupant restraint for each car was different, their effectiveness can only be assessed by the dummy performance. The Chrysler Alpine had standard production lap and diagonal belts; the Calspan RSV had a steering wheel airbag and a passenger inflator belt with knee restraints for both; and the Minicars RSV had airbags with knee restraints. Although the noise level in the Minicars RSV was 165 dB, it cannot be directly compared to the Calspan RSV result of 153 dB since the Minicars RSV windows were closed and the Calspan RSV windows were not.

Although a different type of dummy was used in the Chrysler Alpine test and a direct comparison between the tests should not be made, the indications are that there was a marked improvement of the injury criteria for the heads of the RSV passengers and the Calspan driver. The injury criteria for the Minicars driver's head are within FMVSS 208 but, possibly due to the late deployment of the airbag, are no better than a typical standard production car. The chest accelerations for all the cars were similar. The axial femur forces were higher for both RSVs and reflect the use of knee bolsters as part of the restraint design as compared to the production vehicles' use of lap and diagonal belts as the primary restraint. In all cases the femur loads were below the maximum allowed in FMVSS 208. The high lateral acceleration at the pelvis of the Minicars RSV driver does not necessarily imply an injurious loading as it will depend on the position and distribution of the accelerating force.

Because of the different design concept of the Minicars RSV, direct comparisons of headform impact tests between cars at specific points in the passenger compartment were not always possible (e.g., there is no upper anchorage for a seat belt on the B-post in the Minicars RSV). The impact positions given in Table 3 relate directly to the Minicars RSV and, where possible, the results for the equivalent position in the other two cars have been given. The design requirement to provide a rigid door hinge mounting down the centreline of the roof of the Minicars RSV is reflected in the higher figures for the car's header rail and windscreen pillars (points F, G, and I, Fig 24). The need to cover with an energy-absorbing material certain small but critical impact areas that will not necessarily be identified by the barrier test is highlighted by the Calspan RSV figure for the seat belt upper anchorage and the steering column (point N). The attention given in both RSVs to impact protection over the area of the centre console is shown by the higher figure on the standard production car (point D). Comment has already been made on the need to protect against secondary vehicle impacts when airbags may no longer be providing protection (point A).

CONCLUSIONS

The protection provided for occupants of the Minicar RSV in a 60 km/h 30° angled barrier impact appears to be generally of a high order. A few revised details of interior design and functioning of components would further improve the results.

Comparisons with the Calspan RSV and its baseline car, the Chrysler Alpine, show the improvements in protection that can be provided. Most particularly intrusion around occupants has been prevented and a severe impact to the head of the front passenger has been eliminated. The results show both the good protection in a standard production car that can be provided for wearers of seat belts against most injuries and the high level of protection that is demonstrated to be possible by the RSV cars.

REFERENCES

1. Friedman D. The Minicars Research Safety Vehicle. Presented to the Eighth RSV Conference Wolfsburg October 1980.
2. Smith, B F and Petty S P F. The Results of Headform Impact and Angled Barrier Tests on the Calspan RSV. Presented to the Eighth RSV Conference Wolfsburg October 1980.
3. Lowne R W. A Revised Upper Leg Injury Criteria (Unpublished).
4. Code of Practice for Reducing the Exposure of Employed Persons to Noise. Page 6, Section 4.7 HMSO 1972.

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Design and Development of Modified Integrated Vehicle for Enhanced Crashworthiness

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ABSTRACT

The report summarizes the work of Volkswagenwerk AG in the MIV (Modified Integrated Vehicle) Research Project of the U.S. Department of Transportation, National Highway Traffic Safety Administration.

Within the framework of the MIV Project Volkswagenwerk was requested by NHTSA to develop concepts and structures which would harmonize contradictory design considerations—the greatest possible reduction in dummy loadings with the lowest possible vehicle weight increase under the precondition that the design be suited to current mass production methods. The 4 door-Volkswagen Rabbit was to serve as the basis of the study.

The NHTSA goals mandated the development of new technology in conjunction with new test configurations and devices for lateral impact at 30 mph and frontal fixed barrier impact at 35 mph.

The realization of NHTSA's project goals necessitated the development of an all-new "Integrated Structure," a concept in which the greatest number of components is effective during the defined frontal and lateral impacts.

The specific goals established by NHTSA were met in the MIV project. The results of Phase 1 demonstrate a potential for promising reductions in dummy loadings. However, because these reductions were observed in only a single test, the results are presently not sufficient to justify the incorporation of MIV components into production vehicles. Further research on a broader scale with a broad range of vehicle types is required. The MIV project is an important step, but only one of many which must be taken in the complex research effort necessary to realize further increases in existing levels of passive safety in real world lateral and frontal collisions.

INTRODUCTION

The objective of the MIV project was to optimize two contradictory design considerations—the greatest possible reduction in dummy loadings at the lowest possible vehicle weight increase (max. increase 20 lb/vehicle) with the precondition that the design be suited to mass production.

The MIV is by definition not a totally integrated concept as discussed and presented by Volkswagenwerk AG during the Eighth ESV Conference or as demonstrated in the form of the Volkswagen Integrated Research Vehicles IRVW I and II. The MIV, in contrast, does not include consideration of special energy saving or special emission reduction engine/transmission concepts.

Because vehicle layout, according to established criteria and subsequent reinforcement for modified design criteria, always leads to substantial weight increases with commensurate limitations upon producibility, it was decided not to use the "add-on" strategy, but to develop an all new "Integrated Structure" for the 4 door MIV. This concept requires that the largest possible number of components be effective during the specified frontal and side impacts.

NHTSA's design goals were the 35 mph frontal fixed barrier impact and the 30 mph side impact with the new 1.565 kg (3,450 lb) deformable 19° Crabbed Barrier and the new HSRI Dummy which were specially developed for the side impact.

STATEMENT OF WORK

Vehicle engineering measures for the increased passive safety requirements specified in the project were to be derived from the results of baseline tests as well as from the know-how gained in the ESVW I, ESVW II, RSVW, IRVW I and II projects. The effects of these measures were to be examined in defined tests:

—19° Crabbed Barrier/4 door MIV-60° side impact at 30 mph impact velocity
—4 door MIV/Fixed Barrier head-on impact at 35 mph impact velocity

The NHTSA goals mandate the development of new technology in conjunction with new test configurations and devices for lateral and frontal impacts.

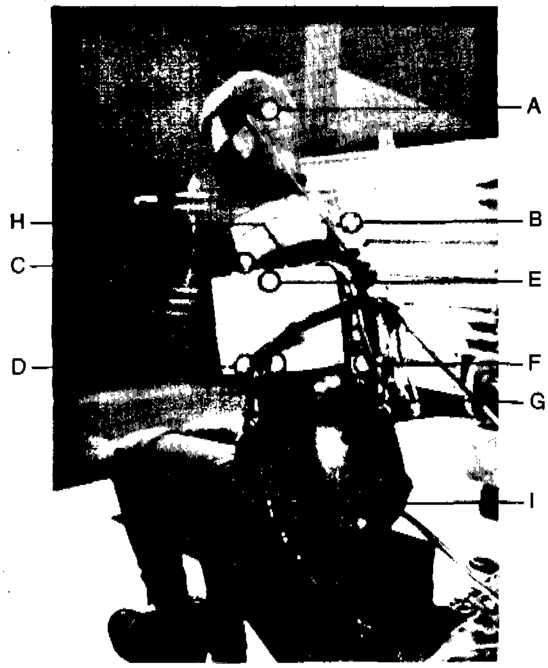
—for greatest possible reduction in dummy loads
—for lowest possible weight increase
—consistent with current mass production methods.

Initially several baseline side impact tests with unmodified vehicles were to be performed at 30, 35, and 40 mph to assess the dependency of impact velocity upon dummy loadings and vehicle deformation.

The new HSRI Side Impact Dummy and the newly developed Crabbed Barrier (Figures 1, 2, and 3) were used. The deformable moving barrier was crabbed at an angle of 19°. The impact is intended to simulate a 60° car-to-car side impact where the velocity of the striking vehicle is twice that of the struck vehicle.

The initial tests were to constitute the basis for modifications to be derived to meet requirements for increased

Figure 1. HSRI side impact dummy sid.



A. Head Triaxial
B. Upper Thorax (T1), Triaxial
C. Upper Sternum, Longitudinal
D. Lower Sternum, Longitudinal
E. Left and Right Upper Rib, Lateral
F. Lower Thorax (T12), Triaxial
G. Left and Right Lower Rib, Lateral
H. Displacement Transducer
I. Pelvis, Triaxial

LOCATION OF 18 ACCELEROMETERS

passive safety in the impact configuration defined in the MIV project.

TEST PARAMETERS AND TESTS PERFORMED

Test Parameters

All tests were run under the following conditions as specified by NHTSA:

—Side Impact:

Striking vehicle:	simulated by the deformable Crabbed Barrier
Struck vehicle:	4 door VW Rabbit or MIV
Impact point:	I = (D + 6) / 0.8693 + 1.5 (in)
Impact angle:	60°
Dummies:	two 50% male HSRI at the impacted side, front and rear seating positions, as delivered by NHTSA

Protection criteria for the HSRI Side Impact Dummy were specified by NHTSA as: "Volkswagen shall use measures so that the largest possible reduction in dummy loads is achieved."

—Frontal Impact:

Impact speed:	35 mph
Impact angle:	0°
Dummies:	two 50% male Hybrid II on the front seats
Protection criteria:	FMVSS 208

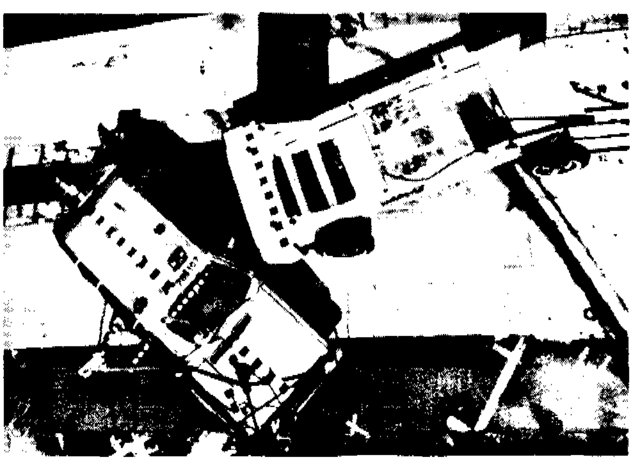
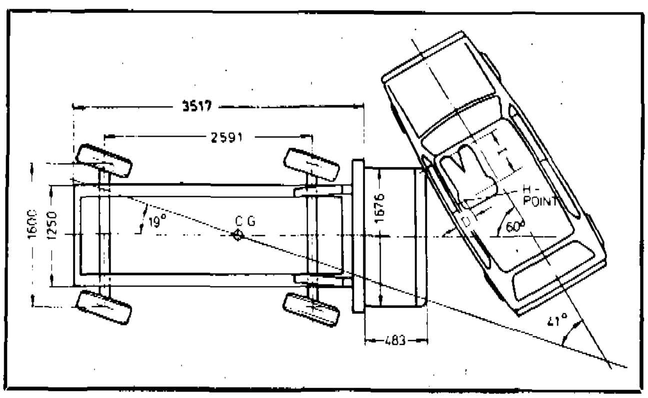


Figure 2. Side impact test configuration.



IMPACT POINT : I=(D+6)/0.8693+1.5 (IN)

Figure 3. Side impact test configuration point of initial contact.

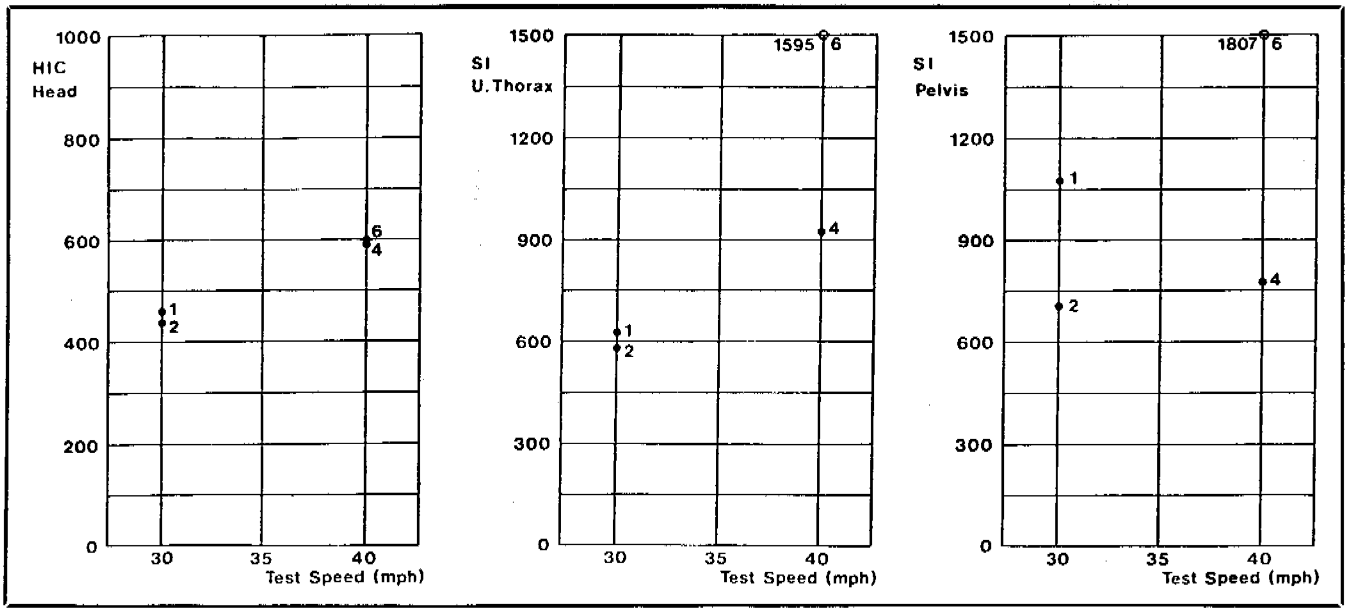


Figure 4. Baseline side impact tests 1, 2, 4 and 6. Scatter determination.

Tests Performed

The following side impact tests were conducted:

—Baseline Side Impact Tests with 4 door VW Rabbits

Test 1	30	
Test 2	30	
Test 3 v =	35	mph
Test 4	40	
Test 6	40	

—Side Impact Tests with 4 door MIV

Test 5	30	
Test 7 v =	30	mph
Test 8	30	

Test 5: Side impact with the new MIV "Integrated Structure" developed in this project and the MIV padding.

Test 7: Side impact with MIV padding only.

Test 8: Side impact with the MIV "Integrated Structure" without MIV padding.

Baseline Tests

Baseline side impact tests were conducted for the following reasons:

a) For determination of the scatter of dummy loadings and vehicle deformation under identical test conditions
b) To evaluate the dependency of dummy loadings and vehicle deformation upon different impact velocities
c) For derivation of modifications for the increased passive safety requirements specified by NHTSA in this project

Scatter Determination

For scatter determination, tests 1 and 2 were performed at 30 mph, and tests 4 and 6 at 40 mph. The scatter for driver dummy loadings is shown in Figures 4 and 5. The transformation of mechanical parameters to medical AIS values (see Figure 5) is described and discussed in the paper of Richard M. Morgan and Hal P. Waters entitled "Comparison of two Promising Side Impact Dummies," presented at the Eighth ESV Conference. The transformation algorithm is still under development. In a comparison of tests 1 and 2, the chest damper, modified by NHTSA, probably caused the greater portion of the scatter. In tests 4 and 6 the scatter was probably caused by the deformation element of the Crabbed Barrier. In test 4 the element had slight exterior cracks.

Dummy Loading as a Function of the Collision Speed

The test results show that there is an increase in dummy loads with increasing impact velocity if only the test results from tests 2, 3, and 6 are compared (Figure 6).

Derivation of Modifications

Analysis of the baseline tests led to the development of the MIV for increased passive safety requirements in specified side impacts.

VW STUDY FOR COMPLIANCE WITH THE MIV REQUIREMENTS IN SPECIFIED LATERAL AND FRONTAL IMPACTS

The NHTSA goal to achieve the greatest possible reduction in dummy loads, in keeping with the objective of

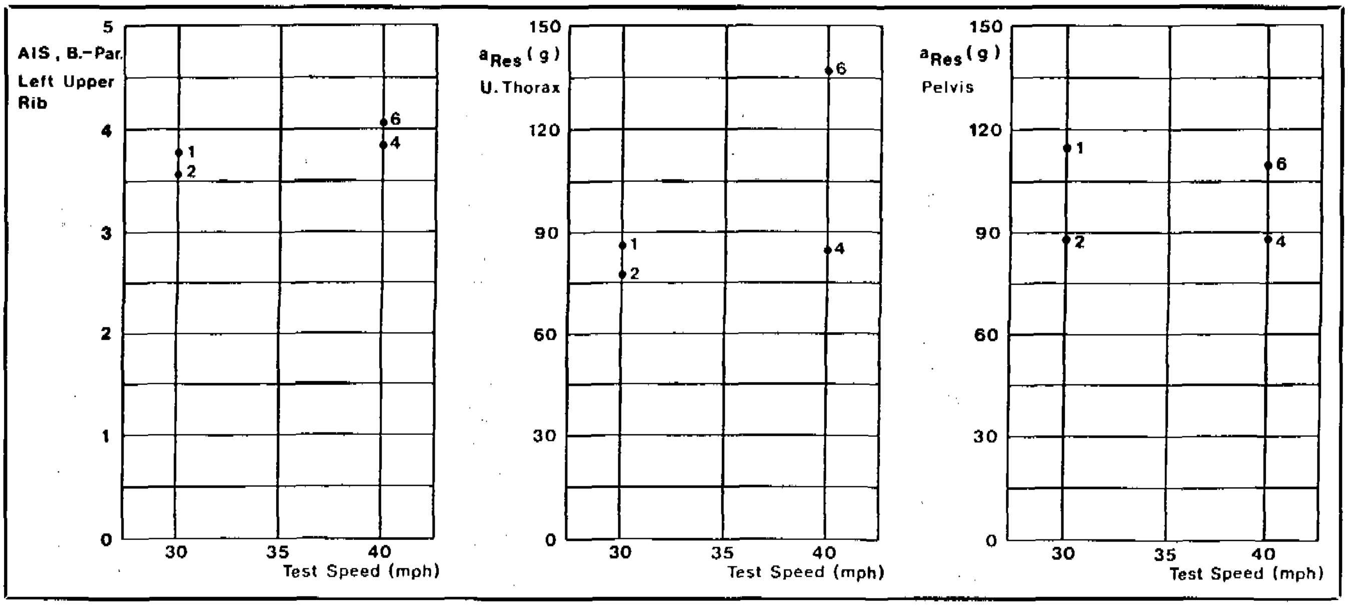


Figure 5. Baseline side impact tests 1, 2, 4 and 6.

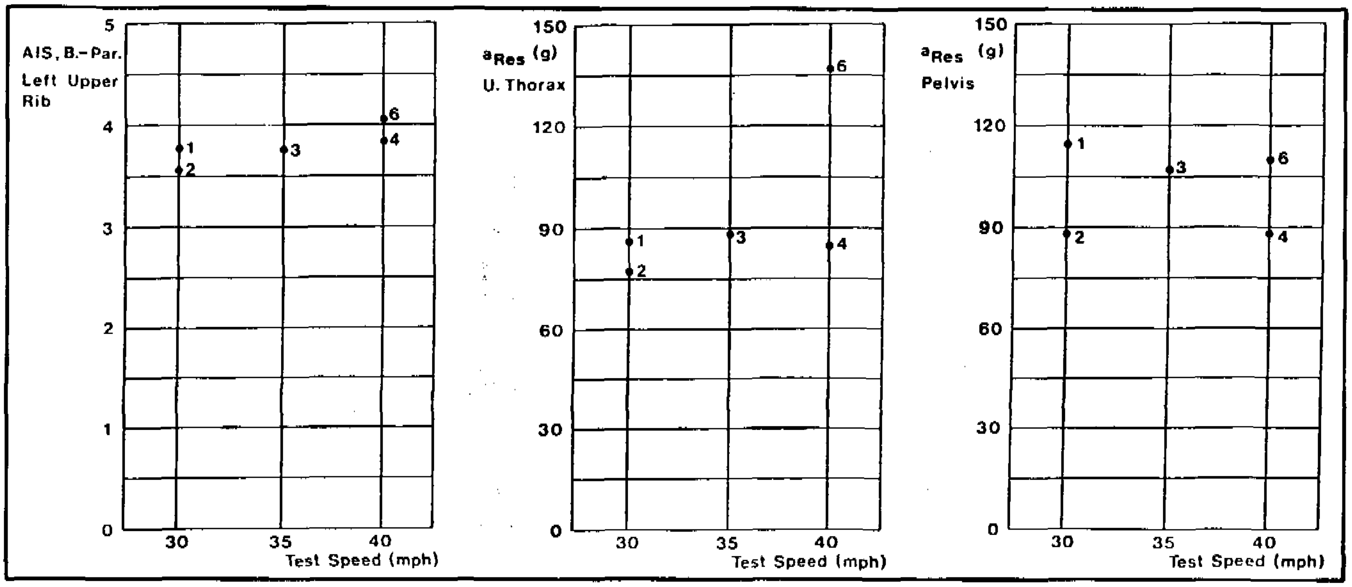


Figure 6. Baseline side impact tests 1, 2, 3, 4 and 6.

lowest possible weight increase together with the prerequisite that the design be suited to mass production, required the development of a new "Integrated Structure" for the MIV. This concept requires that the greatest number of components be effective during frontal and side impacts. The "Integrated Structure" approach involving total redesign, rather than the less effective strategy utilizing add-on parts, is necessary to achieve the goals established by NHTSA.

The MIV Integrated Structure (Figure 7) was developed in conjunction with the unique combination of test configurations and test devices specified by NHTSA in this project.

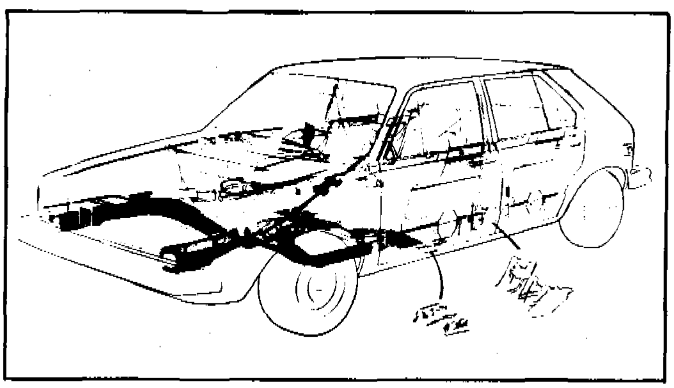
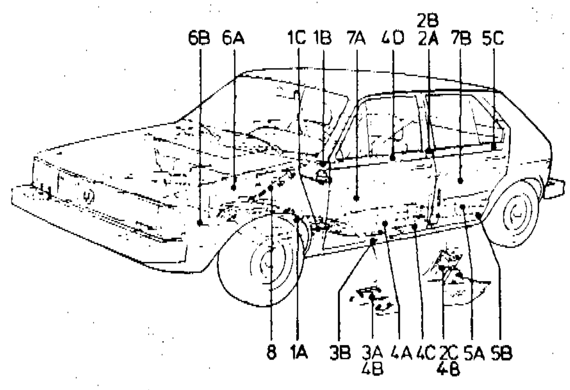


Figure 7. MIV structure.



(1) A – PILLAR
1A WHEELHOUSE BEAM
1B A–PILLAR BRACE
1C HINGE TO A–PILLAR ATTACHMENT PLATE

(2) B – PILLAR
2A WINDOW BEAM SUP.
2B B–PILLAR BRACE
2C DOOR TO B–PILLAR ATTACHMENT

(3) SILL BEAM
3A DOOR BEAM AND SIDE SILL INTERLOCK
3B SIDE SILL BRACING PLATE

(4) FRONT DOOR
4A DOOR BEAM
4B DOOR BEAM INTERLOCK
4C DOOR LOCK MOUNTING
4D SIDE WINDOW BEAM

(5) REAR DOOR
5A DOOR BEAM
5B DOOR LOCK MOUNTING
5C SIDE WINDOW BEAM

(6) FRONT STRUCTURE
6A UPPER BEAM
6B LONGITUDINAL BEAM

(7) DOOR PADDING
7A FRONT DOOR PADDING
7B REAR DOOR PADDING

(8) STEERING SYSTEM

Figure 8. MIV structural components.

The structural components (Figure 8) are:

(1) *A-Pillar*
1A Wheelhouse Beam
1B A-Pillar Brace
1C Hinge to A-Pillar Attachment Plate

(2) *B-Pillar*
2A Side Window Beam Support
2B B-Pillar Brace
2C Door to B-Pillar Attachment

(3) *Sill Beam*
3A Door Beam and Side Sill Interlock
3B Side Sill Bracing Plate

(4) *Front Door*
4A Door Beam
4B Door Beam Interlock
4C Door Lock Mounting
4D Side Window Beam

(5) *Rear Door*
5A Door Beam
5B Door Lock Mounting
5C Side Window Beam

(6) *Front Structure*
6A Upper Beam
6B Longitudinal Beam

(7) *Door Padding*
7A Front Door Padding
7B Rear Door Padding

(8) *Steering System*

TESTS WITH MIV VEHICLES AND COMPONENTS

Side Impact with MIV

The side impact (test 5) with the MIV incorporating the new "Integrated Structure" and MIV side padding demonstrated a promising potential for reductions in dummy loading (Figure 9). Structural deformation was also reduced (Figure 10). The PAP values shown are part of a new algorithm currently under development by NHTSA to transform mechanical parameters into medical AIS values.

The reduction in dummy loadings cannot be reliably attributed or assigned to individual MIV components because dummy loadings are dependent upon test parameters and many other factors including but not limited to:

—force/deflection characteristic of the front structure of the striking car
—force/deflection characteristic of the side structure of the struck car
—force/deflection characteristic and dimensions of the padding, and
—free space between the dummy and the padding.

Comfort is reduced and vehicle operability is impaired by the padding selected and installed primarily under considerations of technical feasibility without emphasis upon comfort or interference with operability.

The demonstrated reduction in dummy loading with the relatively low overall weight increase confirms that

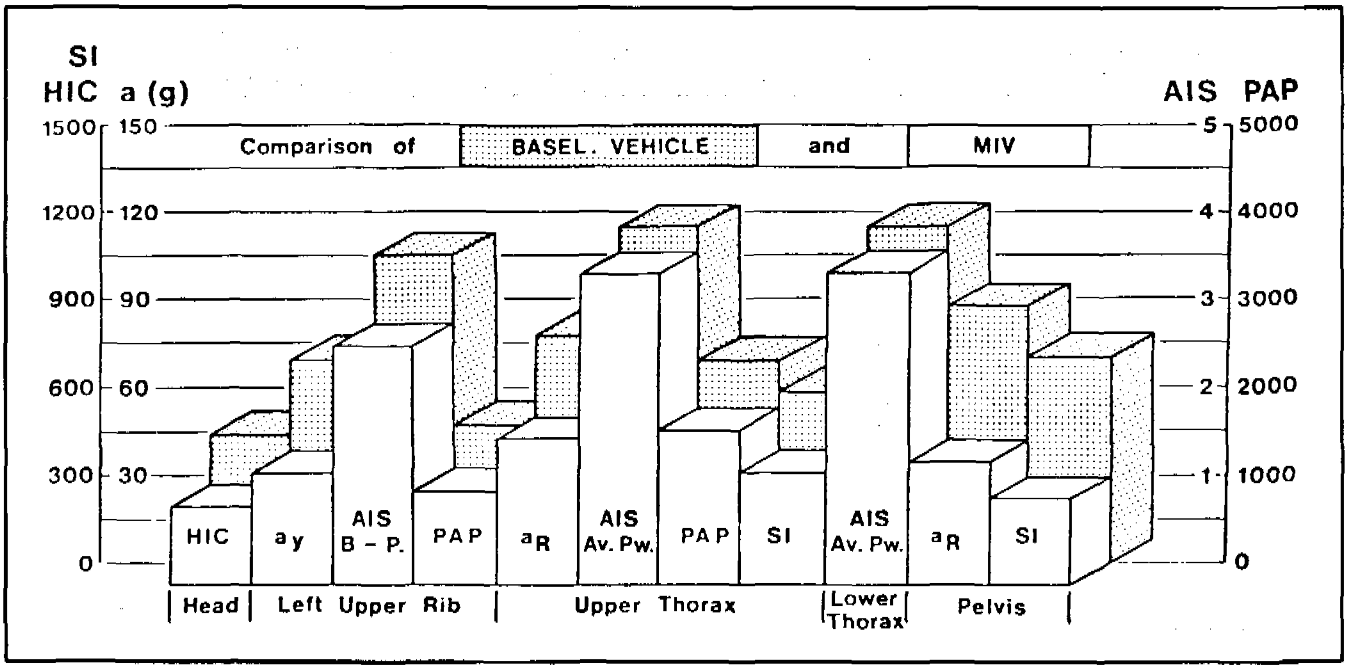


Figure 9. Side impact test 5.

an integrated approach is the only appropriate manner to deal with contradictory considerations of increased levels of passive safety and low weight increase consistent with current mass production methods. The extent to which this potential can actually be realized will depend, in part, upon the performance of MIV structures in defined side impacts when struck by the stiffer MIV frontal structures developed for the 35 mph frontal fixed barrier impact.

Side Impact with MIV Door Padding Only

The objective of test 7 was to evaluate the potential for reduction of dummy loads using only the same door padding as used in test 5 but without MIV structural components. The higher reduction of dummy loads using the "Integrated Structure" and the MIV door padding is evident (Figure 11).

Side Impact with MIV Structure Only

The purpose of test 8 was to determine the effect of the "Integrated Structure" without MIV padding on dummy loads (Figure 12).

A comparison of tests 7 and 8 demonstrates that the left upper rib values in test 7 are lower, some upper thorax and the lower thorax and pelvis values are higher when only the MIV padding is used (Figure 13).

Baseline Vehicle

MIV

Figure 10. Side impact comparison of test 2 and 5.

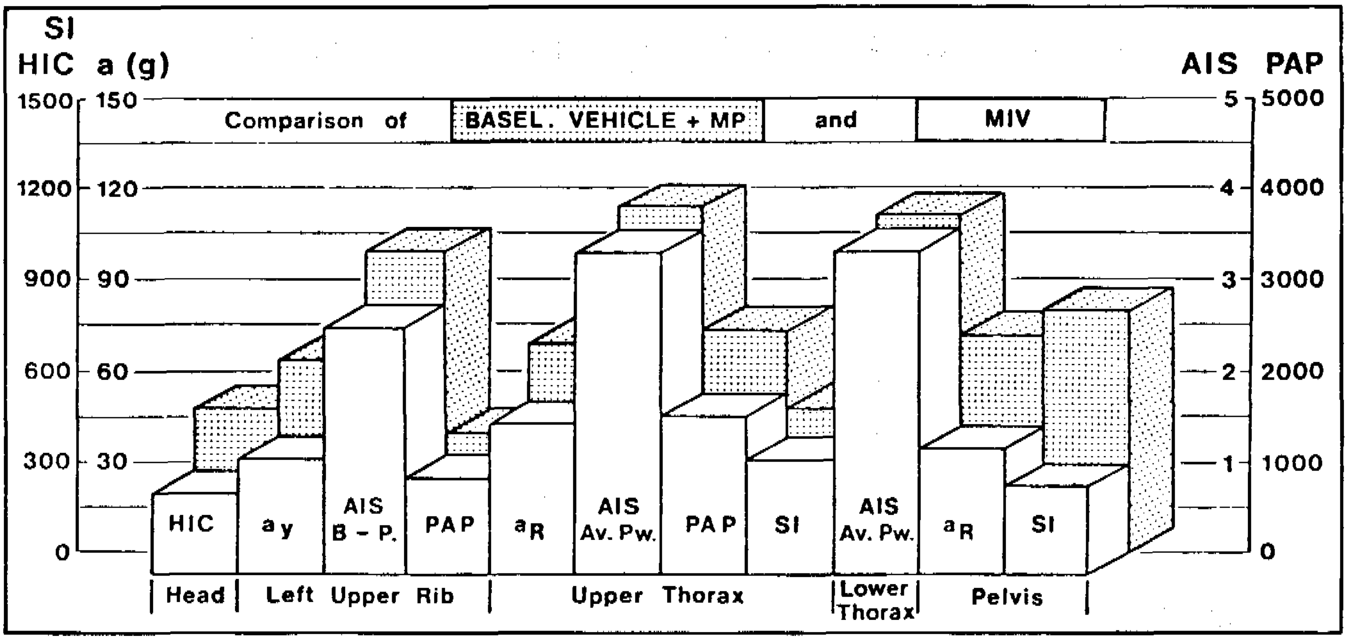


Figure 11. Side impact test 7.

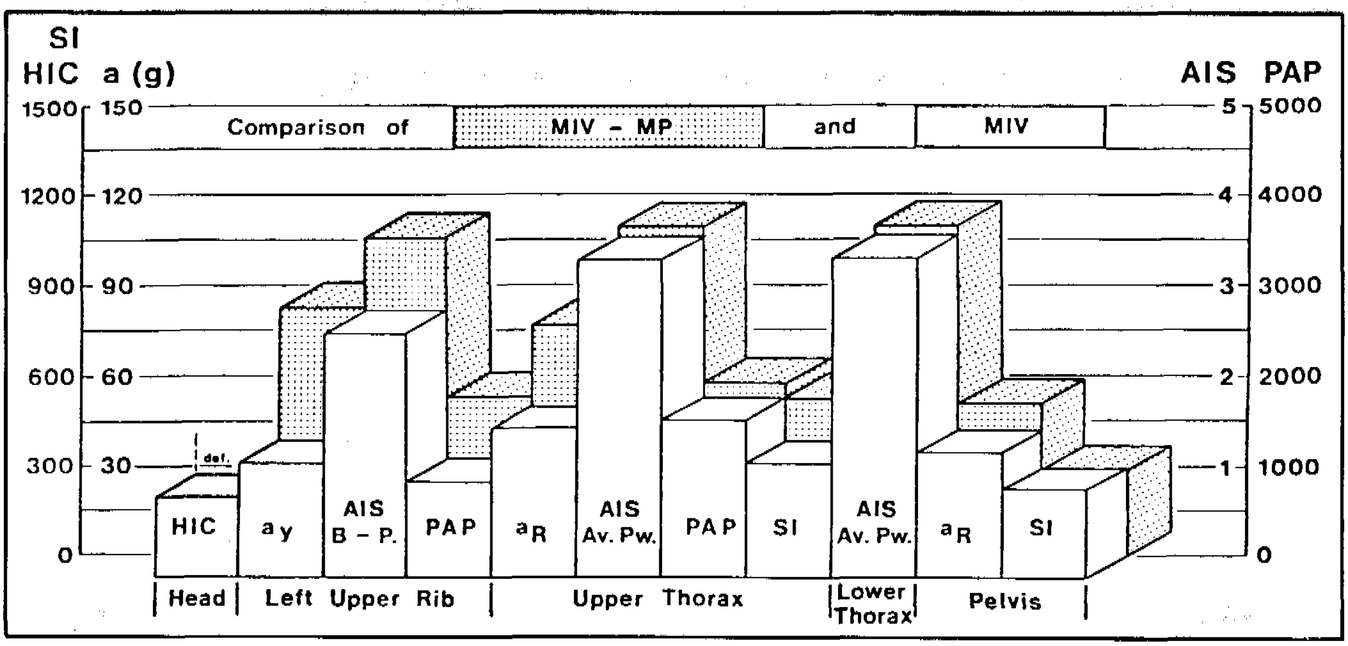


Figure 12. Side impact test 8.

In general, MIV padding will be less effective than the newly developed "Integrated Structure;" it also decreases occupant comfort and interferes with vehicle operability.

Reduction of the thickness of the padding for occupant comfort and non-impairment of vehicle operability will reduce the effectiveness of the "padding only modification."

Frontal Fixed Barrier Impact with MIV

The head-on fixed barrier impact was conducted with the MIV at 35 mph (Figure 14). Working principles of a new passive restraint system and a new steering system were simulated together with the new "Integrated Structure."

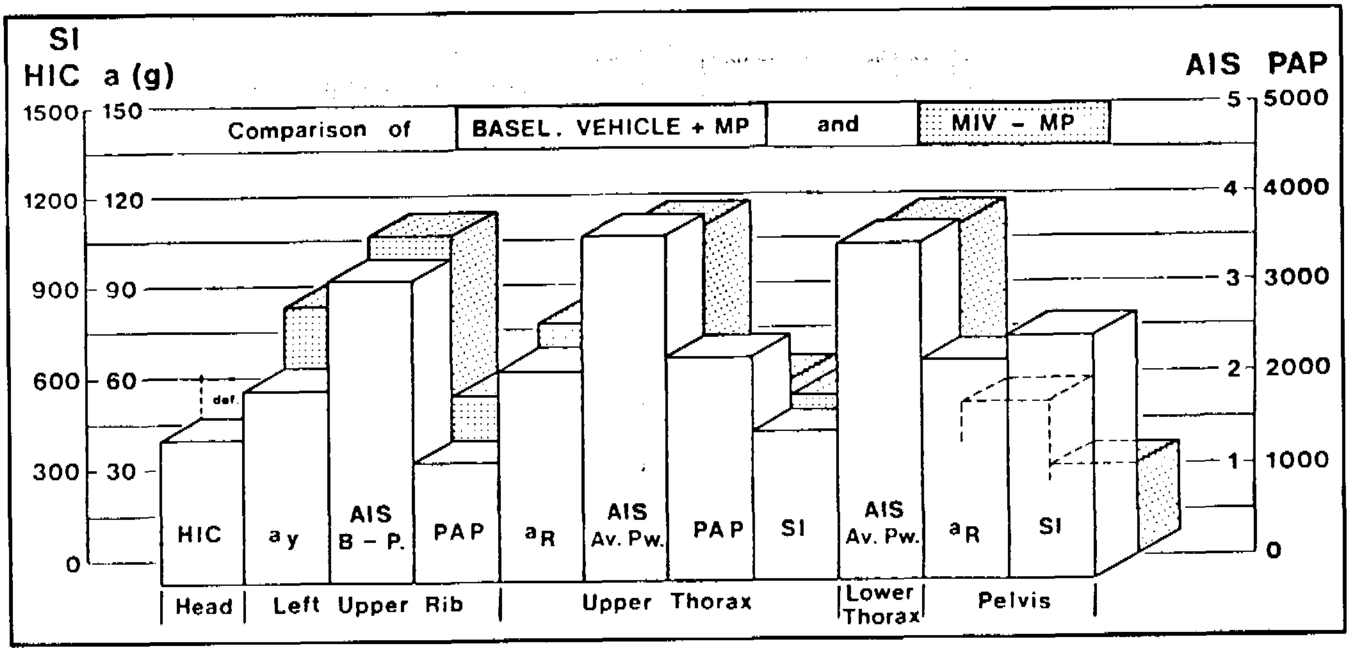


Figure 13. Side impact test 7 and 8.

Figure 14. Frontal impact with MIV.

Impact Speed = 35 mph.

The MIV complied in all respects with impact related FMVSS (Table 1).

SUMMARY

In Phase 1 of the MIV project, VW AG examined approaches which appear technically feasible for the 30 mph side impact with the Crabbed Barrier and the 35 mph frontal fixed barrier impact under the following limiting conditions:

a) Maximum additional weight for the new structure and restraint system modifications: G = 20 lb
b) Maximum padding thickness without widening the vehicle, considering seat positioning and near contact by the 95% male dummy
c) To achieve the greatest possible reduction in dummy loads
d) Maintaining the objective that the design be suited to mass production.

Tests Performed

Five side impact tests were carried out with the 4 door VW Rabbit at 30, 35 and 40 mph to ascertain dummy response at increasing test velocities.

Two of them were conducted with the 4 door Rabbit at 30 and 40 mph in order to evaluate scatter in vehicle deformation and dummy loading.

One side impact was conducted at 30 mph in order to evaluate the effect of the MIV components.

In addition, each side impact test was conducted with

Table 1. Frontal Impact with MIV.

	DRIVER	PASSENGER
HEAD : HIC	554	639
CHEST: A_r (G) (3MS)	38.1	40.3
SI	335	359
PELVIS: A_r (G) (3MS)	46.5	48.2
SI	381	371
FEMUR LOAD L/R (KN)	6.7/6.2	7.2/6.0

only MIV structure and MIV padding to demonstrate the influence of the individual MIV components.

One head-on fixed barrier impact at 35 mph demonstrates the effect of the MIV structure in conjunction with increased frontal impact requirements.

RESULTS

If evaluation is limited to tests 2, 3 and 6, an increase of dummy loads with higher impact velocity can be seen.

Evaluation of all baseline tests (Fig. 6) demonstrates that the scatter of dummy loads is greater than the influence of test velocity. If tests 1 and 4 are excluded because of difficulties with the deformation element (test 4) and the new damper (test 1) modified by NHTSA, repetition of these tests is necessary in order to be able to provide more information about the magnitude of scatter.

Comparison of the side impact tests 2, 5, 7 and 8 at the same test velocity with baseline vehicle, MIV vehicles and components clearly demonstrates that the best overall results in reduction of dummy loads were achieved with the combination of MIV structure and MIV padding. It must be noted, however, that the padding configuration utilized represented a reduction of occupant comfort and impairment of vehicle operability.

Widening the MIV by 140 mm for improved comfort and no impairment of vehicle operability in order to compensate for the 70 mm door padding would, however, probably further increase dummy loadings. In wider vehicles occupant loading may be higher because of the greater distance between dummy and padding. This hypothesis would have to be tested in appropriate vehicular impacts.

The head-on fixed barrier impact was carried out with the MIV at an impact velocity of 35 mph. The working principles of a new passive restraint system and a new steering system were tested in conjunction with the newly developed "Integrated Structure." The test results demonstrated compliance with all Federal Standards associated with the frontal fixed barrier impact.

Considering secondary weight, which is necessarily required in order to correspondingly stiffen load bearing structures and the chassis, the added weight of the MIV components is estimated to be 25 lb. The estimated weight increase is in reference to a specific vehicle with a specific engine/transmission concept from one manufacturer, without considering alternative concepts, or other components such as air conditioner, power steering, etc.

Furthermore the crash test results obtained relate in each case to only one specific test. Even the tests in this project demonstrate that there can be a wide scatter of results under the same test parameters. Statements of general nature or applicability with respect to existing production vehicles can only be derived from this program after tests with additional vehicle types have been completed. Parallel studies should therefore be accomplished on a worldwide scale in order to obtain statements of a general nature. This study should also include further validation of test procedures and devices.

The test devices must be developed and manufactured in accordance with the realities of crash testing practises.

CONCLUSIONS

The MIV demonstrated a promising potential for dummy load reduction in the defined lateral and frontal impacts.

Comfort is reduced and vehicle operability is impaired by the MIV padding utilized in this project.

Further tests with a widened MIV incorporating MIV padding must be conducted to evaluate the effect of increased distance between dummy and side padding, required for comfort and vehicle operability, upon dummy loads and to test the Phase 1 results achieved with closer dummy/padding proximity. It must be emphasized that increase in overall vehicle width will necessarily affect vehicle weight, payload, aerodynamic drag and other coefficients, fuel consumption and possibly consumer acceptance.

The dummy load reductions were achieved with a relatively low overall weight increase and in accordance with current mass production methods. In view of universally accepted considerations of fuel economy and economic use of resources, additional weight should only be incorporated in vehicles where associated advantages clearly outweigh all associated disadvantages and it is assumed that available restraints are used. The use of occupant restraints available today and required to be used in 30 countries, is a prerequisite for the achievement of increased passive safety through the incorporation of MIV structures and components. The frontal fixed barrier impact at an increased velocity of 35 mph can otherwise lead to an overall decrease in passive safety levels if available restraints are not employed because frontal structures will necessarily be stiffer and produce correspondingly higher loadings in other impact types.

The correlation between dummy loading and occupant injury must be established in order to permit statements applicable to real world accidents to be made and to justify incorporation of the MIV components tested into production vehicles.

Further research on a broader scale with a broad range of vehicle types is required to verify and correlate dummy loads and occupant injury with proposed test configurations and real world accident experience. Important considerations of vehicle compatibility cannot be ignored. Furthermore the influence that MIV components will have upon fuel consumption and the economic use of other resources, vehicle operability, comfort and purchase price must be studied in detail before statements of general applicability can be made.

No single isolated measure but rather only Integrated Concepts considering all previously described limiting conditions can be the proper means to achieve further increases in overall vehicle safety. The Integrated Structure with MIV padding of the Research MIV where the greatest number of components is effective during frontal and lateral impacts is the only aspect considered in this project.

The MIV project is an important step, but only one of many which must be taken in the complex research effort necessary to realize further increases in existing levels of passive safety in real world lateral and frontal collisions.

SVAR Alfa Romeo Synthesis Vehicle

3655

Alfa Romeo

THEME OF THE SVAR PROJECT

In the early 70s, projects were initiated on an international scale to improve the passive safety of vehicles. At first it was important to find a solution to set objectives, overlooking the effect of weights, costs, and/or results of production problems.

The sudden deterioration in world energy emphasized the consumption reduction issue alongside the passive safety of passengers—protection of drivers and pedestrians, pollution limits, etc.

The contemporary solution to these problems was not easy since most engine and structural projects are by nature in direct opposition to the demands of energy saving.

To this end, new research vehicles were sought to integrate the various concepts.

Under the ever-present pressure for fuel savings there are prototypes which address only this objective. Recently we have seen aerodynamic research vehicles with some exceptional Cx numbers between 0.20 and 0.30. Engines with extremely low specific fuel consumption are seen, such as the small turbo-diesels with direct injection. Ultralight prototype vehicles utilizing high-cost advanced techniques are another approach to reduce consumption and retain performance.

Finally it should be remembered that the car user, while he instinctively considers the passive safety of his vehicles important, remains very sensitive to the cost of fuel which represents a large percentage of the overall cost of the car's operation.

Alfa Romeo, in order to further its contributions to the research conducted so far, is using a base vehicle and placing large demands for a series of improvements with the simultaneous objectives of reduction in fuel consumption and increasing the levels of passive safety.

An Alfasud has been used to meet these objectives:

- determine fuel economy benefits utilizing today's technology, which could allow for fast adaptation to large production.
- the performance and handling characteristics must remain unchanged.
- obtain results to optimize the characteristics of passive safety.

BASE OBJECTIVES

PERFORMANCE

Maximum Speed	not below the standard base vehicle
Acceleration	
0 → 100 km/h from stop	
0 →1000 m from stop	
0 →1000 m in 5th gear starting from 40 Km/h	not below the standard base vehicle
Fuel Consumption (ECE A70)	
90 km/h	20% reductions as compared to base vehicle
120 km/h	20% reductions as compared to base vehicle
Urban	25% reduction as compared to base vehicle

PASSIVE SAFETY

Forecast verification tests

- 30° frontal impact at 65 km/h against barrier
- lateral car-to-car collision at 50 km/h
- impact at 50 km/h by 1800 Kg by moving barrier
- rollover at 50 km/h (control of fuel losses and dummy retention)
- pedestrian impact (adult or child) at 24 km/h

The dummies used for the tests were the Hybrid II type conforming to Part 572.

Injury criteria for occupant protection and pedestrians in impact tests:

- Head : HIC < 1000
- Chest : max acc. < 60 g/3 ms
- Femur : max axial force < 1000 dN

Performance required according to the following table:

	Frontal Impact	Lateral Impact	Roll Over	Rear Impact
Injury level	o	o		o
Doors must remain closed during impact	o	o	o	o
One door must be operative following impact	o	o	o	o
Possibility to remove dummies by hand following impact	o	o	o	o
No fuel leakage	o	o	o	o
Absence of fire	o	o	o	o
Total containment of occupants during impact	o	o	o	o
No failure of seat anchorages	o	o	o	o

RESEARCH PATHS

The basic objectives or goals of the research have been addressed according to the following groupings:

- *To lower fuel consumption*
  - Adoption of a high efficiency engine
  - Optimization of gearbox and final drive ratios
  - Lowering the aerodynamic drag-coefficient
  - Weight reduction
  - Reduction of rolling resistance
- *To increase safety*
  - Reinforcement of the front structure for improved frontal oblique impact resistance
  - Reinforcement of the rear structure to provide improved energy absorption during rear impact
  - Reinforcement of doors to reduce intrusion during car-to-car impact
  - Reinforcement of the windshield header area and addition of a roll bar in the central roof zone
  - Spoiler installation on engine compartment hood to protect pedestrians

MODIFIED VEHICLES

In order to carry out the required analysis, a vehicle was built which only included those features which tended to reduce fuel consumption (as indicated by the ESVAR-Energy Savings Vehicle Alfa Romeo), and another vehicle was developed to offer higher levels of people protection (SVAR-Synthesis Vehicle Alfa Romeo).

The ESVAR vehicle is to be considered a transitory effort to reduce fuel consumption, while leaving the handling qualities and occupant protection levels the same as those of production Alfasud vehicle.

The SVAR instead is the final product combining benefits of the ESVAR with those of improved passive safety by means of select reinforcement of the structures.

REFERENCE VEHICLES

One must take into consideration that a production Alfasud vehicle offers these principal characteristics:

Vehicle Body

- Front wheel drive. 4 cylinder opposed engine positioned longitudinally
  - Overall length 3995 mm
  - Overall width 1590 mm
  - Wheelbase 2455 mm
  - Track, front 1390 mm
  - Track, rear 1360 mm
  - Empty weight (DIN) 905 kg

Engine

- Flat four
- Bore 84 mm
- Stroke 67.2 mm
- Displacement 1490 cm^3
- Compression Ratio 9.5 : 1
- 2 carburetors, each with twin throats
- Maximum power DIN 70 KW (95 Cv) (6000 rpm/1')

- Maximum torque DIN 130 Nm (13.3 kgm) (3500 rpm/1')

Driveline

- Single dry disch clutch
- 5 speed transaxle

  Ratios

1st	1 : 3.75
2nd	1 : 2.05
3rd	1 : 1.38
4th	1 : 1.02
5th	1 : 0.82

- Final drive ratio 3.54 : 1 (11/39)

Performance

• Maximum speed	174 km/h
• Acceleration	
0 → 100 km/h from stop	10.70 s
0 →1000 m from stop	32.40 s
0 →1000 m in V from 40 km/h	40.65 s

Suspension and Tires

- Front suspension is McPherson struts and stabilizer bar
- Rear suspension is a solid axle located by a Watt link and Panhard rod
- Tires are 165/70 SR 13, wheel 5J

Fuel Tank

- Beneath rear seat, forward of rear axle

Vehicle Fuel Consumption

- Consumption ECE
  90 km/h 6.2
  L/100 km (37.9 mi/U.S. gal)
  120 km/h 8.1
  L/100 km (29.0 mi/U.S. gal)
  Urban 10.6
  L/100 km (22.2 mi/U.S. gal)

Compliance with European Standards for Passive Safety

The vehicle satisfies all European Standards in effect, including these:

- Steering system
  Reg. ECE 12
  Directive 74-297/EEC
- Seat belt anchors
  Reg. ECE 14.01
  Directive 81/575/EEC
- Seat anchors
  Reg. ECE 17.01
  Directive 81/577/EEC
- Visibility
  Reg. ECE 46
  Directive 79/795/EEC

Conformity with Emission Standard

- ECE 15.03-78/655/EEC

Conformity with External Noise

- ECE 51-81/334/EEC

FUEL CONSUMPTION REDUCTION

HIGHER EFFICIENCY ENGINE

After recent successful experiences by Alfa Romeo, it was decided to prepare a small number of Alfasud boxer engines with a microprocessor controlled electronic fuel injection and ignition system (C.E.M.) developed by Alfa Romeo.

Air fuel ratio and spark advance optimization in the whole engine operating range, correction for coolant and air temperatures, and fuel cut off during coast down ensure overall enhancement of engine efficiency and improved fuel economy. High accuracy of the microprocessor controlled ignition system made possible a compression ratio of 10.2 : 1. Work in process with knock sensors will hopefully bring this ratio to a higher value. The Complete Electronic Management System is programmed to permit a "modular" mode of operation: that is to say, the engine operates on 4 or 2 active cylinders according to the load conditions required by the driver.

2 cylinder operation is achieved simply by shutting off fuel injection in 2 of the 4 cylinders. In this way, the overall efficiency of the engine operating at varying low loads and at idle increases considerably. As low load operation and idling are very frequent in city driving, the final result is better fuel economy in these conditions.

Going on with the engine description and the schematic on the following page, we see (Fig. 1) injectors, and major engine components.

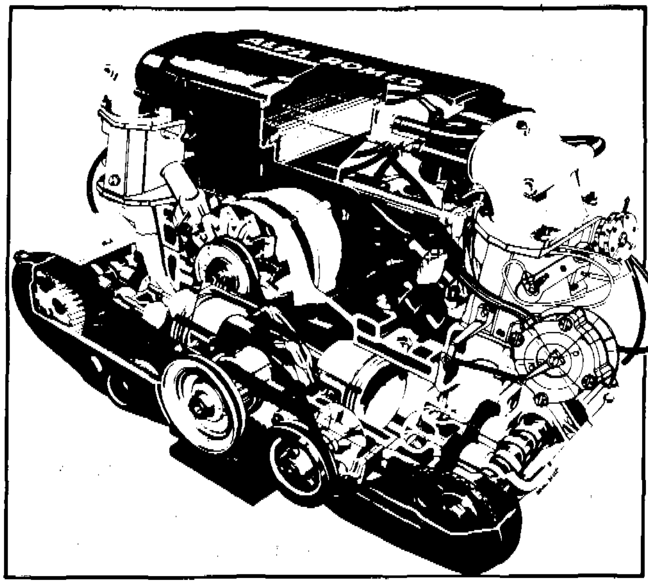


Figure 1. CEM engine.

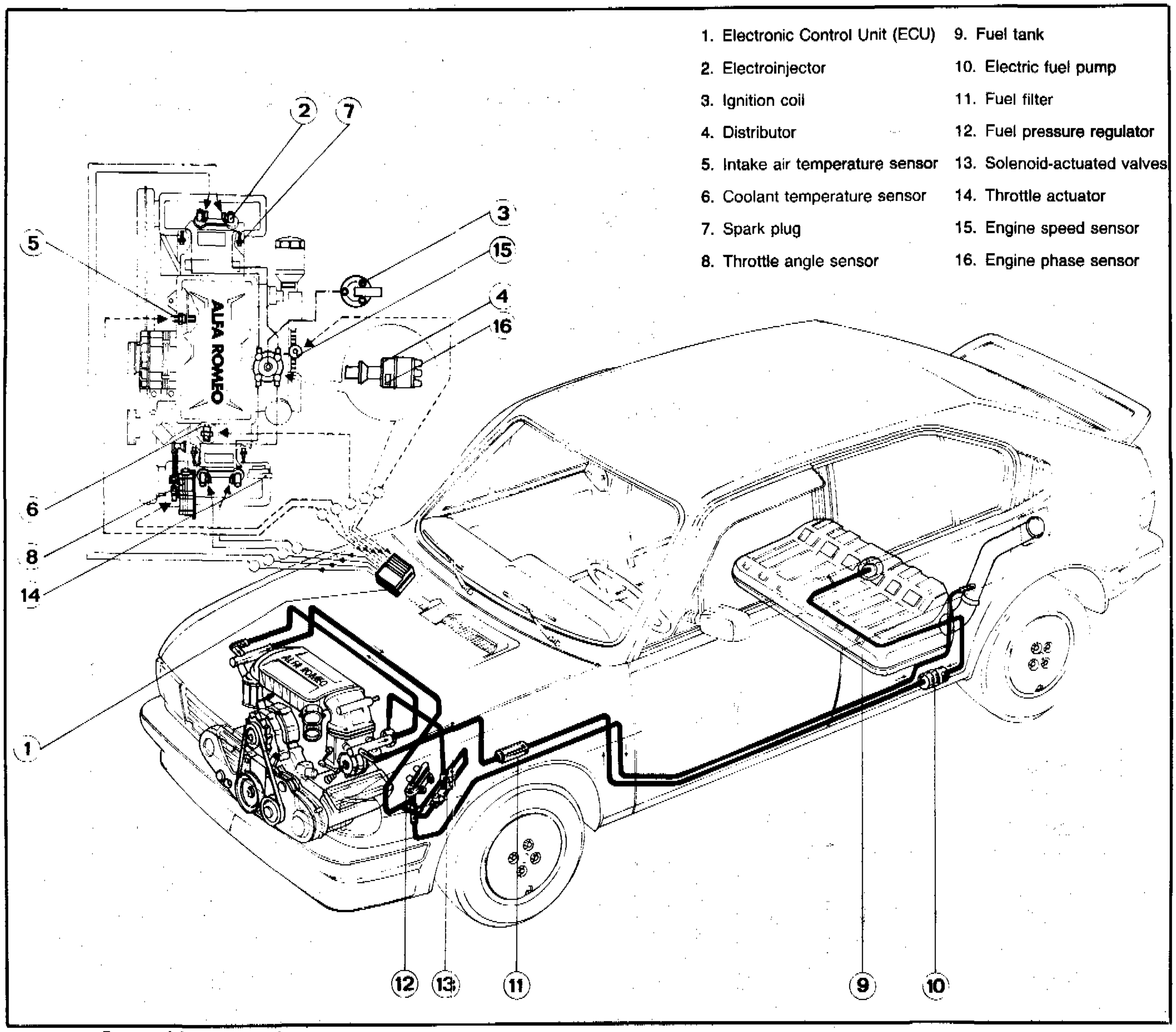


Figure 2. General layout engine.

The engine is fitted with the Complete Electronic Management, and can be seen in Figure 2 with its control box, sensors, and actuators.

The sensors are for:

- throttle angle
- engine speed
- engine phase
- coolant and intake air temperature

These sensors supply information to a digital microcomputer, based on an 8-bit microprocessor which, on the basis of calculations, algorithms and memory maps (program and mapping occupy 6 K bytes) drives the following actuators:

- 4 electroinjectors for fuel metering
- 1 special coil for spark advance
- throttle actuator to control engine idling speed

The idle actuator is useful on the 4 active cylinder CEM to secure constant idling speed under all conditions, but is essential for the "modular" mode of operation because maintaining idling speed with only 2 active cylinders requires wider throttle angles than would be with 4 cylinders in operation.

Flexibility of the system is such, that it was possible to develop the "modular engine" algorithm to achieve these interesting features:

- the passage from 2 to 4 cylinders and back to 2 is quick and smooth.
- 4 cylinder operation continues until the engine is warmed up.
- when the engine is running on 2 cylinders the two pairs change after a certain time and the accelerator is released in order to provide even temperatures in the engine and its combustion chambers. The driver is not aware of this pair switching.

- to ensure good driveability when starting from stop, a program provides 4 cylinder operation. For fast acceleration 4 cylinder operation continues until the change from 1st to 2nd gear is made.

This electronic controlled flat 4 Alfasud engine has the following specification:

displacement 1490 cc

max power (5400 rpm)
70 KW (95 Cv)

max torque (3500 rpm)
133 Nm (13.5 kgm)

In Figure 3 the B.S.F.C. map of this engine is shown as it relates to 4 cylinder operation.

Figure 4 demonstrates the difference in B.S.F.C. while operating in the modular mode. Notable is the benefit of reduced consumption during low speed operation typical of city use, as well as suburban trips at moderate speeds ($\leq$ Km/h).

OPTIMIZATION OF FINAL DRIVE RATIO

With the intent to operate the engine in conditions more favorable for lower fuel consumption, a more direct (longer) ratio was selected (3.15 compared to 3.54).

Below is a comparison of the overall drive ratios:

Ratio	Km/h/1000 rpm	
	3.15	3.54
4th Gear	32.39	28.29
5th Gear	40.29	35.23

A performance comparison between the base vehicle and the modified vehicle can be seen in the test results.

DRAG REDUCTION

Aerodynamic research has been carried out in the Pininfarina Wind Tunnel facility.

The steps from the original configuration to that of the final are these:

$$\text{baseline vehicle} \begin{cases} S = 1.714\ m^2 \\ Cx = 0.423 \\ Scx = 0.725\ m^2 \end{cases}$$

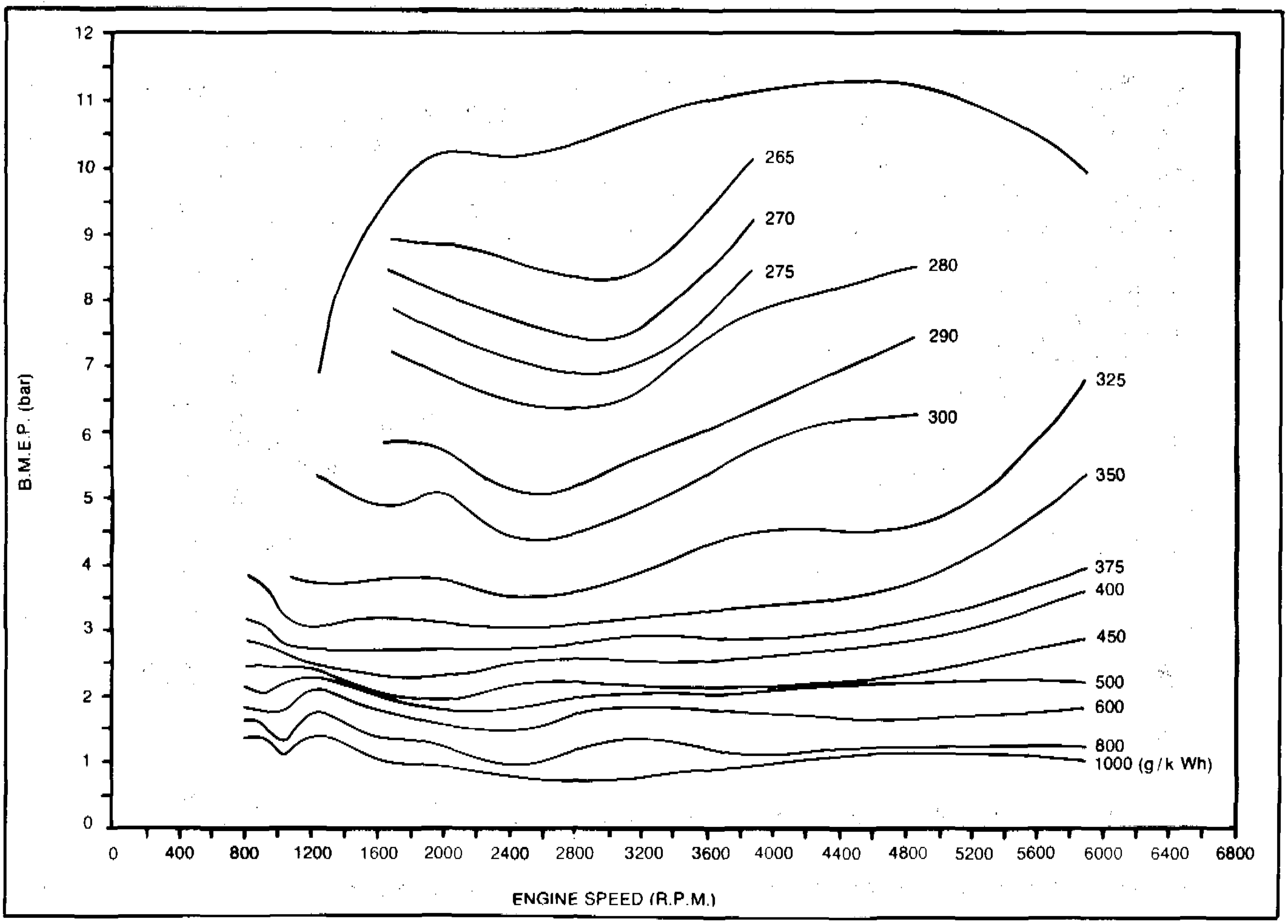


Figure 3. B.S.F.C. map 4 cylinder operation.

	Cx benefit
• Front air dam optimization	0.014
• Spoiler	0.037
• Wheel housings	0.006
• Nose and cooling air inlet	0.012
• Platform underside modifications	0.005
• Front door deflectors	0.021
Total gain	0.095

Final values of aerodynamically improved vehicle
$$\begin{cases} S = 1.714\ m^2 \\ Cx = 0.328 \\ Scx = 0.562\ m^2 \end{cases}$$

Drag reduction 22.5%

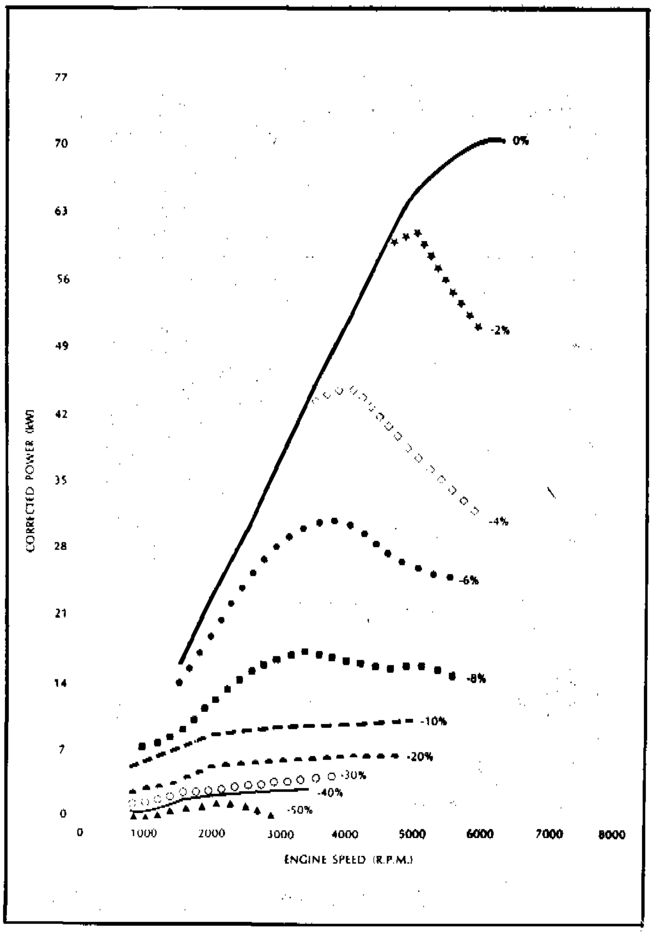


Figure 4. Map of final B.S.F.C. reduction achieved with C.E.M. modular Engine.

WEIGHT REDUCTION

Efforts at lightening have been made generally throughout the body, with the following limitations:

- weight reduction could not cause a compromise in complying with European safety standards for the ESVAR vehicle.
- structural resistance of the body/chassis could not be changed in any way that would cause a compromise to the basic objective of improving occupant protection.

The final results are shown here:

* Body Reduction	kg. 27,500
* Engine Reduction	kg. 6,000
* Mechanical components Reduction	kg. 35,500
* Interior & trim Reduction	kg. 12,000
* Spoiler, air dam, deflectors, etc. Increase	kg. 4,000
Total weight saved	kg. 77,000
Weight saving as compared to baseline vehicle	8.4%

REDUCTION OF ROLLING RESISTANCE

Figure 5 shows a typical curve for tire rolling resistance on an average vehicle, where 30% of the total resistance still remains at 80 km/h.

The ESVAR and SVAR vehicles are equipped with Pirelli P8 tires 165/65 R 14 on $5\frac{1}{2}$ J $\times$ 14 wheels which permit high levels of active safety, durability, comfort, and which reduce the power lost to rolling resistance.

The characteristics of these tires are a lower section, use of newly formulated materials both in the carcass and tread. A particular tread design is employed.

Figure 6 shows the reduction of rolling resistance between traditional cross-ply, radial steel belted, and the new P8 tires.

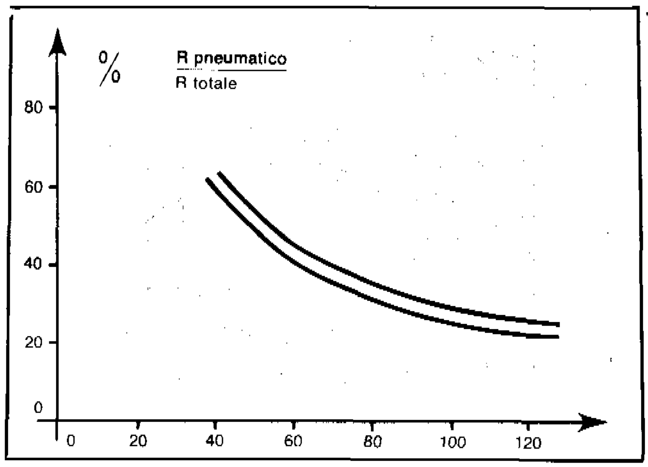


Figure 5. Rolling resistance.

IMPROVEMENT OF PASSIVE SAFETY CHARACTERISTICS

The new objectives created a need to improve passive safety performance by strengthening body structures, which normally result in weight increases.

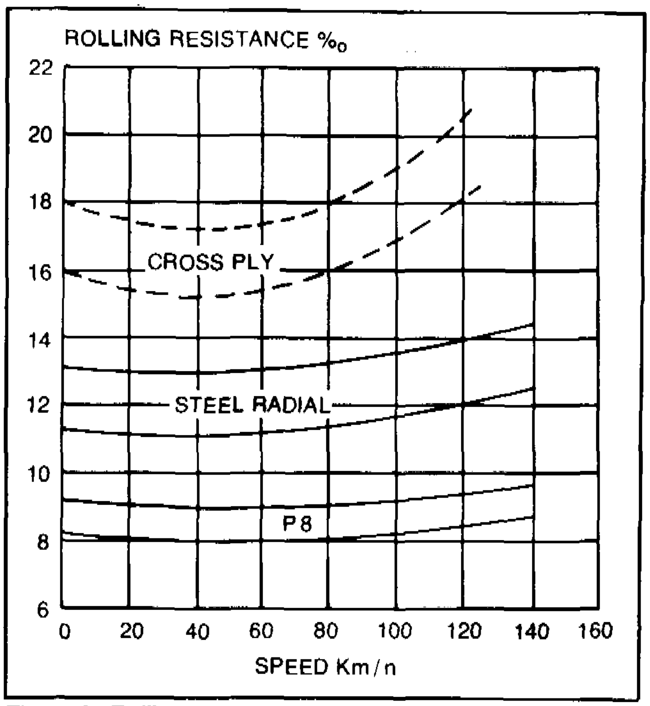


Figure 6. Rolling resistance for various types of tires (source Pirelli).

This weight increase was clearly in contrast with fuel saving efforts and therefore much effort was spent to maintain any weight gain within small limits by the use of aluminium alloy in some components.

The weight gain limits were developed as follows:

- *Oblique frontal impact at 65 km/h*
  platform modifications consisting of **reinforcing longerons** in the forward portion with stiffening webs beneath the pedal zone
  Weight penalty + *6.3 kg*

- *Car-to-car-lateral collision*
  reinforcing door beams and **strengthened "A" pillars**
  Weight penalty + *25.0 kg*

- ***Rear impact at 50 km/h***
  rear reinforcement of the platform by longerons
  Weight penalty + *8.7 kg*

- *Rollover at 50 km/h*
  addition of header zone reinforcement and roll bar in center zone
  Weight penalty + *2.0 kg*

- ***Weight** increase due to aerodynamic modifications*
  + *12.0 kg*

Total weight gain **54 kg**

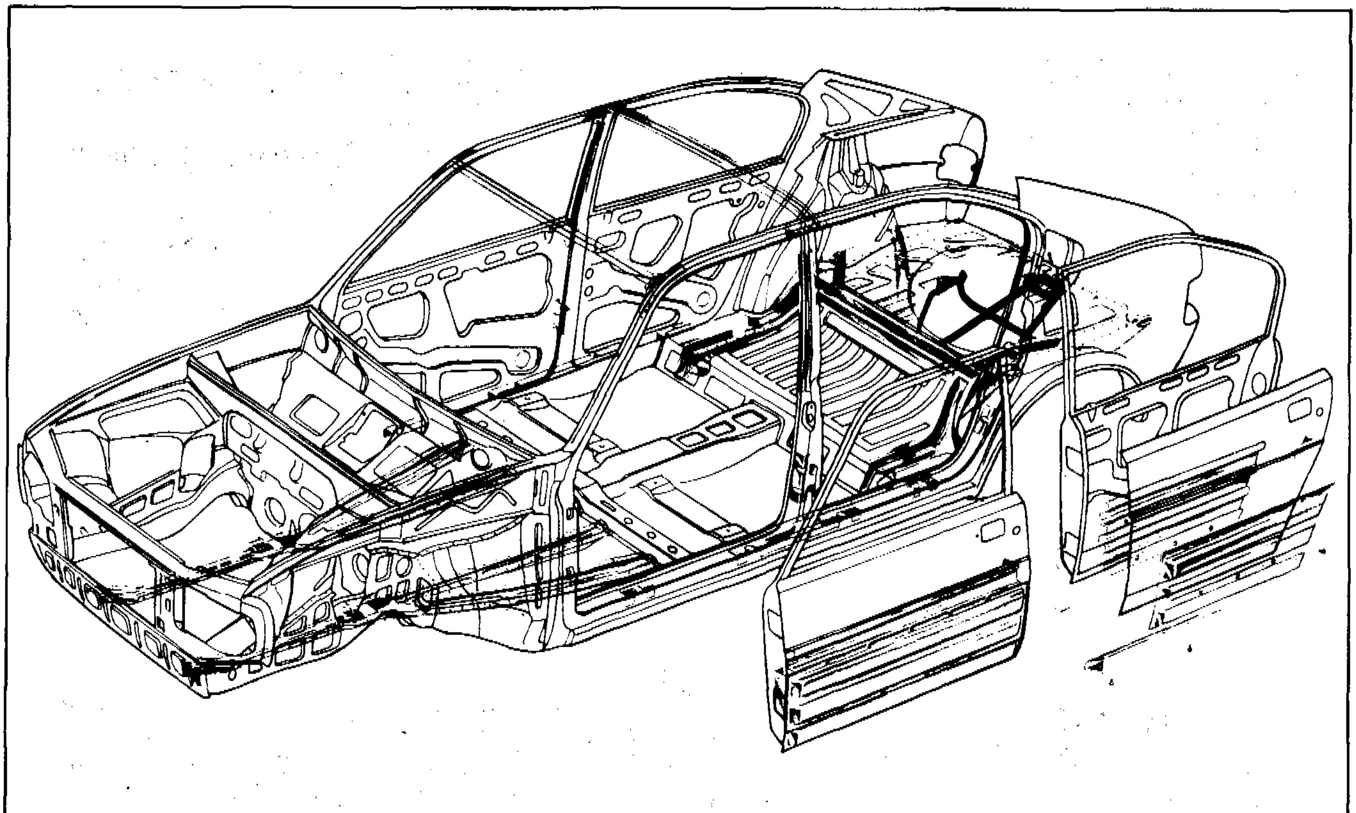


Figure 7. Shows the additional reinforcement required.

Modified vehicles characteristics			
	Baseline Vehicle	ESVAR	SVAR
Engine 1490 cm^3	Carburetors	Complete Electronic management	Complete electronic management
Final drive ratio	3.54	3.1	3.1
Weight DIN (Kg)	905	828	882
Coeffic. Cx	0.423	0.328	0.328
Tires	Standard production	Low rolling resistence	Low rolling resistence

MAIN FEATURES OF THE ESVAR AND SVAR VEHICLES

On the table we have summarized the modified characteristics as compared to the base vehicle. We remember that the lightening of the body/chassis has been voluntarily limited, in order not to jeopardize the safety tests to which the vehicle would have undergone after the addition of the reinforcements.

Figure 8 depicts the General Layout of the SVAR as defined. In evidence are the details of the aerodynamic improvements such as air dam, spoiler, and door window deflectors.

PERFORMANCE AND FUEL CONSUMPTION

ESVAR VEHICLE

Performance		
	Baseline Vehicle	ESVAR
—Top speed, 4th gear Km/h	174	>185
—Acceleration from stop from 0 to 100 Km/h-sec	10.70	9.80
—from 0 to 1000 m - sec	32.40	31.12
—Acceleration in 5th gear from 40 Km/h-sec	40.65	41.60

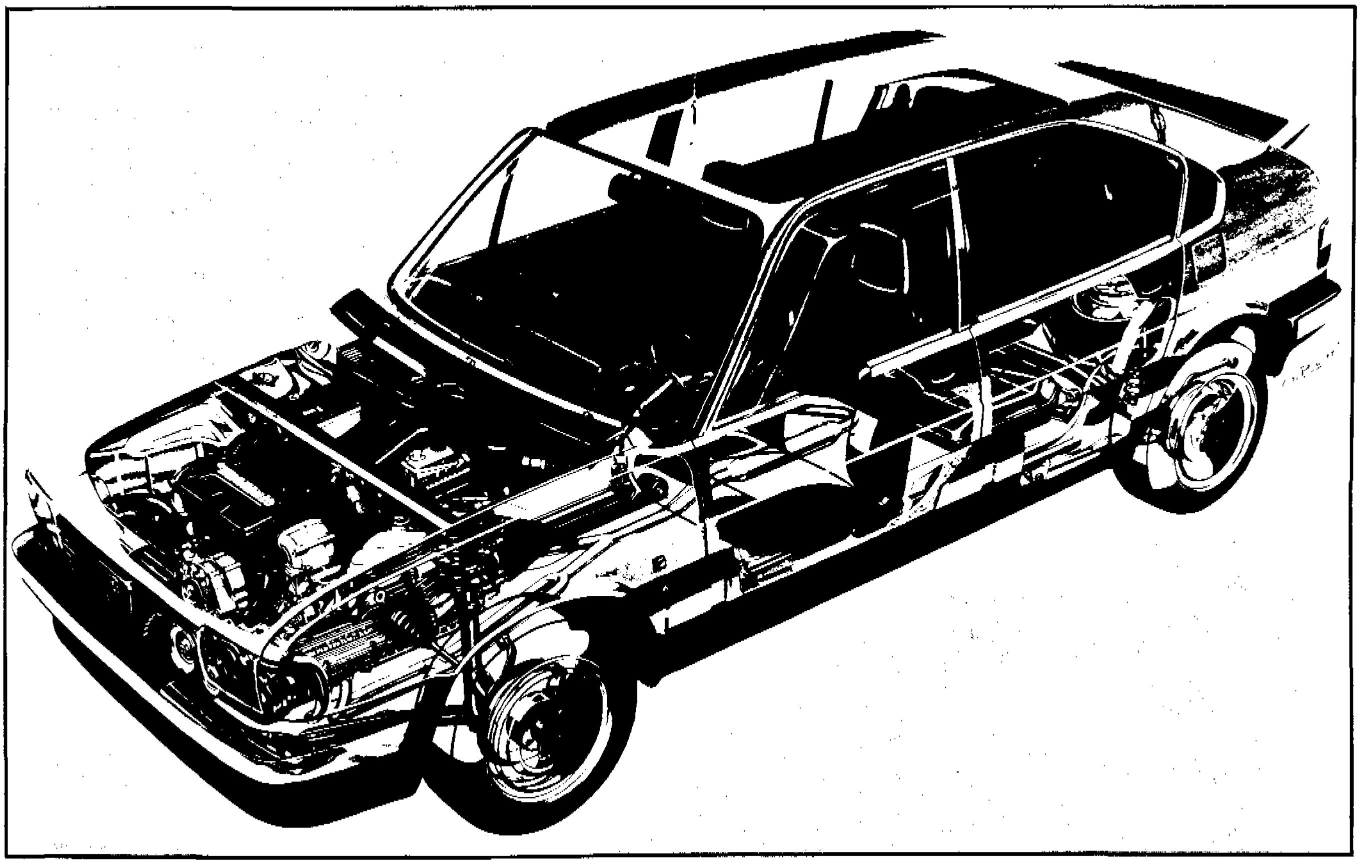


Figure 8.

Weight saving and aerodynamic advantages can be seen in the acceleration times and maximum speed.

Acceleration from 40 km/h in fifth gear, due to the longer final drive ratio, now requires 41.60 seconds, or 0.95 seconds longer than the base vehicle. This performance is still considered acceptable.

Fuel consumption - l/100 Km		
	Base vehicle	ESVAR vehicle
90 Km/h constant	6.2	4.9
120 Km/h constant	8.1	6.3
Urban cycle	10.6	7.8

• Fuel consumption

Here the fuel saving feature of the modular mode, when operating on 2 cylinders, can be seen as a considerable reduction in the 70 km/h range.

At 90 km/h the fuel saving advantage is about 20%, increasing with speed up to 22% at 140 km/h.

• Fuel consumption during the ECE urban cycle

Below are the results obtained with engines in 4 cylinder and modular modes. According to the ECE standard, the inertia weight used on the base vehicle and the ESVAR are equal, since the weight reduction has not been sufficient to permit the use of a lower inertia weight class. Therefore the benefits are derived from the engine and the longer final drive ratio.

Fuel consumption - ECE Urban cycle - l/100 Km		
Base vehicle	Vehicle ESVAR	
	Mode 4 cylinder	Mode modular
10,6	9,2	7,8
The saving has been 13,2% between the base vehicle and the ESVAR 4 cylinder. Accounting for a 5% longer final drive and complete electronic management of the engine	(injection + ignition) a saving of about 8% can be seen in a simulated ECE cycle. In the modular mode, the data shows a reduction down to 7,8 litri/100 Km which yields an overall fuel saving of 26,4% as compared to the base vehicle. If the ≪ effect of the longer final drive ≫ is dropped out, then the modular mode itself will yield a saving of about 21,4%. Overall, it is interesting to note that the difference between the constant 4 cylinder mode and the modular mode is 15,2% (from 9.2 to 7.8 l/100 Km).	

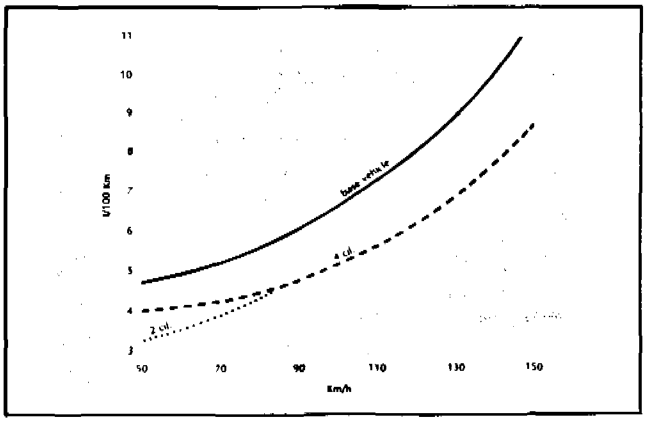


Figure 9.

The saving has been 13.2% between the base vehicle and the ESVAR 4 cylinder. Accounting for a 5% longer final drive and complete electronic management of the engine (injection + ignition) a saving of about 8% can be seen in a simulated ECE cycle.

In the modular mode, the data shows a reduction down to 7.8 liter/100 km which yields an overall fuel saving of 26.4% as compared to the base vehicle.

If the "effect of the longer final drive" is dropped out, then the modular mode itself will yield a saving of about 21.4%.

Overall, it is interesting to note that the difference between the constant 4 cylinder mode and the modular mode is 15.2% (from 9.2 to 7.8 l/100 km).

SVAR VEHICLE

Performance		
	ESVAR vehicle	SVAR vehicle
—Top speed, 4th gear	>185	>185
—Acceleration from stop from 0 to 100 Km/h-sec	9.80	10.10
from 0 to 1000 m - sec	31.12	31.50 (1)
—Acceleration in 5th gear from 40 Km/h -sec	41.60	42.65 (2)

1) The higher time of the SVAR is attributed to higher weight.
2) The fifth gear acceleration time of 42.65 sec as compared to 40.65 sec of the base vehicle is due to the final drive ratio.

Consumption - l/100 Km		
	ESVAR vehicle	SVAR vehicle
90 Km/h	4,9	5,1
120 Km/h	6,3	6,4
ECE Urban cycle	7,8	7,8

During constant speeds the difference is due to the heavier weight of the SVAR, while in the urban cycle no difference is seen due to the same inertia weight class.

SAFETY TESTS

OBLIQUE FRONTAL IMPACT

The results obtained during frontal impact at 65 km/h against a fixed barrier at an angle of 30 degrees to the trajectory of the vehicle are:

	Driver dummy	Passenger dummy
HIC	360	384
Dummy head max acc. g/3ms	49	61
Dummy chest max acc. g/3ms	43	30
Dummy femur max load left, right dN	308/455	168/60

Verified the required performances during the impact: i.e., doors remains closed, no fuel leakage, no fire, etc.

REAR IMPACT

1800 kg moving barrier rear impact at 50 km/h two dummies, left front and left rear, retained by active belts.

Results injury levels:

	Driver dummy front	Passenger dummy rear
HIC	51	26
Dummy head max acc. g/3ms	30	14
Dummy chest max acc. g/3ms	51	13

Performances required positively verified: non-opening doors, fuel leakage, rear car deformation (changement point H versus front 7 mm).

LATERAL IMPACT CAR TO CAR

Target SVAR impact velocity 50 km/h. Collision angle 90 degrees; SVAR car equipped with three dummies Hybrid II, two in the front, the third in the rear, with active belts.

Results:

	Driver dummy	Front dummy	Rear dummy
HIC	47	98	261
Dummy max acc. g/3ms	30	35	67
Dummy chest max acc. g/3ms	45	54	19

Verified all performances: doors were kept closed upon collision, unable to close or open left front and rear doors, no leakage in the fuel system, etc.

ROLLOVER

SVAR vehicle, two dummies Hybrid II retained by active belts. Rollover at 50 km/h.

—no opening of doors
—possibility to open doors after impact
—no dummy ejection
—no fuel leakage
—no fire

PEDESTRIAN IMPACT

The SVAR has impacted at 25 km/h a Part 572 Hybrid II adult dummy and 6-year-old dummy.

Injury levels:

	Adult	Child
HIC	290	78
Max head acc. g/3ms	58	36
Max chest acc. g/3ms	29	22
Max pelvis acc. g/3ms	20	35

ACTIVE SAFETY

The optimal characteristics of stability, handling, and braking of the vehicle have been checked by usual Alfa Romeo standards and based on the subjective evaluation of expert staff test drivers, as well as by specific instrumentation tests.

The dynamic behaviour of the SVAR has proven proficient, as expected, and therefore acceptable. In our opinion the vehicle can be easily controlled by drivers of different abilities and experience.

Though the complete RSV program could not be completed due to reasons of time, space, proving grounds, and/or equipment availability (i.e., simulated lateral wind), "open loop" tests were nevertheless conducted to show:

—lateral adhesion
—handling
—braking

Active safety testing is done by expert staff test drivers at Alfa Romeo's Proving Grounds in Balocco, where the ASTM skid number ranges from 70 to 80.

For the tests the vehicles are instrumented with:

Hardware	Measured Parameters
stabilized inertial platform	lateral acceleration
rate gyro	angular velocity yaw angle
electrical transducer	steering wheel angle
electrical transducer	drift angles
optical sensor	vehicle velocity and stopping distance
pressure transducer	brake pedal force

Handling and lateral adhesion tests are performed with the vehicle loaded to 60% of its max gross weight.

For braking tests, vehicle loads are 60% and 100% M.G.W.

LATERAL ADHESION

- *Response rate*

For checking the behavior rates of the vehicle, tests are done on circular pads at the speeds and lateral adhesion (g) required.

Figure 10 shows the yaw response at lateral acceleration rates of 0.4 g for steering angle of the wheels; the ratio between the steering wheel angle and steering gear ratio is used.

Values measured are within prescribed limits.

The test results permit an interpretation in terms of a "stability factor" K.

The figure resulting from the SVAR characterizes a "stability factor" between 2 and 3.10^{-3} sec^2/m^2.

These values are indicative for an average vehicle in terms of understeer. (Fig. 11).

- *Steering pad*

Data are taken from the vehicle as to its behavior rates on a radius of 37.5 m up to the point of where front end loses adhesion.

Figure 12 illustrates the relation of the steering angle to the lateral acceleration.

This is indicative of the high acceleration level to the progressive behavior of the vehicle.

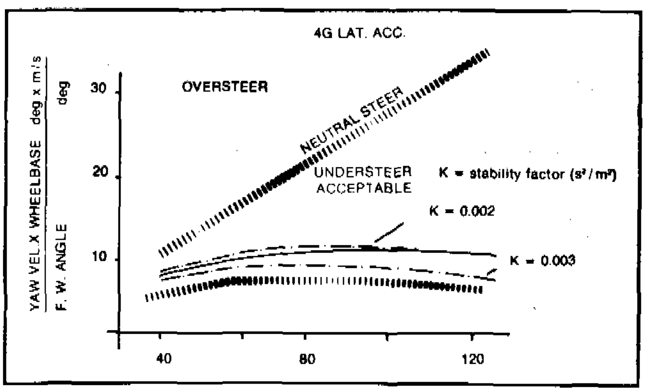


Figure 10. Yaw response rate.

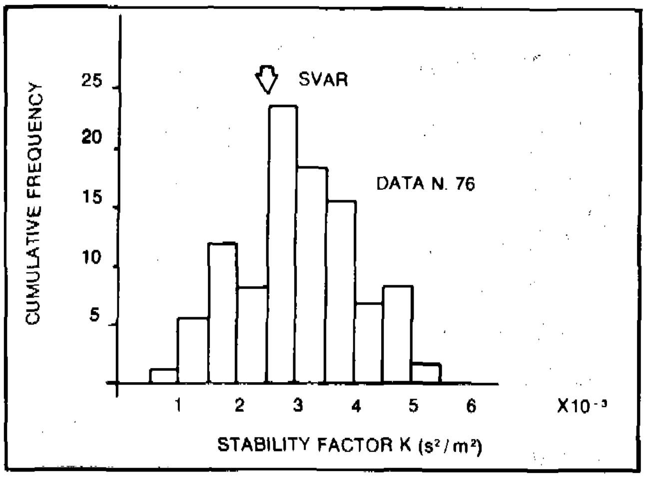


Figure 11. Stability factor histogram, k at 0.4 g lateral acceleration.

HANDLING

- ***Maximum lateral acceleration***

The scope of this test is to measure the highest lateral acceleration with various tire inflation pressures.

The lateral acceleration values measured are not necessarily the highest achievable, but are above those required anyway.

Surface	Tire Pressure	Lateral Acc. Required	Lateral Acc. Measured
Dry	Design value	0.60	>0.75
	120%	0.60	>0.75
	80%	0.55	>0.7
	120% front 80% rear	0.63	>0.7
	80% front 120% rear	0.59	>0.7

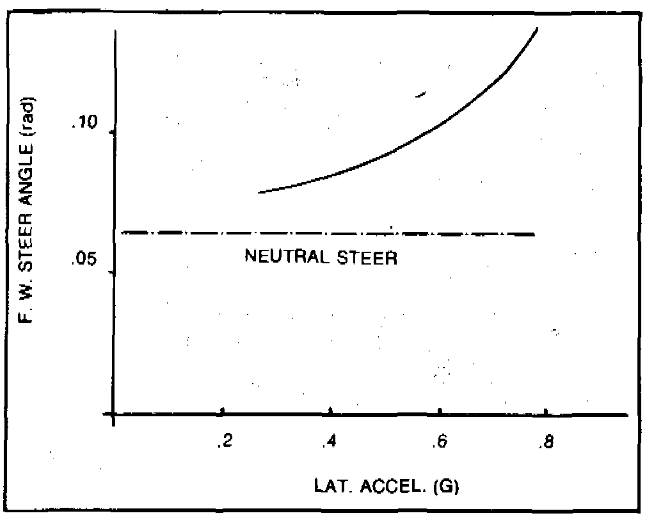
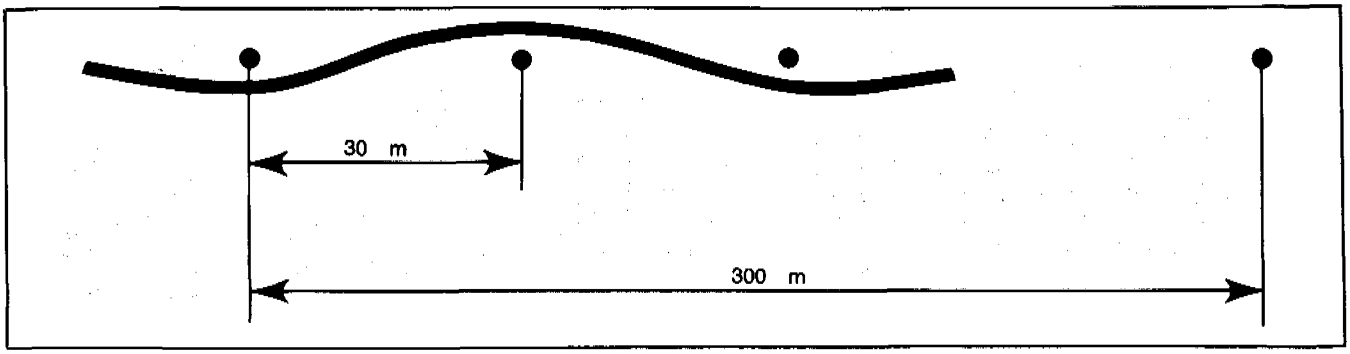


Figure 12. Steering angle response rate (radius 37.5 m).



• *Slalom*

This test is performed over a course of 300 m with 10 pylons spaced 30 m apart.

The slalom average speed is above the minimum required, during tests "overturn" was never verified.

Minimum average velocity	
Required	Measured
80 Km/h	90 Km/h

BRAKING

• *Braking straight-line*

Straight-line braking distances are measured three times for each test condition:

- complete baseline braking system
- system without servo
- system without front circuit
- system without rear circuit

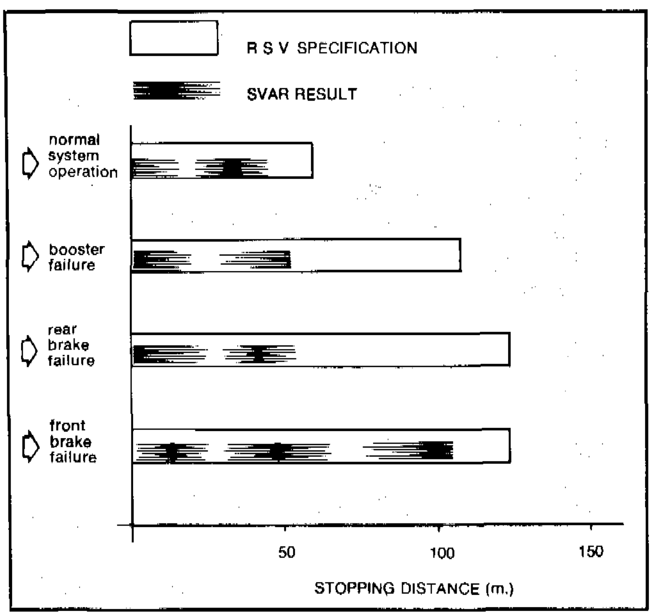


Figure 13. Stopping distance—straight line.

Initial velocity is 96 km/h on a braking lane 3.7 m wide.

As demonstrated in Figure 13, the vehicle is characterized by a braking distance much lower than that required.

As well, the vehicle did not deviate from its path, stopping in a straight line without wheel lock-up.

• *Braking in curves*

This test is carried out only using the complete baseline system.

The vehicle, while travelling at 64 km/h on a 108 m circular track (0.3 g lateral acceleration) is stopped in a distance much shorter than that required (Fig. 14).

The vehicle is characterized by a minor deviation from its circular path, which is easily corrected by a slight steering correction.

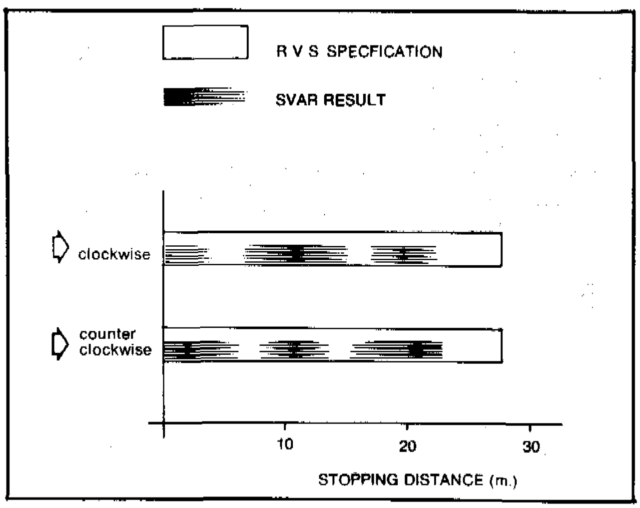


Figure 14. Braking in curve—stopping distance.

CONCLUSIONS

A production vehicle can show reductions in fuel consumption while not altering the philosophy or criteria for occupant protection.

Almost all for the modifications done on the ESVAR are possible using today's technology.

There is evidence of rather important cost/investment problems. Some solutions of "controlled economy" could permit introduction to production in short or medium terms. Other solutions require consideration of cost/benefit. Certain applications may be valuable as "image" for the manufacturer and therefore beneficial. Much depends, in the end, on the eventual cost increase of petroleum and on technological developments which today are very costly.

The SVAR was constructed to obtain indications of solutions which could be further studied in order to optimize occupant protection.

It is worthwhile to underline the fact that the ESVAR vehicle is, in the end, slightly lighter than the base vehicle. It is equipped with all of its devices and inherits as well the advantages of low fuel consumption.

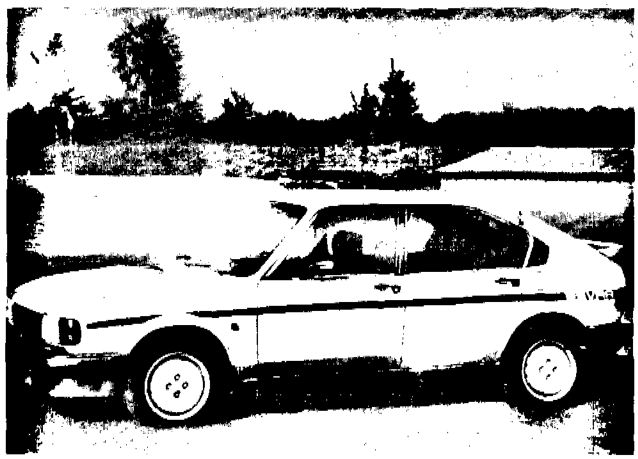
The results obtained are significant for future designs that have requirements for improved protection with a minimum increase in weight and cost.

From these lessons, it is seen that about 30% of the weight gain could be eliminated by rationalizing the structure.

Overall results of the safety tests indicate that it is necessary to continue the research, obtaining more data for future rational projects.

With this last note we conclude the Alfa Romeo report on the studies of today's need to reduce fuel consumption and occupant protection, concluding that it is possible to achieve progress in a light compact vehicle, while retaining the performance objectives—which in the original vehicle were quite high.

The research continues.



ESVAR

SVAR

APPENDIX

MAIN TECHNICAL DATA

		Base vehicle	ESVAR	SVAR
Overall length	mm		3995	
Overall width	mm		1590	
Wheelbase	mm		2455	
Front track	mm		1390	
Rear track	mm		1360	
Empty weight (DIN)	Kg	905	828	882
Engine: flat 4				
Bore	mm		84	
Stroke	mm		67,2	
Displacement	cm³		1490	
Compression ratio		9,5:1	10,2:1	10,2:1
Max power DIN - KW/rpm/1'		70/6000	70/5400	70/5400
Max torque DIN Nm/rpm/1'		130/3500	134/3500	134/3500
Clutch			single dry disc	
Transaxle			5 speed	
			I : 3,75	
			I : 2,05	
			III : 1,38	
			IV : 1,02	
			V : 0,82	
Axle ratio		3,54: 1	3,1 : 1	3,1 : 1

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The German Research Car Project

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ABSTRACT

The paper presents results of the German research car project. Four prototype cars were built by Audi NSU, Daimler-Benz, Volkswagen and a group of high school institutes. Technical details of the prototypes are described which were chosen to meet the project goal of an integral improvement in safety, energy and resource conservation, environmental compatibility, economy and utility.

INTRODUCTION

In 1978 the German Ministry for Research and Technology started the research car project (Fig. 1) in order to determine the technological potential of a combination of the most promising individual solutions, thus devising an integral concept of a passenger car of the future.

The fundamental ideas of this project and some technical details were reported on the 8th ESV Conference in Wolfsburg, 1980. The project ended September 1982; most results of the demonstration and evaluation phase are to be reported in a short time.

In this paper, some results from a more generalizing point of view will be presented, whereas in the following three papers of this Conference, emphasis is laid on passive safety features of the research cars.

In contrast to other projects which aimed at only one field of automotive technology this project (Fig. 2) was set up to cover the full range of development needs.

It was mainly to demonstrate future technology with the potential to meet the whole range of conflicting demands on future vehicles. The presented technologies should have the potential for large series production.

Beside the mandated average 30% improvements and the general requirements (Fig. 3), it was open to the companies to compensate a smaller improvement in one field by a higher efficiency in another field. Thus the competitors were enabled to concentrate more on one special field of their interest, or to set priorities particular to the company's production politics.

Audi NSU (Fig. 4) tried to meet the goal with technologies of the next 10 years. Focal points of interest were vehicle body structures and use of alternative materials.

- —Daimler-Benz emphasised the development of a ceramic gas turbine for a large size limousine and the implementation of features for driver's aid and comfort.
- —The university group focussed on exterior effects of automobiles, i.e., emission of noise and exhaust gas as well as safety-measures for pedestrians and cycle riders.
- —Volkswagen ranked economy and utility highest; another focal point was use of alternative materials.

In the following some general trends and results are shown.

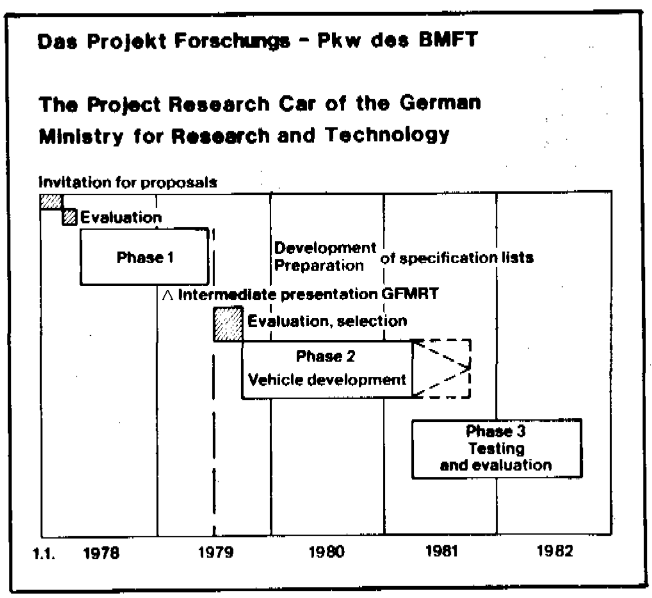

Figure 1. Time schedule for the research car project.

30% Verbesserung bei

- **Sicherheit**
- **Energie - und Ressourcenverbrauch**
- **Umweltschutz**
- **Wirtschaftlichkeit und Nutzwert**

30% Improvement for

- **Car Safety**
- **Consumption of Energy and Ressources**
- **Environmental Protection**
- **Economy and Utility**

Figure 2. Basic goals in the project.

- **4 Sitzplätze, Seats**
- **> 400 kg Zuladung, Payload**
- **Komfortmaße mindestens heutiger Standard, at least present standard of driving comfort**
- **Fahrleistungen, Driving Performance**
  - **0 - 100 km/h ≤ 13 s**
  - **V_{max} ≥ 140 km/h**
  - **Reichweite > 400 km, cruising range**
- **Erfüllung gültiger Gesetze in der BR Deutschland und EG, compliance with regulations and standards in the FR of Germany and European Community**

Allgemeine Richtwerte zum Lastenheft des Forschungs-Pkw

Figure 3. General requirements.

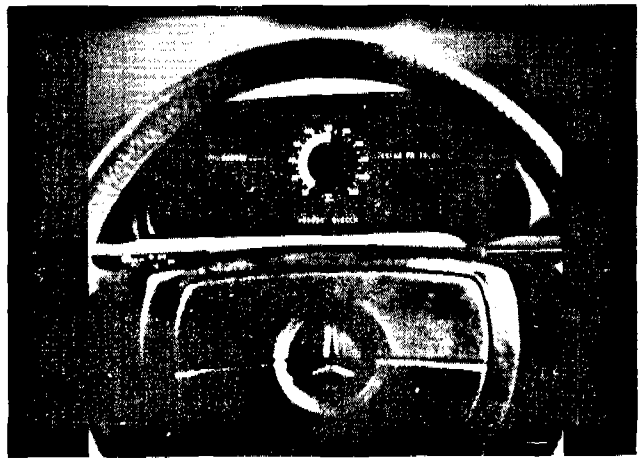

Figure 5. Daimler-Benz, minimal permanent display.

SAFETY

The 30% improvement for vehicle safety was defined for summing up measures for accident avoidance and mitigation of injuries.

Although a number of new techniques were presented in the prototypes, it can be stated that safety was not of highest priority. Despite that the goals seem to be met. As measures for improved passive safety will be reported in the following three papers, only some remarks on accident avoidance features will follow here.

Generally seen emphasis was laid on driver information systems. Principally such systems give support to the driver in his complex task of driving his car within the traffic flow as well as it controls reliability and safety related features of the vehicle itself. By this the driver's need for memorizing and simple or complex thinking operations are reduced.

One major point is the reduction of permanently displayed information on operational status to an absolute minimum, e.g., driving speed, fuel reserve and daytime; further information is available on request only. (Fig. 5).

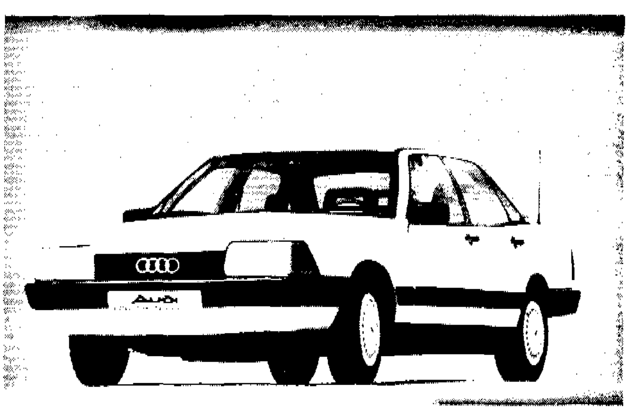

Figure 4. The Audi research car.

Vehicle operational reliability control works automatically and generates warning information according to safety priority. Warnings of high priority because of dangerous operation status which call for immediate stop are displayed in the primary field of view.

One example for an in-vehicle route guidance and driver's information systems is called ALI (*A*utofahrer *L*eit- und *I*nformationssystem), the display of which is shown in the mid section of Figure 6.

An ALI-equipped vehicle reports its presence and destination when entering the area covered by the system. The information is transmitted via induction loop to a roadside unit. Recommended direction for the particular destination of the vehicle is taken from microcomputer in the roadside unit, and is then transmitted back to vehicle via the same induction loop, which also detects speeds and types of all other vehicles passing by. Roadside unit data of a cross-section are preprocessed and transmitted to the control centre. There further evaluations are carried out with particular emphasis on the optimum routes for the desired destinations of all vehicles in the

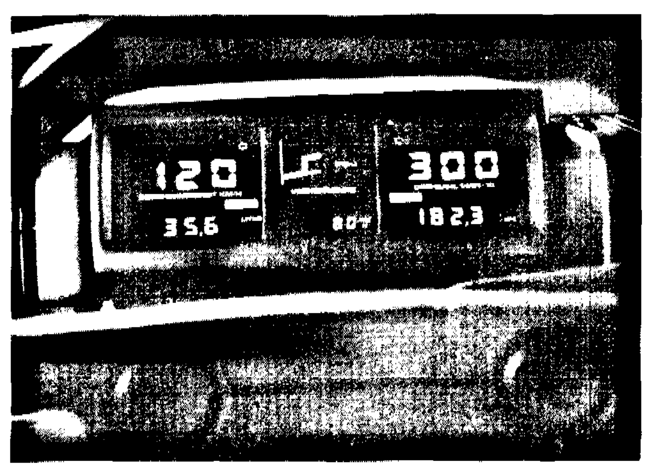

Figure 6. ALI, driver's route guidance and information system; Volkswagen research car.

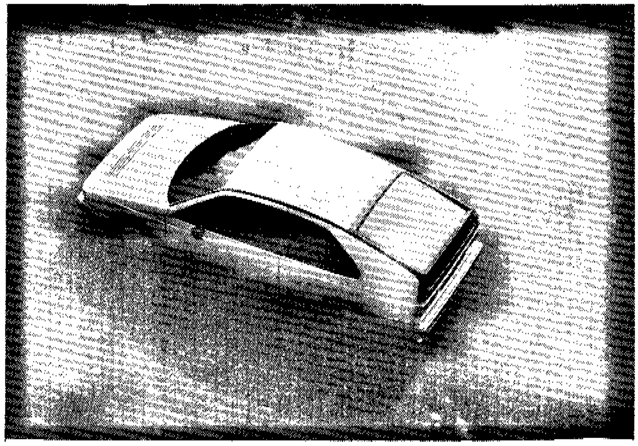

Figure 7. Volkswagen research car; view from the top.

control area. Alternative routes are assessed with reference to the overall objective of

—reduction of travelling time
—reduction of vehicle operating costs
—reduction of number of accidents.

This system was successfully tested with promotion of the Federal Ministry for Research and Technology with participation of more than 400 vehicles in the Ruhrgebiet Autobahn area.

Improvement of *conditional safety* played quite an important role in all research cars. Climatization of the compartment will be of greater importance with larger and more sloped windows (Fig. 7). Ventilation, temperature and moisture will be controlled electronically.

A future solution could be utilization of heat-pipe techniques. Heat exchangers for air conditioning systems will transmit heat from exhaust gas or motor cooling fluid to the heating air as well as it will transmit heat from the compartment air to the cooling fluid of the air conditioner.

Panel shape of the heat exchanger can be used for door inside panel installation for example (Fig. 8).

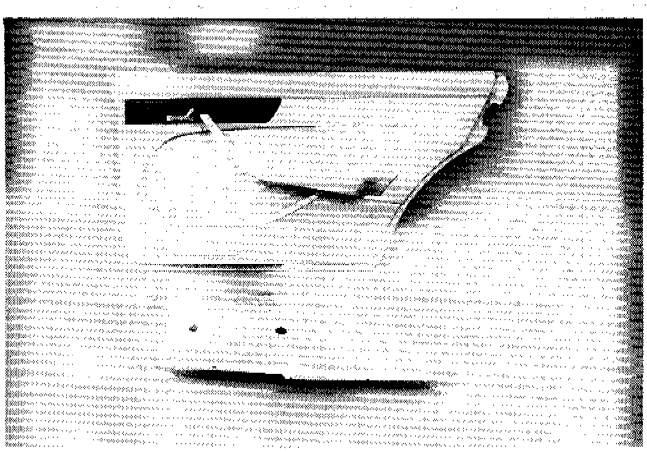

Figure 8. Panel shaped heat pipe for indoor installation; Daimler-Benz.

With respect to *driving behaviour* if can be said that vehicle layout can be varied to a great extent to control dynamic behaviour. However, criteria for what the ideal vehicle behaviour for the "normal driver" really is, do not sufficiently exist, neither with respect to comfort nor to safety. So it can be stated that wheel-suspensions of the research cars more or less are state-of-the-art layouts.

By summarizing, it can be said that safety was not of highest priority although a series of new technologies was presented. Nevertheless, the goal of 30% improvement in this field seems to be reached.

ENERGY CONSUMPTION AND ENVIRONMENTAL PROTECTION

The goals for fuel consumption and the results of the different motor types are given in Figure 9.

The demand for a fuel consumption reduction of at least 30% compared to 1978/79 model cars is surpassed.

At the beginning of the project this claim had been criticized as too hard to reach because of the pretended conflict to the claim for 30% exhaust emission reduction.The energy shortage of the years after as well as the given results lead us to the opinion, that the demands were well founded. Each of the four competitors in the project ranked energy consumption being of the highest priority.

The piston engine of today is predicted being the vehicle engine of the future, too. Consequent use of some fundamental principles gives an astonishing potential for improved efficiency.

Not referring to details, some of the principles used in the project will be reported here:

1. Choice of thermodynamically most favourite combustion process: It was not surprising that each of the participants made use of at least the Diesel engine in one of these prototypes. Consequently they made use of the direct injection Diesel engine for a passenger vehicle.

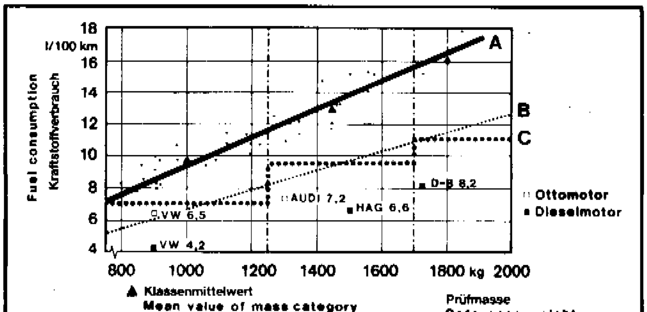

Figure 9. Fuel consumption of 1978/79 model cars and research cars; goals and results.

Kenndaten Diesel - Motoren		HAG	VW	D-B
Hubraum	cm^3	2500	1191	3308
Leistung	kW (PS)	72(98)	33(45)	110(150)
Einspritzung		direkt	direkt	indirekt
$b_{e\ min}$	g/kWh	237	218	255
Verbrauch	l/100 km			
90km/h	Konstant	4,6	3,3	5,7
120km/h	Konstant	6,0	4,9	7,5
Stadtverkehr / City		7,8	4,2	9,8
Durchschnitt 25/25/50		6,55	4,2	8,2

Figure 10. Data of the diesel engines in the research cars.

Some basic data from the three finished Diesel engines (Fig. 10) show that this engine type shows outstanding fuel consumption in combination with exhaust gas and noise emissions below the limits given for the project.

2. All of the piston engines, and this is the second principle, are supercharged. This is for Diesel engines as well as for spark ignition engines (Otto-engines).
3. The third principle is to eliminate idling and thrust mode engine operation totally. This has been realized in the Diesel-version of the VW-car. Power is to be generated only then when it is needed to cover driving resistance or when it is demanded for acceleration by the driver via driving pedal. More information is given in the paper by Volkswagen.
4. The fourth possibility is to operate the engine only in the near of its point of optimum fuel consumption and to shift control-function to the gear. Theoretically of best advantage are continuous variable transmissions with sufficiently spread converting ratio combined with electronically controlled engine-power transmission-management.
   With an ideal (100% mechanical efficiency) CVT, fuel consumption can be reduced by 30% compared to mechanical 4-speed gear box by running the engine just along minimum fuel consumption control characteristic.

Engine and gear box performance maps are laid down in a microprocessor (Fig. 11), the control strategy being that for every single point in the power map the product of engine and gear box efficiency gets a maximum.

First results with UNI CAR show that the used CVT "Transmatic" is an interesting alternative with respect to mechanical efficiency, speed of ratio change, spread of ratio, specific power and costs.

The only alternative engine in the project is the gas-turbine-version (Fig. 12) in one of the Daimler-Benz cars, developed parallel to the Diesel version. This gas-turbine is dual shaft with rotating heat exchanger disk, single stage centrifugal compressor with backward curved rotor blade tips, ceramic combustion chamber, single stage axial gas generator turbine, single stage axial power turbine, adjustable inlet guide vanes, electronic control of fuel-supply. All internal hot sections are made of ceramics.

Test bench work has been successful; first in-vehicle tests have been carried out in September.

With respect to fuel consumption the goals set in the project were reached. With regard to exhaust gas emission it must be said that the given limits (CH + NO_x = 10 g/test and CO = 36 g/test; European Test Cycle acc. to ECE R 15) could not be achieved reliably in all cases. In those spark ignition engines it could only be achieved by giving up the achieved optimum fuel consumption values; but even then the given fuel consumption limits were sufficiently reached.

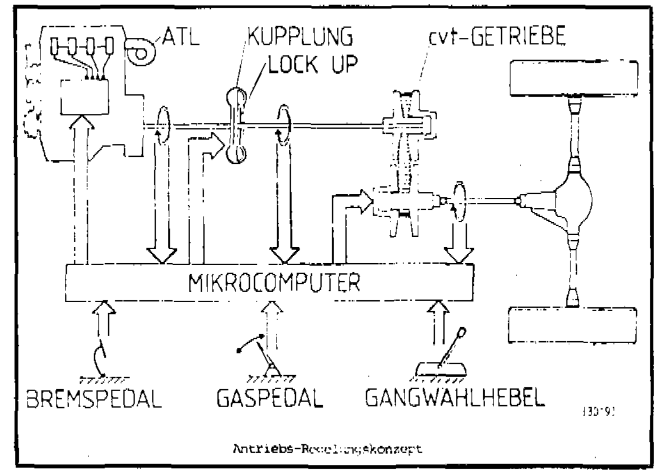

Figure 11. Scheme for motor-transmission control (University Group).

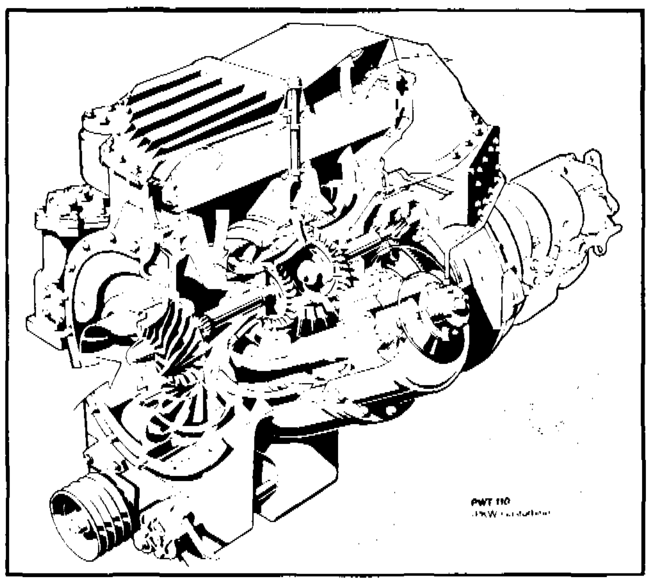

Figure 12. Schematic representation of the Mercedes-Benz research turbine.

We think that some more detail work which could not be done due to the short project duration could result in better emission results.

For the Diesel engines all limits for exhaust gas emission, particulates included, could be achieved, the latter even without filtering.

Related to noise emission the set limit of 73 dB(A) according to ISO 362 was regarded as difficult to fulfill because of the levelsetting tire noise. The results, however, show that with the help of acoustical capsules for the engines a noise level of 72 dB(A) could be measured even for direct injecting diesels.

BODY DESIGN CONCEPTS

Guide lines for body design in the research cars can be described as follows:

—principally retaining today's production procedures, modifications with respect to use of alternative materials, subsystem production and assembly as well as to final assembly should be investigated
—the whole body design ought to play an important role in vehicle economy improvement by reduced weight and favourable air drag
—expenditure on energy during manufacture and recycling were to be considered in design.

The principle way for improvements in this respect seems to be the consequent separation of body functions into the supporting structures and the outer cover giving vehicle shape.

The supporting framework (Fig. 13) consists of a 3-dimensional framework of thin surface elements and high-strength rigid beams—in all four prototypes these structures are made out of steel sheets.

On one side an optimal ratio between vehicle outer dimensions and passenger compartment space demands for minimal beam measures. On the other side survival space in accidents demands for an extremely rigid compartment, up to this both can only be done by steel obviously.

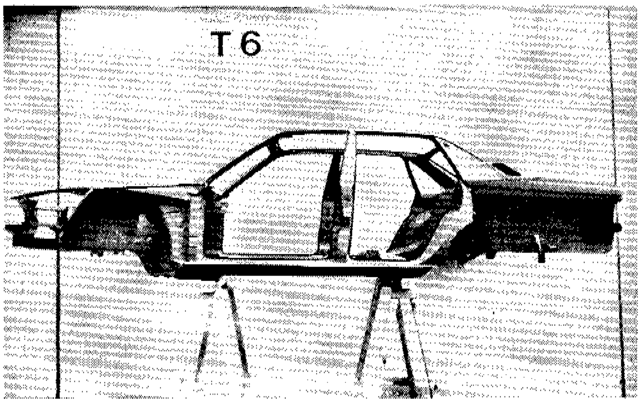

Figure 13. Body structure of Audi research car.

Other results were obtained with regard to the outer cover included the roof and the lower floor panel. Here the use of new materials will increase in the near future (Fig. 14).

All four prototypes show plastic front sections with integrated bumpers. Mostly they consist of an GFRP- or aluminium cross member and a PUR body and skin. Main advantages are the drastically reduced number of parts in connection with greater freedom for design.

Side doors unanimously were made of aluminium. Audi here also realized the functional separation of door structures. First into an aluminium structure carrying the lock, window lifting mechanism and door hinges as well as incorporating the side intrusion guard; second into the inner door cover and the outer door cover (aluminium).

As to side panels and mud guards lightweight materials will be used; both aluminium and plastics are considered; a distinct trend to one of these materials cannot be seen yet.

The most extensive structural modification can be seen for the Audi car. Normal as well as steer forces acting on roof and floor ask for extensive reinforcements for the steel panels.

For this purpose the roof as a sandwich construction out of a honeycombed aluminium core and GFRP-shells could be advantageous.

The floor unit (Fig. 15) consists of a GFRP-construction with directed fibers from high-temperature-resistant resins. Reinforcements for panels and supporting beams are made of PU-hardfoam cores. For anticorrosion purposes the floor asembly covers the side fenders up to the doors.

The problems for this structural layout are the assembly between steel frame and plastic subassemblies by gap-filling adhesives. Another problem is that roof and floor can only be mounted after completion of supporting framework including total surface treatment.

On the other side this assembly sequence offers big advantages for mounting the equipment of the passenger compartment. Additionally roof and floor can totally be preassembled away from the main assembly line on special work benches with all equipment including mechanical devices, electric wiring, carpets, seats etc.

Beside the just mentioned structural design works, an important contribution to energy saving was given through a drastical reduction of air drag. With realistic chassis design the air drag coefficients for the four research cars were between 0.24 to 0.29.

ECONOMY AND UTILITY

Utility of a vehicle is ruled by its

—transport capacity
—reliability
—safety

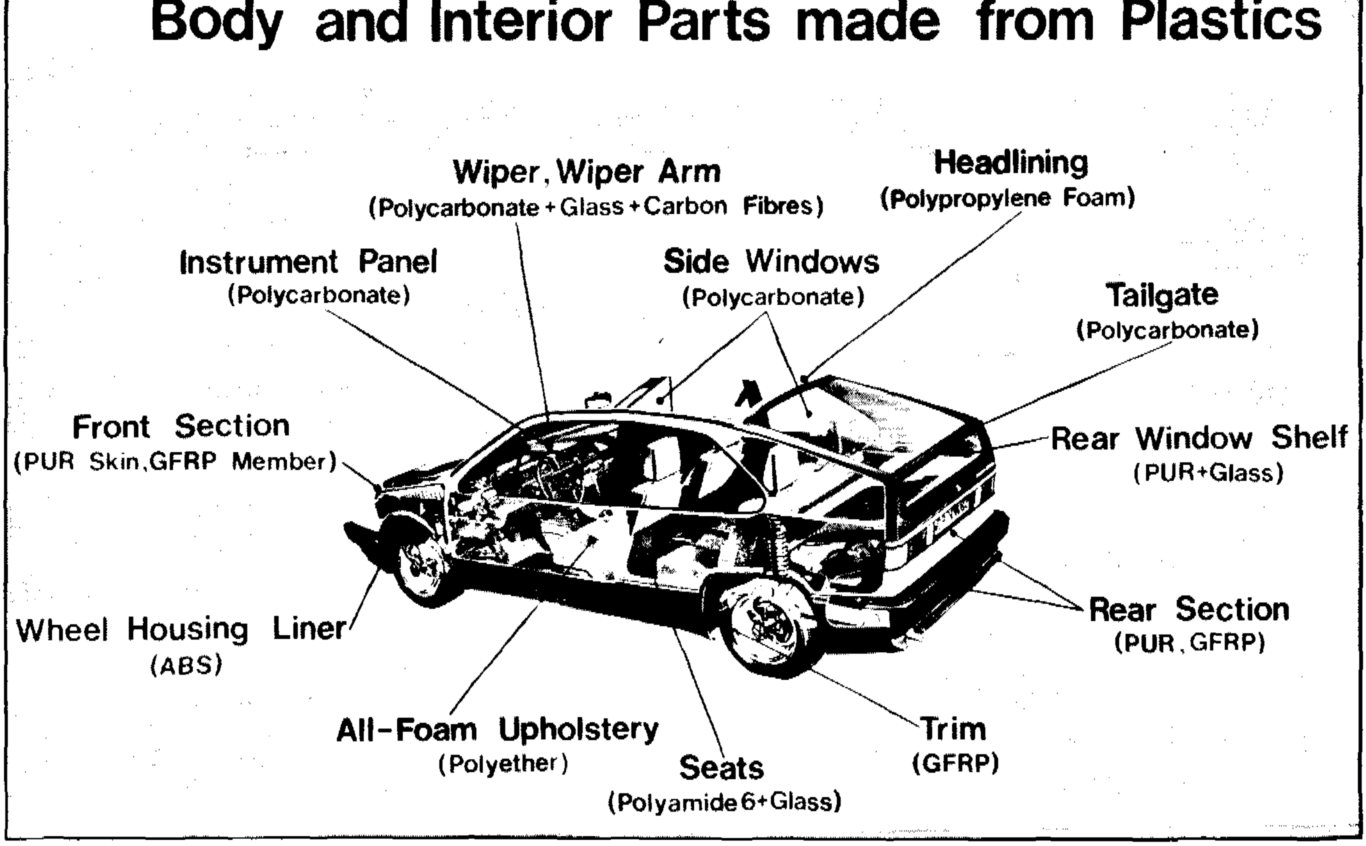

Figure 14. Body and interior parts made from plastic (Volkswagen).

—environmental compatibility
—life expectancy and depreciation

Regardless to economy, utility can be improved by high sophisticated technology—their interrelation is governed by costs. The optimal ratio between them depends much on the expectational attitude of the buyer of a specific vehicle class.

So a concluding valuation of the four vehicles with respect to 30% improvement in economy and utility is hard to give. A purely subjective remark at this time can be given yet:

—Even the few examples in this paper show that for the above mentioned factors governing utility a remarkable improvement can be stated
—An improved utility can be proposed because most of the presented technologies in one field of demands did not affect negatively other fields of activity—that was just the aim of the project
—The competitors in the project ranked economy very high for their work. These decisions made in 1978/79 have been verified by the international economical developments
—The demand of the project for technical solutions with the potential for large series production as well as the short project duration excluded realization of long-term technologies but did also avoid exotic, unrealistic solutions.

The four prototypes indeed demonstrate effective and economical solutions for an improved automotive technologies for the last 20 years of this century. For this reason the German Federal Ministry of Technology regards the project as being successful.

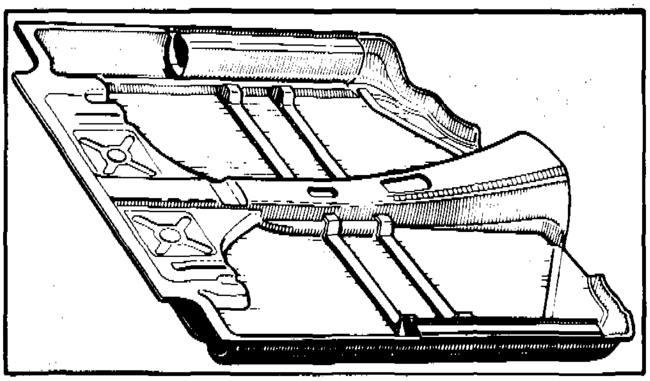

Figure 15. GFRP construction of floor panel (Audi).

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Exterior Safety and Side Protection with the Uni-Car

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ABSTRACT

The integrated research vehicle UNI-CAR is the result of a four-year cooperative effort among four West German universities. The following were the points of emphasis for the research performed:

—energy savings
—noise reduction
—safety improvement.

By virtue of its specific experience in the field, the Institute for Automotive Engineering of the Technical University of Berlin was responsible for the area of safety.

Almost 50 percent of persons killed in traffic accidents in West Germany are either pedestrians or cyclists: what we call "the outside victims." This situation has been fully taken into account by the safety concept of the UNI-CAR. Extensive protection has been provided for pedestrians and cyclists by the geometrical design and the use of soft materials (foam) for the front end of the car. Aerodynamic requirements were also able to be taken into account in this concept. The configuration was provided in such a manner that protective criteria were observed up to 50 percent in cases of collision speeds of 45 km/h (28 mph).

A second focal point in the safety concept of the UNI-CAR was side protection: the side impact is one of the dominant collision types, especially in city traffic. Approximately 20 percent of all deaths among car passengers result from cars struck from the side; their number amounts to approximately 10 percent of all traffic deaths. The test velocity for the car-to-car side collision was set at 50 km/h (31 mph). This speed would include 75 percent of all side crashes resulting in injuries.

Verified measures were employed to prove that the officially stipulated safety gain of approximately 30 percent was achieved. We must point out, however, that some of the solutions as chosen are not yet ready for mass production.

INTRODUCTION

Similar to the United States in 1974 with its Research Safety Vehicle Program (RSV), the West German Federal Minister for Research and Technology initiated in Germany in 1978 a program for the development, construction, and testing of a research passenger car. In the West German case, however, no particular point of emphasis was intended for special concentration, as was the case in the RSV and, especially, for the ESV projects. Instead, the emphasis in Germany was to achieve decisive improvements in the features of present day standard factory models, with emphasis on the following R & D objectives:

—conservation of energy sources and other natural resources
—environmental benefits
—safety (30 percent)
—economy and efficiency

Compensation was to be allowed in the pursuit of these goals.

Proposals were primarily solicited from the German automobile industry. A collaborative composed from four German university institutes—from Aachen, Berlin, Darmstadt, and Stuttgart—also applied for this project, and they were awarded this contract. For the first time in Germany, a project was started which admits to the opportunity to incorporate specific experience in the complete development of a passenger car. Structural and construction work assumed the Karmann company. The first prototype was introduced after the extremely short period of 23 months (Fig. 1). Testing of the total of 4 prototypes will be completed by the end of 1982.

As part of the scope of responsibilities of the Technical University of Berlin, this presentation is intended to describe which safety concept was chosen for the UNI-CAR, and under what prescribed constraints this selection was made. Measures implemented for increasing the exterior safety (for pedestrians and cyclists) and side-crash protection will be described; with the aim of test results, estimates will be made with regard to the increase in safety which can be expected.

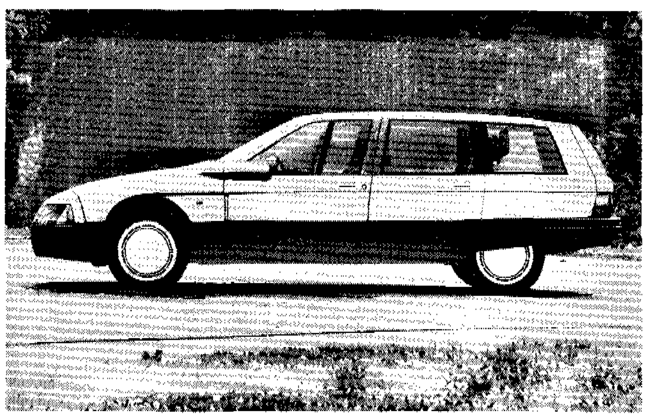

Figure 1. Prototype 1 of the UNI-car.

SAFETY CONCEPT OF THE UNI-CAR

The collaborative of the universities selected a total of three emphases for development for the UNI-CAR:

—reduction in fuel consumption by the following features: use of a diesel engine with direct injection, utilization of an electronically controlled CVT gear system, and drastic reduction of the air resistance
—reduction in noise emission by means of encapsulation of the engine and the exhaust pipe
—increase in passive safety, especially toward the outside.

The first two developmental goals—better aerodynamics and less noise emission—have resulted in form-determining and structural measures. These measures, in turn, act as constraints for the vehicle body and, therefore, for the safety concept and the design of the car interior. These restriction conditions include the following:

—a front end with a smooth surface, rounded off in all directions
—a low, long, and gently inclined front end
—a marked withdrawal of the roof edges at the sides
—a sharply inclined windshield
—a spacious middle tunnel running throughout the interior.

The following safety concept was chosen under the prescribed constraints and objectives for protective measures:

—a medium-large and medium-heavy vehicle as a compromise among self protection, partner protection, and compatibility
—slight increase in the structural and interior safety in the event of a head-on crash
—improvement in the restraint system for the front-seat passengers
—marked improvements in structural and passenger-compartment safety in the event of a side crash (test conditions: 90 degree car-car collision with an impact velocity of 50 km/h (31 mph) against the target vehicle at rest)
—considerable improvement of the exterior safety with regard to pedestrians and cyclists (test condition: collision velocity of 45 km/h (28 mph)).

EXTERIOR SAFETY, MEASURES TAKEN, AND TEST RESULTS

Design of the Front End

As a compromise between the requirements placed by the aerodynamic principles involved (a low, gently inclined front end) and by the pedestrian safety considerations (moderately developed, rounded-off leading edge of the hood, with sufficient overall height for deformation paths), the form shown in Figure 1 was selected. The aggressiveness represented by the form is mitigated by sufficient coil distance (distance between the street surface and the head dent in the hood: 1.95 m for the UNI-CAR and 1.75 m, for comparison, for the VW Golf), and by integrated bumpers, headlights, and exterior mirrors.

Impact-Energy Absorption at the Front End

The following safety measures and structural design features were chosen to be provided in the form of polyurethane foam to ensure sufficient deformation paths:

—a soft face with a deformation path of approximately 150 mm (Fig. 2)
—an impact-energy-absorbing hood, with a deformation path of approximately 70 mm (Fig. 3)
—an energy-absorbing windshield frame, with a deformation path up to approximately 45 mm (Fig. 4)
—a peripheral, energy-absorbing roof edge, with a deformation path of approximately 15 mm (Fig. 5).

The safety measures employed are summarized by perspective views in Figures 6 and 7.

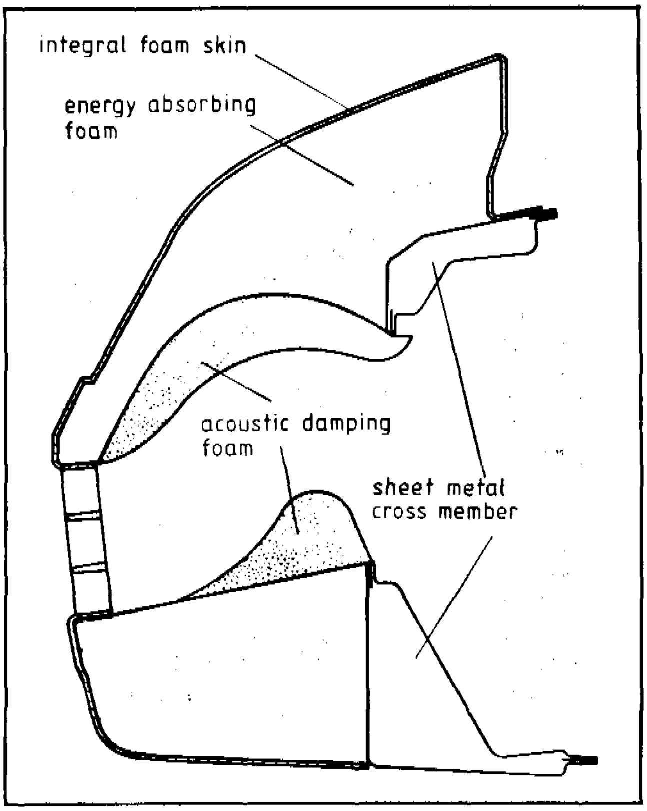

Figure 2. Soft face.

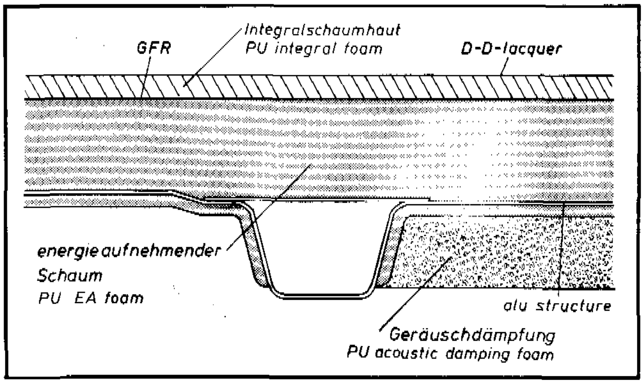

Figure 3. Hood.

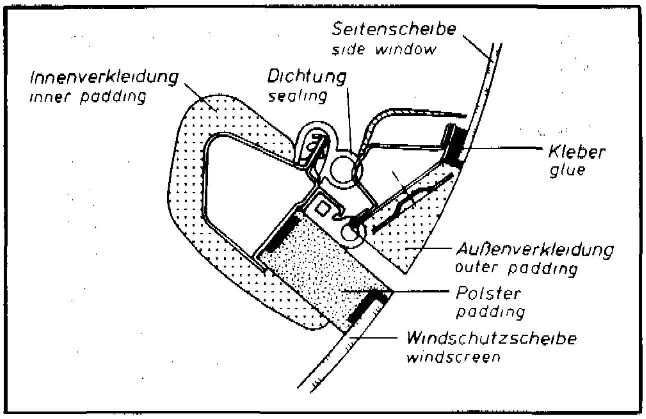

Figure 4. Padding of the windshield frame.

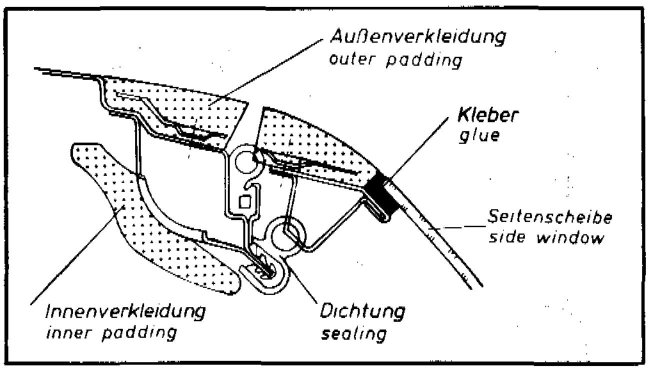

Figure 5. Padding of the roof edge.

Test Results

Approximately 90 percent of all vehicle-pedestrian accidents in West Germany take place within built-up communities, i.e., on streets in which a speed limit of 50 km/h (31 mph) is prescribed. Consequently, collision speeds for the tests were set at 25 km/h (16 mph) and 45 km/h (28 mph) in an attempt to correspond to realistic conditions; furthermore, the test pedestrian was struck

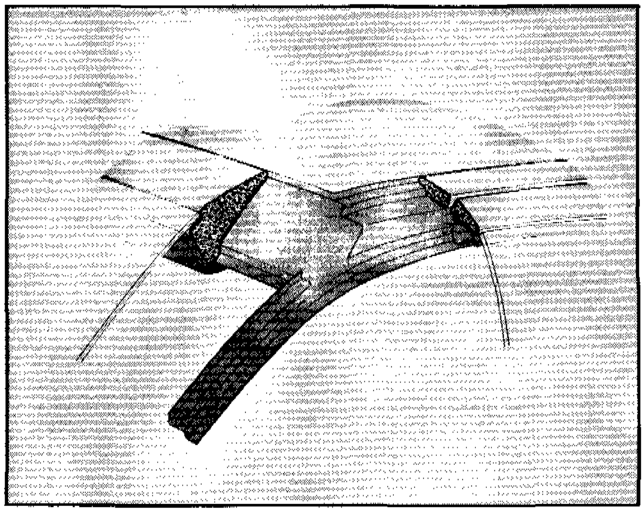

Figure 6. Section through the roof frame.

from the side by a braking car: all of which conditions serve to cover approximately 85 percent of all car-pedestrian accidents.

Since the UNI-CAR was intended to be designed to take into account the body sizes of a medium-sized child (1.25 m tall) and of the "50-percent male" (1.74 m tall), dummies were selected in accordance with the respective data for six-year-old children and for the 50-percent man.

Several versions of the UNI-CAR, each with variations in material characteristics, were available for the tests: three different front faces and hoods, each with various degrees of foam rigidity, were tested. For comparison purposes, a car with a similar outer contour—a Citroen CX—was also incorporated into the test program. This was to enable estimates to be made concerning form-related influences with respect to earlier tests with pontoon-shaped test cars.

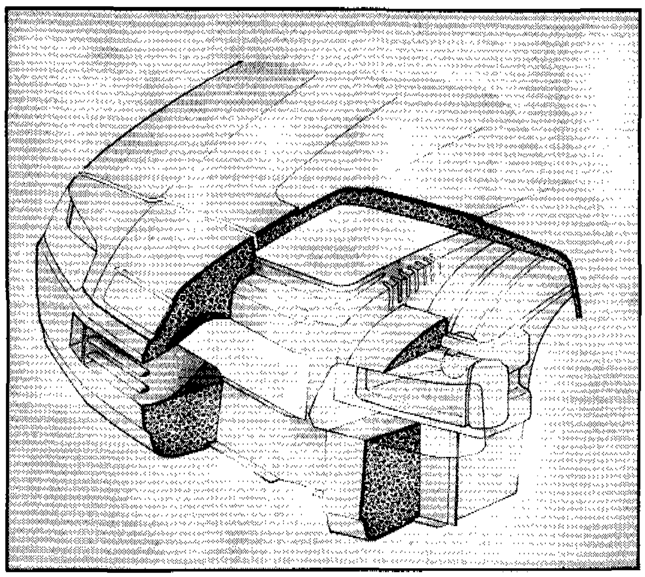

Figure 7. Section through the front end.

Comparisons of test results with pontoon-shaped vehicles and wedge-formed ones such as the UNI-CAR will always demonstrate different motions sequences and loading conditions, as a result of geometric factors. We must point out that hoods with front edges at the normal limousine height are associated with extremely high thorax loads and very long trajectory lengths for children; extremely low design forms, on the other hand, present the danger of increased head-impact velocities of adults on the hood.

The UNI-CAR compromise reached among aerodynamics, constructed size, design, visibility conditions, and deformation paths represents an acceptable mean in the configuration of the car body contour with regard to safety provided for child and adult pedestrians. In this regard, Figure 8 shows a plot of the head-impact velocity perpendicular to the hood surface, as a function of the car-pedestrian impact velocity. The test values are therefore similar to well-known results from other investigations, despite the flat form involved here. A somewhat

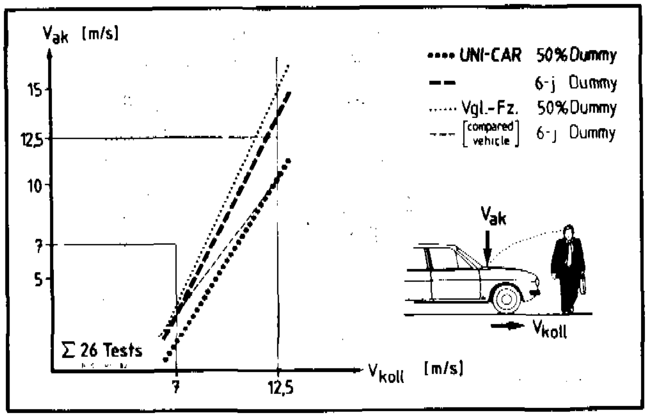

Figure 8. Head impact velocity as a function of the collision velocity, in car-pedestrian tests.

higher contour would, however, have been more favorable. The pedestrian body-wrap distance should be taken into consideration in such a manner that, even at collision velocities of 45 and 50 km/h (28 and 31 mph), the head impact will always take place in an area restricted to the hood.

Figure 9 shows the influence of padding the hood on pedestrian head loads. Here the HIC (head injury criterion) values of the UNI-CAR are represented together with those of the comparison vehicle for similar head-impact velocities. Since, in the case of the 50-percent-male dummy struck from the side, a considerable portion of its rotational energy is relatively frequently absorbed by the impact of arm and shoulder onto the hood, rather than by the head itself, the collision velocity had not been chosen as a criterion of comparison.

These tests show quite clearly that the versions of the UNI-CAR favorable for production purposes were, un-

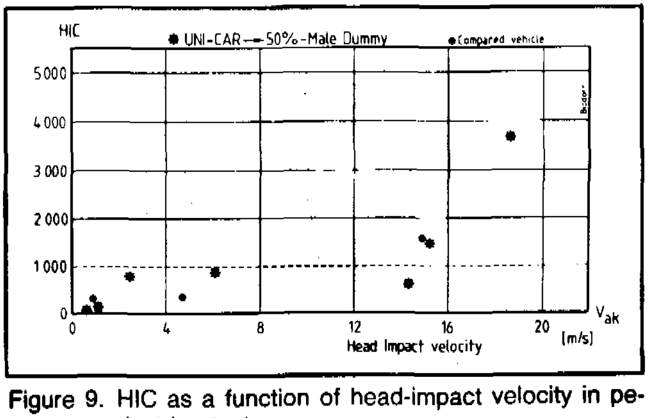

Figure 9. HIC as a function of head-impact velocity in pedestrian tests.

fortunately, relatively rigid and did not therefore result in the improvements which had been expected. Those features which were primarily unfavorable were the aluminum supporting frames for the heavier hood versions which had been padded with energy-absorbing polyurethane foam that proved to be too dense. Also problematical was the excessively strong car body shell at the soft face, in the vicinity of the headlights in their wells, as well as the seam along the hood. The last point here was especially disadvantageous in the case of the child dummy.

Good results, however, were achieved through use of a sandwich hood made of a layer of polyurethane between two layers of glass-fiber-reinforced plastic; test measured values are shown here in Figure 10. Further development work is necessary here, however, in order to solve still-remaining problems involving manufacturing expense, form distortion, and exactness of fit: these must be solved in order that the inherent advantage for pedestrian safety can in fact be implemented.

In order to arrive at conclusions which can be repeatedly reached under more easily reproducible conditions, various versions of the hood, with their corresponding models, were subjected to separate testing under a drop-weight apparatus. Insofar as the distance to immovable auto components in the engine compartment remains sufficient (the attempt was made to ensure up to 120 mm of intermediate space, with the exception of several critical

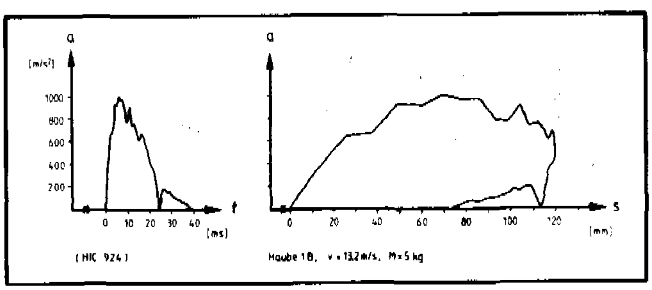

Figure 10. Path-of-force characteristic for a sandwich hood of polyurethane between glass-fiber-reinforced plastic.

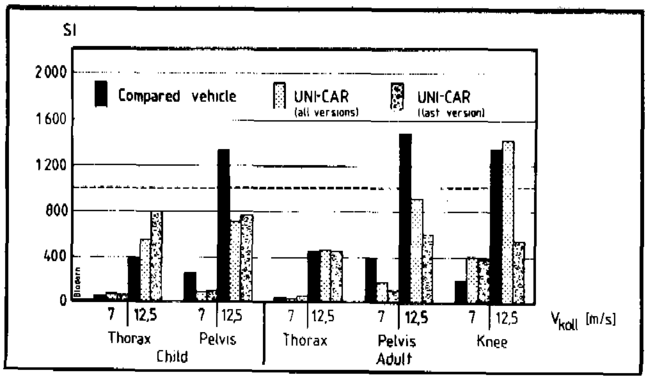

Figure 11. SI as a function of the collision velocity in pedestrian tests.

points, with a minimum of 70 mm intervening room), and if large, nonsupported surfaces which could be deformed in their entirety were kept within certain limits, then tolerable HIC figures up to velocities of 45 km/h (28 mph), with very high energy absorption, are indeed possible. See Figure 10.

Figure 11 shows the influence of the soft face, for which the SI (severity index) calculated for pelvis and thorax is compared for the various test vehicles. The advantages of the UNI-CAR are more apparent here than for the tests for the hood, primarily responsible as it is for head injuries.

The reason for this phenomenon is the known fact that favorably designed sheet-metal hoods can also result in low loading figures—if the victim does not happen to strike any bracing elements. In the case of a front end made of sheet metal, however, the presence of bracing, edges, and corners can hardly be avoided; in any case, the intention is to pass the 5 mph test as stipulated in FMVSS 215, without harm to the pedestrian—and this would not be possible with a metal front end.

As with the hood, the version of the soft face with the greatest yielding characteristics proved to be most superior here as well. One of the results from a soft face made entirely of integral polyurethane foam, which was also included in the testing, showed that forces applied to the pedestrian could indeed be reduced: here, the beneficial effect was achieved by elimination of the bracing and reinforcement normally featured locally at the cooling-air intake, at the headlights, and at the body seams. The addition of foam to these points resulted in more than doubling the weight here, however.

The acceleration-time sequence plots alone, however, do not suffice to explain all the differences observed in collision sequences with respect to all accident evidence and traces and damage done to the dummies and the test vehicles. With tests conducted using the conventional comparison car, it was observed that the following types of injuries were suffered in almost every second test: dummy legs and knee joints were damaged by the pronounced bumper edges, and collarbones were broken by impact of the elbow on the hood in the vicinity of the engine. Furthermore, splinters from headlight covers and

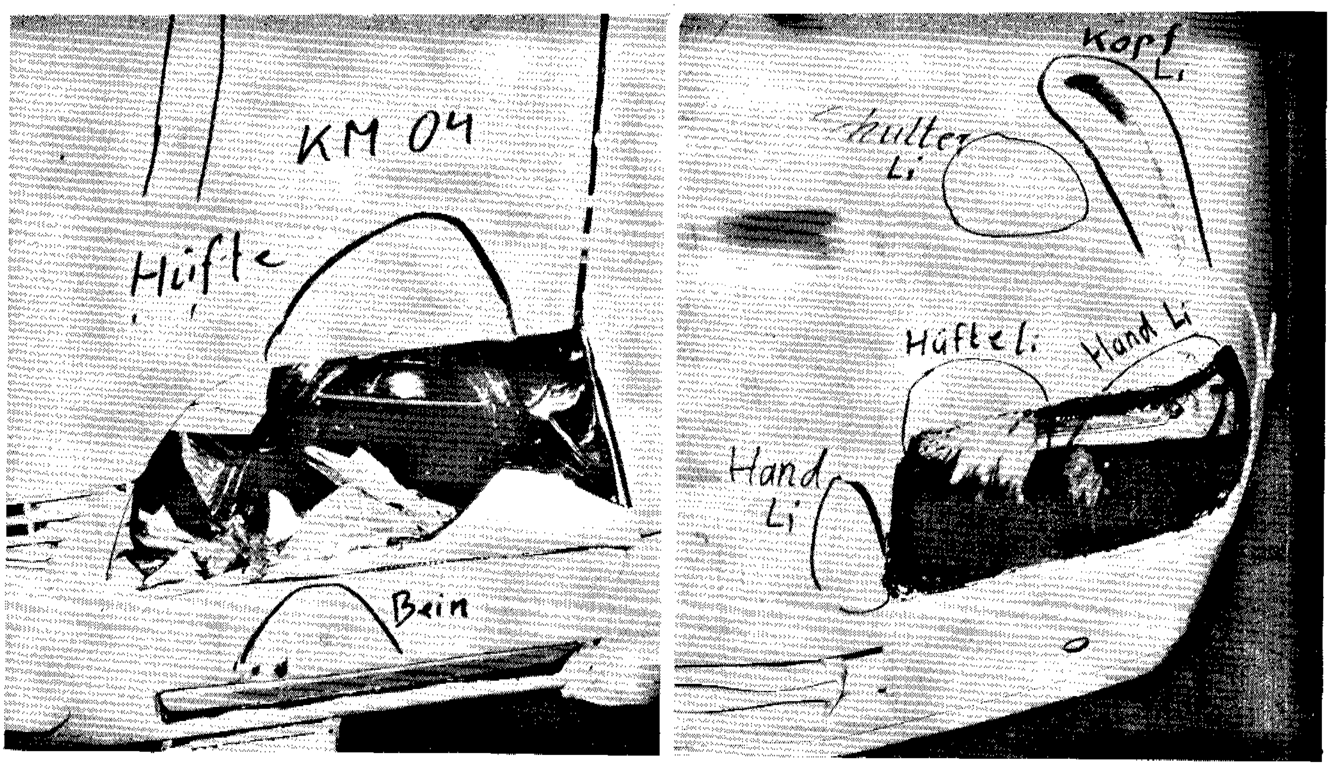

Figure 12. Damages to the comparison vehicles from pedestrian tests (right side UNI-Car; impact locations marked with different colours).

hood latches protruding partially through the hood metal to the outside would also have given real cause for critical injuries in the case of an actual accident. The dangers here are not correspondingly recorded in the acceleration-time printouts, however. Figure 12 shows the two cars compared in testing in the headlight area after a collision with a 50-percent dummy at 45 km/h (28 mph). The UNI-CAR has remained for the most part undamaged, and will therefore be significantly less aggressive in respect to the types of injuries which could be expected from these damaged vehicle parts.

SIDE CRASH PROTECTION, MEASUREMENTS, AND TEST RESULTS

Side Protection Measures

The side protection system consists of a transverse bracing which is rigid in compression: two transverse beams behind the front seats, between the "B" pillars. The bracings are provided with additional rigidity by the seat pans. See Figure 13. The door braces and latches ensure that, in case of a side crash, an interlocked bracing system will function to withstand initial forces applied in bending and, for greater deformations, in tension. To guarantee direct transmission of tension forces (i.e., without first having to overcome play), careful design of the connection points was necessary (e.g., pillars, hinges, door, lock, etc.). See Figure 14.

By virtue of seats which cannot be adjusted in the longitudinal direction, it was possible to provide uniform optimal side padding for all sizes of passengers. The seats have been moved a relatively great distance toward the middle of the car, thereby allowing for considerable side intrusion before the occupants are struck by the penetrating parts of the car.

Finally, interaction (collision) between the left and the right passengers is extensively avoided by virtue of the high transmission tunnel and shoulder padding. See Figure 15. An additional advantage is provided by anchoring the top of the three-point safety belt system on the *inside* rather than at the outside.

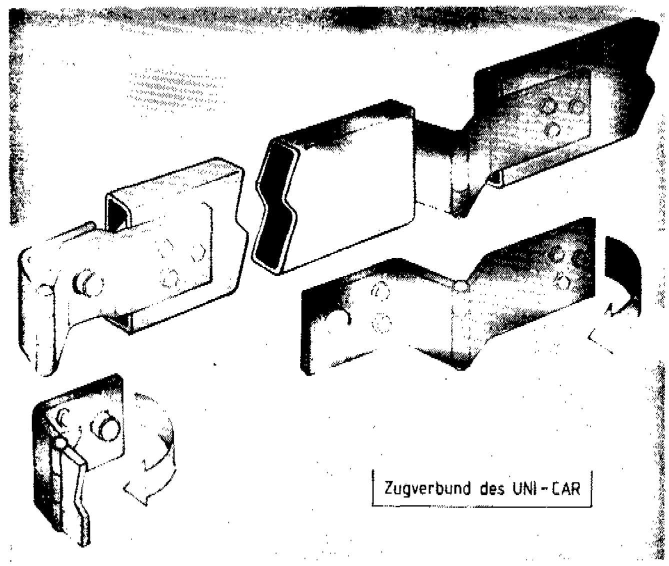

Figure 14. Hinges and locks on the UNI-Car.

Test Results

Investigation was made of the effectiveness of the various cross-bracing elements, individually and in interaction. For reasons of cost, the tests were conducted with standard factory car models which had been modified in accordance with the improvements made with the UNI-CAR. The following results were determined:

—By virtue of the bracing, considerably more seating room remains available.

—Best effectiveness was achieved by an integrated sys-

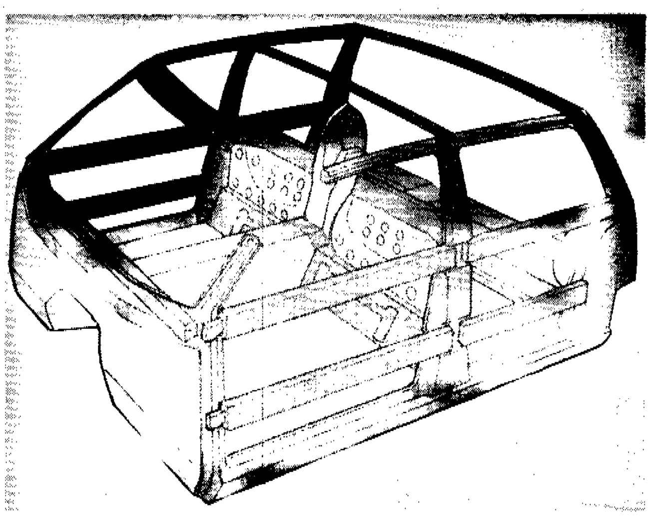

Figure 13. Passenger compartment of the UNI-CAR.

Figure 15. Interior padding in the UNI-CAR.

Table 1. Assessment of the safety benefits.

Traffic Participants	Fatality rate absolutely (FRG 1980)	Fatality rate (coll. with car) (%)	Reduction of fatality rate (%)	Safety benefit (%)
Pedestrians	3095	23	40	9.2
Bicyclists	1142	9	40	3.6
Mofa, Moped, Mokick	765	5	40	2.0
Motorcyclists	1232	9	20	1.8
Occupants in frontal impacts	3912	37	20	7.4
Occupants in side impacts	1825	17	25	4.3
Other	1070	—	0	0
Sum	13041	100	—	28.3

tem with the door braces and the cross braces. Intrusion from side crashes was reduced from 465 mm with unbraced vehicles, to 225 mm, i.e., to less than half.

—The free space remaining as a result of the above phenomenon can be utilized for minimization of forces acting on passengers by means of providing suitable padding of the side doors. This is achieved by ensuring as great a padding deformation path as possible for acceleration of passengers up to the lateral vehicle velocity after a crash from the side.

—In the striking car, the passengers and vehicle will be subjected to slightly higher collision forces as a result of the bracing reinforcement provided in the struck vehicle. The safety advantage gained on the other hand by the maintenance of more survival space in the target vehicle passenger compartment more than compensate for the insignificant worsening of conditions for the striking car, with the result that this slight disadvantage is acceptable.

ASSESSMENT OF THE SAFETY BENEFITS

Calculation of the safety benefits gained in the area of passive safety is performed in accordance with a new prognosis method. The individual steps are as follows:

—probability of injury as a function of the collison velocity, with the present state of vehicle design
—gain in speed which results experimentally after introduction of the safety measures, with equal loading
—injury probability as a function of the collision speed, with UNI-CAR conditions
—distribution of speeds in actual accidents
—breakdown of participants into AIS (abbreviated injury scale) classes by means of collision speed, with present state of automotive design
—shifted breakdown of participants into AIS classes using the collision speed, with UNI-CAR conditions
—distribution of pedestrian injuries in West Germany
—reduction in the proportion of those injured in West Germany
—reduction in the number of deaths and severe injuries.

If the above procedure is applied to all relevant collision types for which the UNI-CAR could bring improvements, a safety gain of approximately 30 percent could be achieved with respect to the number of traffic deaths. See Table 1. This figure results from inclusion of estimates made in the comparison of data from:

—actual traffic accidents
—test results with present conditions of automotive design (standard factory models)
—test results with the UNI-CAR.

This safety benefit results from the following breakdown:
13% for pedestrians and bicyclists
4% for motorcyclists
7% for car passengers in a head-on crash
4% for car passengers in a side crash.

As a result, the stipulations set in the relevant Loading Specifications for a safety gain of 28 percent in the area of passive safety were in fact satisfied by the cumulative effects of advantages from the various accident types, as well as with respect to the death rate.

REFERENCES

1. (—): Ausschreibung zum Projekt "Demonstration automobiltechnischer Forschungsergebnisse in integrierten Gesamtkonzepten von PKW-Versuchsmodellen," Bundesminister für Forschung und Technologie (BMFT), Bonn (1978).
2. Bandel, J.: Der Forschungspersonenwagen, ATZ 82, (1980) 2, S. 59-62.
3. Breuer, B.: The pedestrian-oriented, low-noise and economical research car Proceedings International Symposiun on Traffic and Transportation Technologies, Volume C II, S. 70-88, Verlag TÜV Rheinland GmbH, Köln 1979.

4. Appel, H., Blödorn, J., Kühnel, A., Pasch, R., Rattaj, H., Willumeit, H. P., Wollert, W.: Das Sicherheitskonzept des Forschungs-PKW UNI-CAR. VDI-Bericht Nr. 418, 1981, S. 123-130.
5. Potthoff, J.: Zur aerodynamischen Formgebung des Forschungs-PKW UNI-CAR. VDI-Bericht Nr. 418, 1981, S. 219-230.
6. Liedl, W., Schwarz, R.: Noise reduction concept for UNI-CAR research passenger car. Internoise 1981, Amsterdam.
7. Kühnel, A., Blödorn, J., Appel, H., Pasch, R., Rattaj, H., Wollert, W.: Realisierung und Wirksamkeitsnachweis von Sicherheitsanforderungen am Beispiel des Forschungs-PKW. Unfall- und Sicherheitsforschung Straβenverkehr, Heft 36, 1982, S. 152-157.
8. Kühnel, A.: Der Fahrzeug-Fuβgänger-Unfall und seine Rekonstruktion, Dissertation 83, 1980, Berlin.
9. Pasch, R., Kühnel, A., Wollert, W., Blödorn, J., Rattaj, H., Appel, H.: Structural rigidity and occupant loading in the case of the side collision. VII. International IRCOBI Conference on the Biomechanics of Impact, 1982, Cologne.
10. Blödorn, J., Wollert, W., Kühnel, A., Pasch, R., Rattaj, H., Appel, H.: Anwendung von Polyurethan-Schaumstoffen zur Verbesserung der Äuβeren Sicherheit beim PKW. Kunststoffe 72 (1982) 4, S. 217-221.
11. Appel, H., Breuer, B., Essers, U., Helling, J., Willumeit, H. P.: UNI-CAR—Der Forschungs-Personenwagen der Hochschularbeitsgemeinschaft. ATZ 84 (1982) 3, S. 107-115.
12. Kühnel, A., Appel, H., Blödorn, J., Pasch, R., Rattaj, H., Wollert, W., Willumeit, H. P.: Sicherheitsgewinn und Innenraum des UNI-CAR. XIX. Intern. FISITA-Congress, 1982, Melbourne, Australia.
13. Breuer, B.: Der Forschungs-Personenwagen UNI-CAR. XIX. International FISITA-Congress, 1982, Melbourne, Australia.

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The Safety Aspects of the VW Auto 2000

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INTRODUCTION

The tasks which research and development work is called upon to fulfill have become increasingly more critical. This does not, however, alter the fact that the motor car has to satisfy a large number of various, conflicting requirements. For the research division of the Volkswagenwerk, this means representing the integral demands made on the motor car of tomorrow. As long ago as 1973, the concept of the IRVW was born and represented in hardware. As far as this concept is concerned, nothing has changed up to this conference. Contrary to the well-known demands, a whole series of additional demands now have to be fulfilled. Figure 1 shows these conflicting demands. Because of the causal relations, vehicle safety must not, in our opinion, be seen in isolation, also with regard to the further development of vehicles. In this respect, the "Auto 2000" research project is a logical continuation of our research work up to now. The VW Auto 2000 project is demonstrated in the following along with the results achieved to date.

DESCRIPTION OF THE VW AUTO 2000 CONCEPT

General

The VW 2000 research vehicle has already been described in detail in several articles (1) (2). For this reason, the general description can be limited to the aims and a few highlights together with the results. The aim of the project was to represent the future of motor car engineering up to the year 2000. Given this aim, the vehicle concept was to be optimized along with a significant improvement of vehicle safety, a reduction of exhaust gas and noise emission and increased fuel economy. Along with alternative materials for all areas of the vehicle, the use of electronic aids for the three electronic centres in the vehicle was to be investigated in particular. As a result, the 2-door saloon shown in Fig. 2 was displased at the IAA (International Automobile Exhibition) in Autumn 1981 in Frankfurt with the 3-cylinder Diesel engine and at the 1982 Hannover Trade Fair with the spark-ignition engine. In 1982, selective follow-up work was carried out, the results of which are given in the following.

The 4-seater vehicle permits a payload of 400 kg. The luggage compartment at the rear has numerous possible variations and means that the vehicle can be used to perform a whole range of transport tasks. The two research prototypes are fitted with two different engines—a 4-cylinder spark-ignition engine and a 3-cylinder direct-

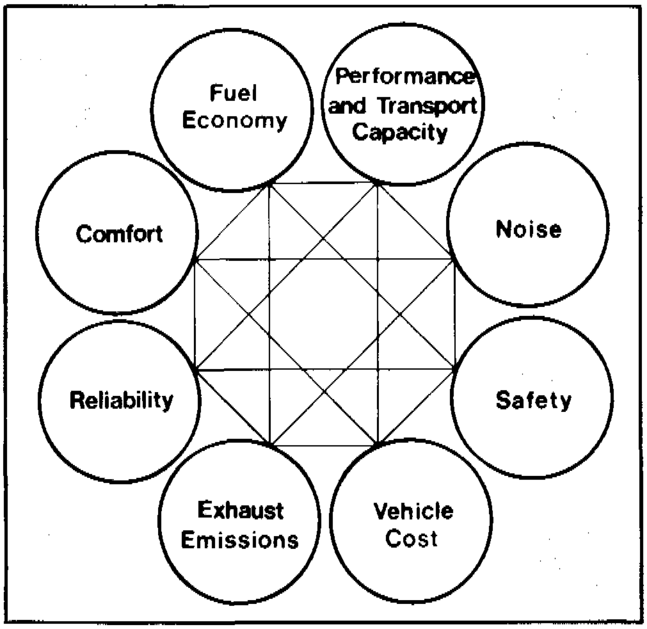

Figure 1. Conflicting demands in car development.

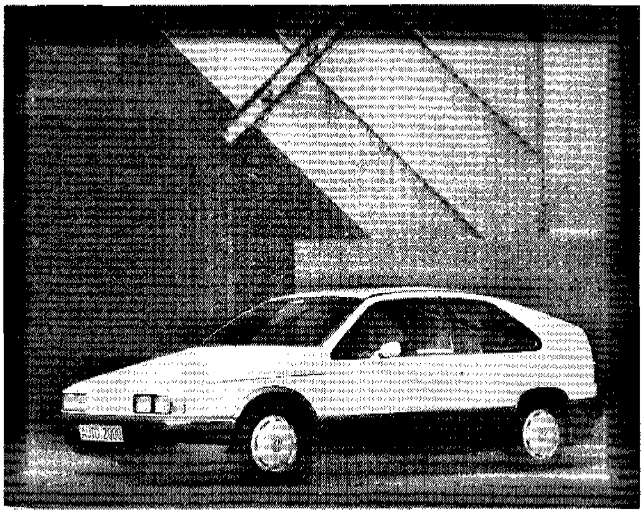

Figure 2. Volkswagen car 2000.

injection Diesel engine. Together with the transmissions selected for each engine, the vehicle consumption and performance values shown in the tables resulted.

The fact that these values were achieved with comparatively high performance should be particularly emphasized. However, in the course of the work the conflict between a further reduction of exhaust gas emission and an increase in fuel economy became apparent. It was only possible to achieve these consumption figures by means of the low drag coefficient of $c_D \times F = 0.25 \times 1.86 = 0.47$, i.e., substantially lower than the mean value of new vehicles sold in Germany in 1981 of $c_D \times F = 0.81$ (Fig. 3). Despite the use of a great number of alternative materials, it was not possible to lower the vehicle weight

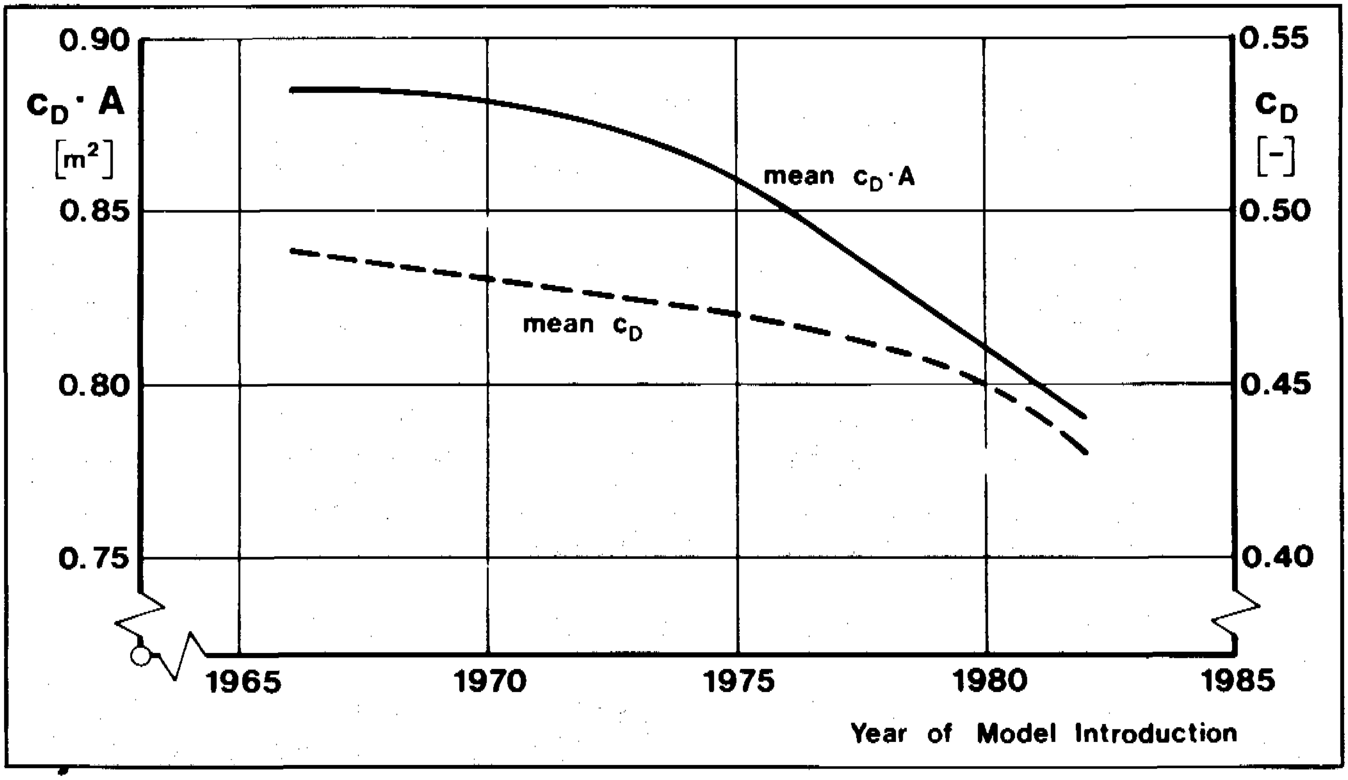

Figure 3. Evolution of c_D and $c_D \times A$ worldwide.

much below the mean value of present-day production vehicles. One reason for this is the large number of additional items of equipment, the weight of which must be compensated for by reducing weight elsewhere.

Diesel Engine and Stop/Start System

The Diesel engine was designed as a 3-cylinder direct-injection engine with electronically governed Diesel injection pump. Of the possible supercharging devices, an exhaust turbocharger was selected. The consumption and performance of the Auto 2000 achieved with this combination are shown in Figures 4a-4c. The engine/clutch management system is worthy of particular mention here. The clutch system was designed as shown in Figure 5. The controlled clutches K1 and K2 cause the engine to be switched off when the vehicle is stationary or when decelerating. If this system had not been integrated in the vehicle concept, fuel consumption would have been approximately 17% higher in the ECE urban cycle and approximately 4% higher in the US 75 test. Exhaust gas emissions were also reduced by switching off the engine. The measured values for the different test methods were:

ECE exhaust gas test:
CO = 3 g/test   HC + NOx = 6 g/test
US exhaust gas test:
CO = 0.92/mile HC = 0.3 g/mile NOx = 1.2 g/mile

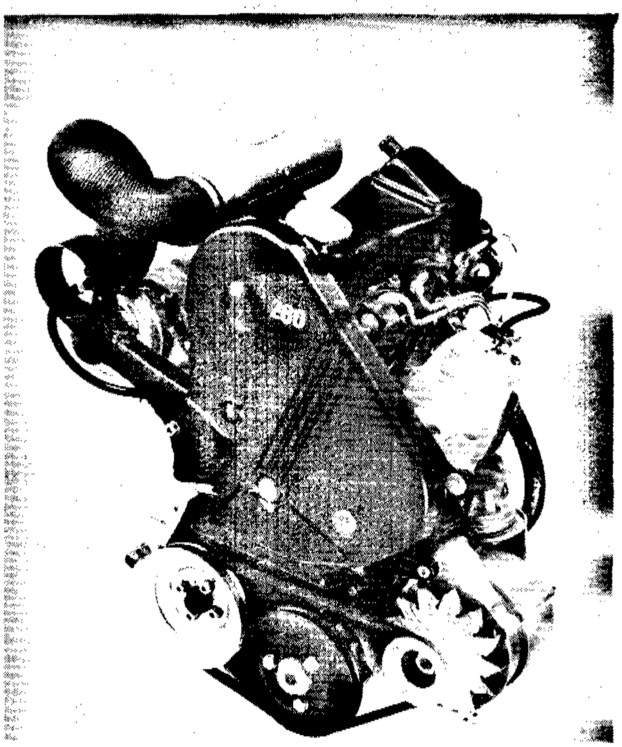

Figure 4a. 3-cylinder diesel engine (direct injection with turbocharging).

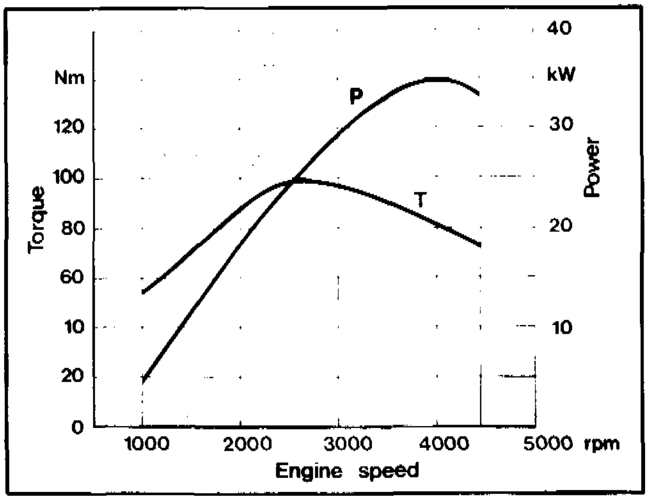

Figure 4b. Full throttle characteristics of turbocharged direct injection diesel.

		Diesel Engine
Top Speed	km/h	150
Acceleration 0-100 km/h 40-100 km/h in 4.th.Gear	s	20
Fuel Consumption (DIN 70 030) ECE-Test constant 90 km/h constant 120 km/h 1/3 Mix	l/100 km	 4.2 3.3 4.9 4.1
Pollutant Emissions $CO/HC/NO_x$		Within Present European Limits
Noise Emission	dB (A)	73

Figure 4c. Operational data (diesel-version).

Spark-Ignition Engine with Automatic Transmission

The spark-ignition engine used was a 1.06 litre engine with mechanical supercharging, petrol injection, knock limit control and map-controlled high-power transistorized ignition system. Figure 6a shows this engine with the mechanical supercharger controlled via a variable drive. The results achieved are shown in Figures 6b and 6c. Related to the limited pollutants, there is a clear conflict between a further reduction of pollutant components and of fuel consumption.

Acoustic Capsule

To reduce exterior noise, a vehicle acoustic capsule as shown in Figure 7 was designed for both engines. The

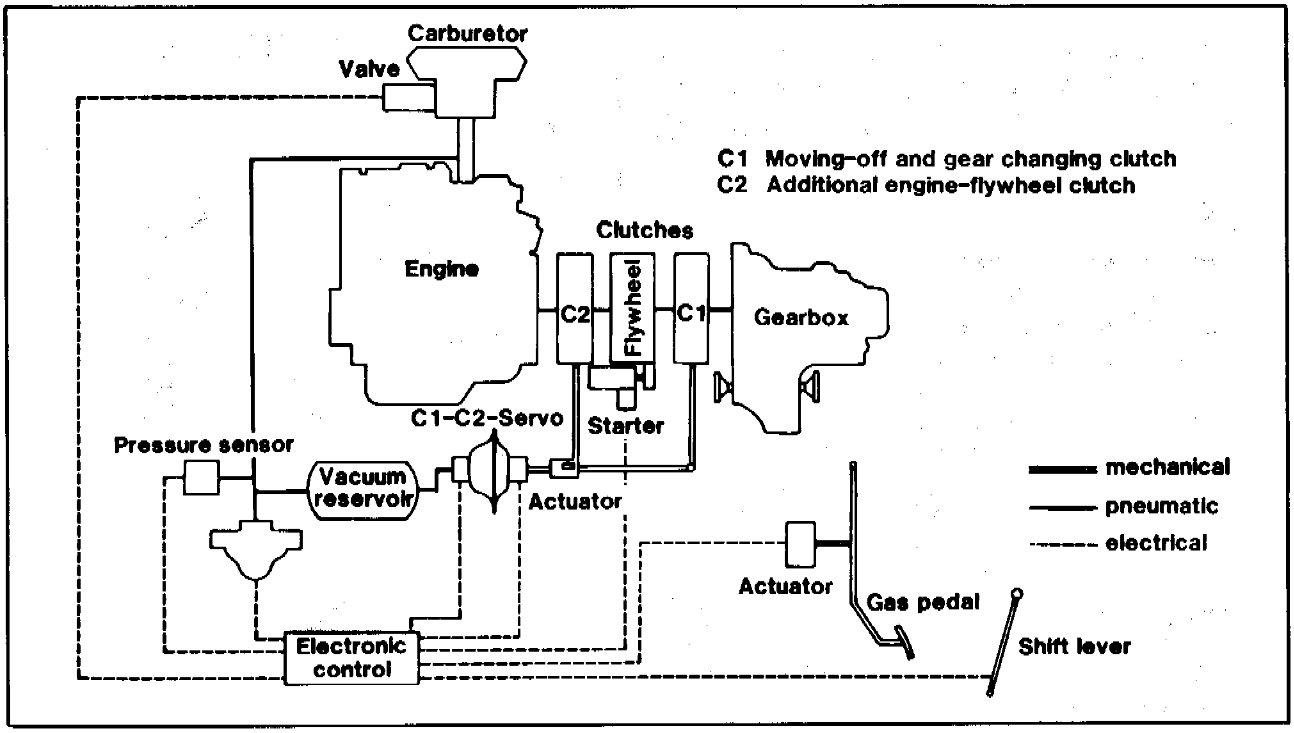

Figure 5. Start-stop system with flywheel inertia usage.

installation of this capsule has reduced exterior noise in the ISO pass-by test by 6-7 dB (A) in comparison with the legal type approval test value of 80 dB (A). On the vehicle with the spark-ignition engine, installation of the capsule components highlighted the problems concerned with the rise in temperature in the engine compartment. For a solution appropriate for series production, the capsule cannot for this reason be used to the same extent as in the Auto 2000, with the result that the reduction in noise would not be as great.

SAFETY ASPECTS

Accident Avoidance

In the field of accident avoidance a number of additional components were tested which have not yet been installed in this form as standard in vehicles. Here, we are dealing with the following features:

- driver information centre with the ALI system
- tyre pressure indicator
- synthetic voice indicating warnings
- antiskid device

A sub-frame with wishbones was selected for the front axle and a plastic design with countersteering rubber bearings for the rear axle. These bearings, which are also installed in the VW Passat, contribute to directional control, particularly in the event of side forces. The built-in antiskid device was developed together with the Teves company for the Auto 2000. Figure 8 shows the system selected. The hydraulic unit combines in a compact design the master cylinder, brake servo, accumulator, electric motor, pump and antiskid pressure modulator. The system is based on a three-circuit brake system (front wheel, rear wheel), with the front wheels being controlled individually and the rear wheels jointly (select low). The tests carried out showed that with this system steerability in particular is maintained when braking on a bend and on μ-split carriageways. The exact tyre inflation pressure also contributes to perfect vehicle handling as well as to the maintenance of comfort and low rolling friction. The Bosch system installed has 4 pressure sensors in the tyres and transmissions from tyres to chassis. The sensor, which

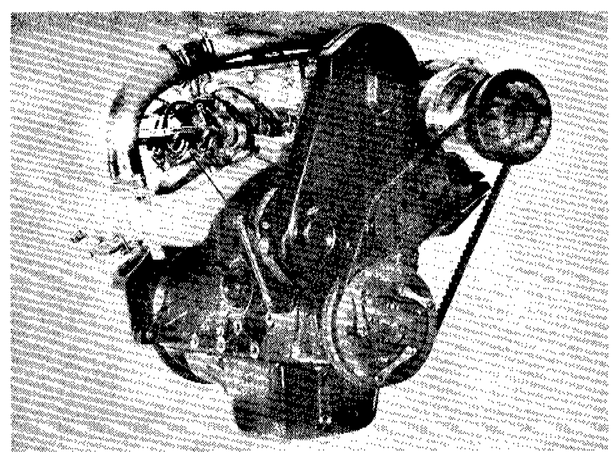

Figure 6a. 4-cylinder SI-engine (Comprex-Supercharging).

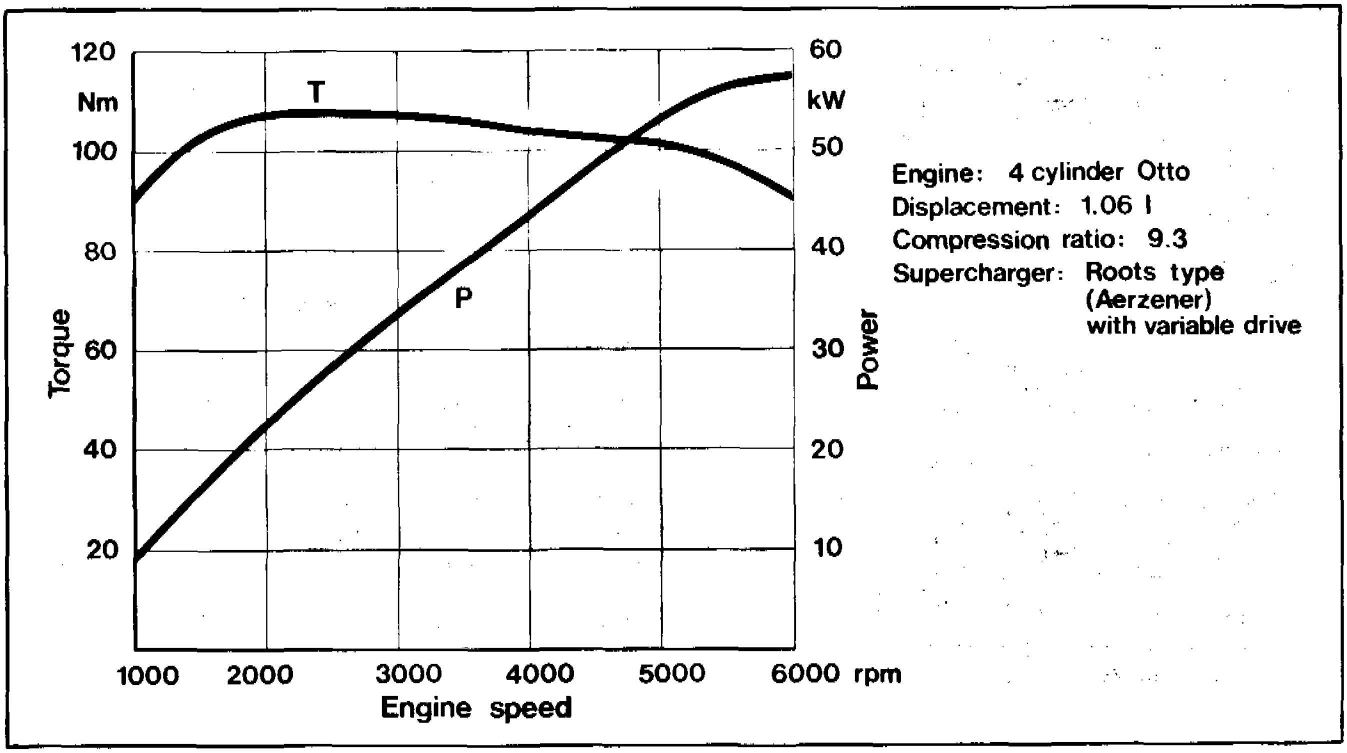

Figure 6b. Full throttle characteristics of supercharged Otto engine.

		Spark-Ignition Engine
Top Speed	km/h	180
Acceleration 0–100 km/h 40–100 km/h in 4.th.Gear	s	 12
Fuel Consumption (DIN 70 030) ECE-Test constant 90 km/h constant 120 km/h 1/3 Mix	l/100 km	 7.9 4.3 5.6 5.9
Fuel Economy US-Test City Highway Combined	mpg	 32 50 38
Pollutant Emissions CO/HC/NO_X (ECE)		Within Present European Limits
Noise Emission (ISO DP 362)	dB (A)	73

Figure 6c. Operational data (SI-version).

is screwed into the rim, consists of a reference pressure chamber and a metal diaphragm which, when bent, actuates a contact so that if the pressure is too low a DC voltage signal is transmitted to the driver information centre where the synthetic voice utters the phrase "tyre inflation pressure too low." The ALI system should be seen as a further element towards accident prevention. This system gives the driver information on the flow of traffic. There is still a great safety potential in a continuous flow of traffic with regard to reducing the number of accidents.

Mitigation of Injuries

Particular attention was paid to mitigating injuries in the event of an accident. The measures taken can be divided into two areas:

Protection of pedestrians:	rounded body, no sharp-edged body parts, windscreen made of Sekuriflex (special tempered safety glass), deformable bonnet.

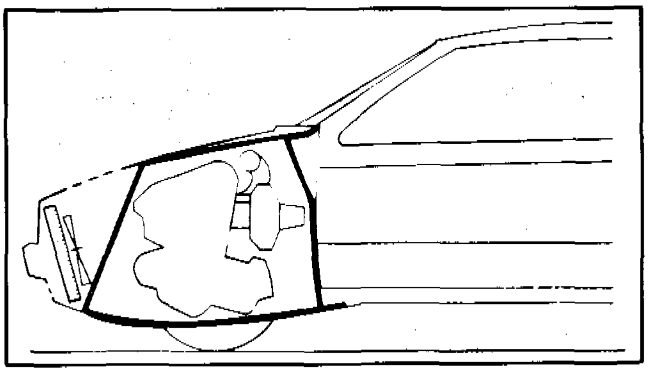

Figure 7. Capsule concept.

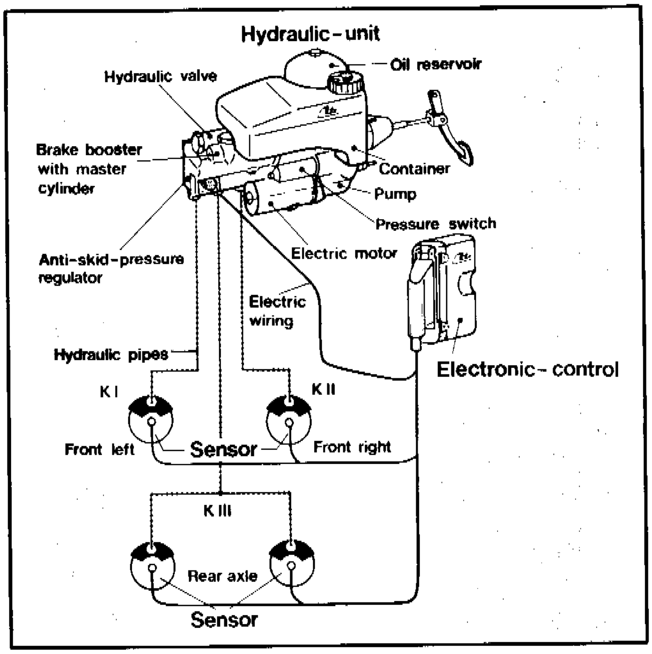

Figure 8. Anti-skid device.

Protection of occupants:	energy-absorbing body, special safety steering column, passive seat belt system.

An optimum design of the body was aimed for taking into account legal requirements, the constraints imposed by aerodynamics, the vehicle curb weight of approximately 800 kg together with the engines and transmissions selected.

The wheelbase is 2450 mm, the front track width 1410 mm and rear track width 1358 mm. The passenger compartment dimensions are: front/rear headroom 956/923 mm; front/rear elbow width 1455/1426 mm and the so-called comfort dimension (distance from pedals at front to front edge of rear seat bench) 1825 mm. To achieve a design satisfying this range of requirements, the latest findings of the Finite Element Method were used. Figure 9 shows the FEM mesh of the research vehicle with the appurtenant comparative results with regard to calculation and testing. The comparison shows that along with the optimization measures of the FEM model, the test conditions must also be exactly simulated. For energy absorption in crashes, optimization runs for the longitudinal members were carried out, likewise with FEM methods. Figure 10 shows the mesh of a longitudinal member with the results of the quasi-static pressure test. On the basis of the theoretical investigations, the structure for the body in white was designed as shown in Figure 11. For head-on collisions, a design with straight longitudinal members was elaborated which absorbs the energy on two planes. The contact surfaces on the pillars were made larger specially for the door arch.

The new developed special Sekuriflex windscreen was bonded to the body frame, as shown in Figure 12. The structure of the windscreen also means an increase in safety for occupants not wearing a seat belt. This windscreen has an additional plastic foil on the innerside which helps to avoid lacerations of the face and the sometimes occurring penetration through the windscreen during crash. The Sekuriflex windshield is now under testing related to the other performance criteria in Germany. Figure 13 shows a section through the side door. Because of the relatively large door opening of the 2-door body, it was necessary to design the arch accordingly. Together with the energy-absorbing inner door parts, a further improvement is to reduce the danger of injury in the event of collision from the side. For the front seats, the passive seat belt system of VW, body belt with knee bolster, was fitted (Fig. 14). The system of VW body belt together with the special breakaway steering column (Fig. 15) gives protection up to 30 mph or more in accordance with the requirements of US-FMVSS 208. The following results are those of sled impact tests carried out with Golf bodies, equipped with the passive restraint system:

Δv = 37 mph		Driver	Passenger
HIC	(-)	789,0	739,0
a res chest	(g)	47,6	39,6
F femur left	(kN)	5,09	4,45
F femur right	(kN)	4,25	5,67

As is generally known, the head impact in particular is higher in the event of a real crash than in the impact test due to the different way in which vehicle and dummy behave. Nevertheless, it can be assumed that FMVSS 208 is met up to 30 mph or more.

Initial tests with a modified Hybrid II-dummy were also carried out to check the protection of pedestrians. The results are listed in the following:

Position of dummy	Impact speed (mph)	Dummy data (t ≥ 3 ms)			
		Head		Chest	Pelvis
		HIC(-)	ares (g)	ares (g)	ares (g)
Mid front of vehicle perpendicular to the car	15,6 22,3	161 191	54,7 48,0	24,9 36,5	31,0 40,8

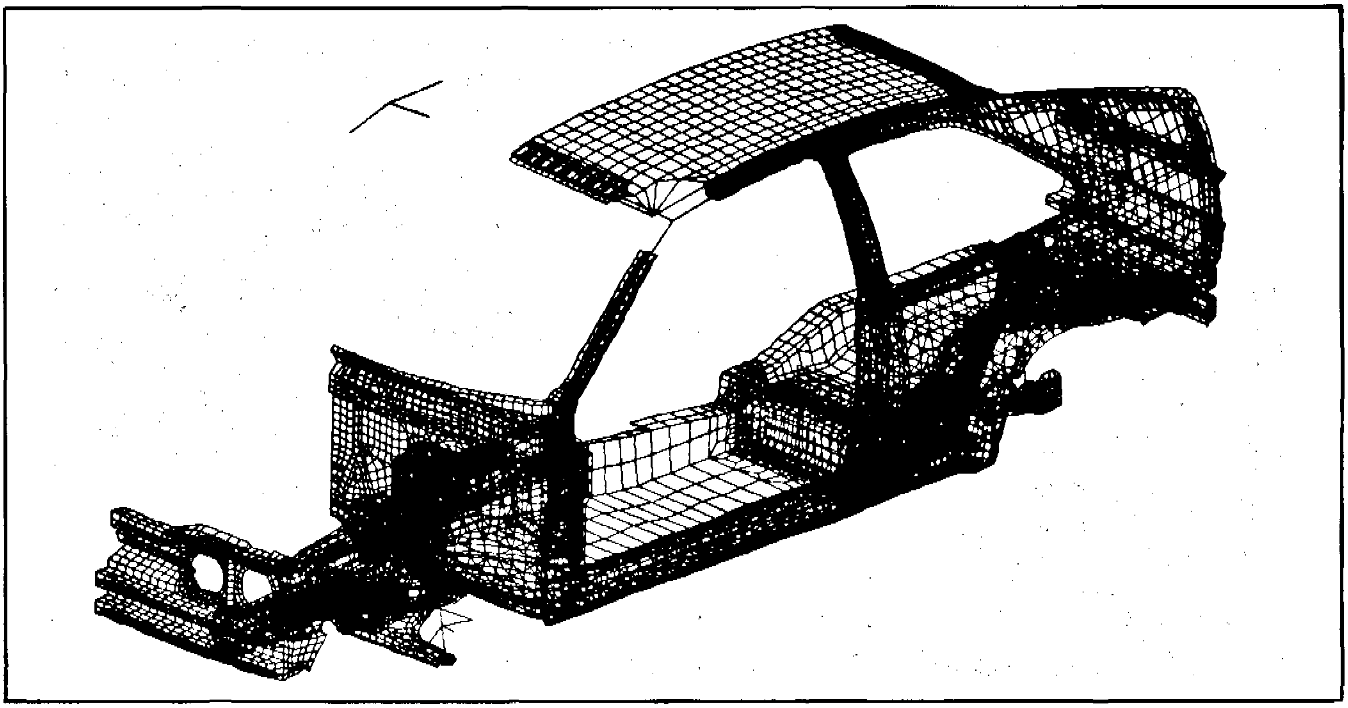

Figure 9a. Finite element analysis.

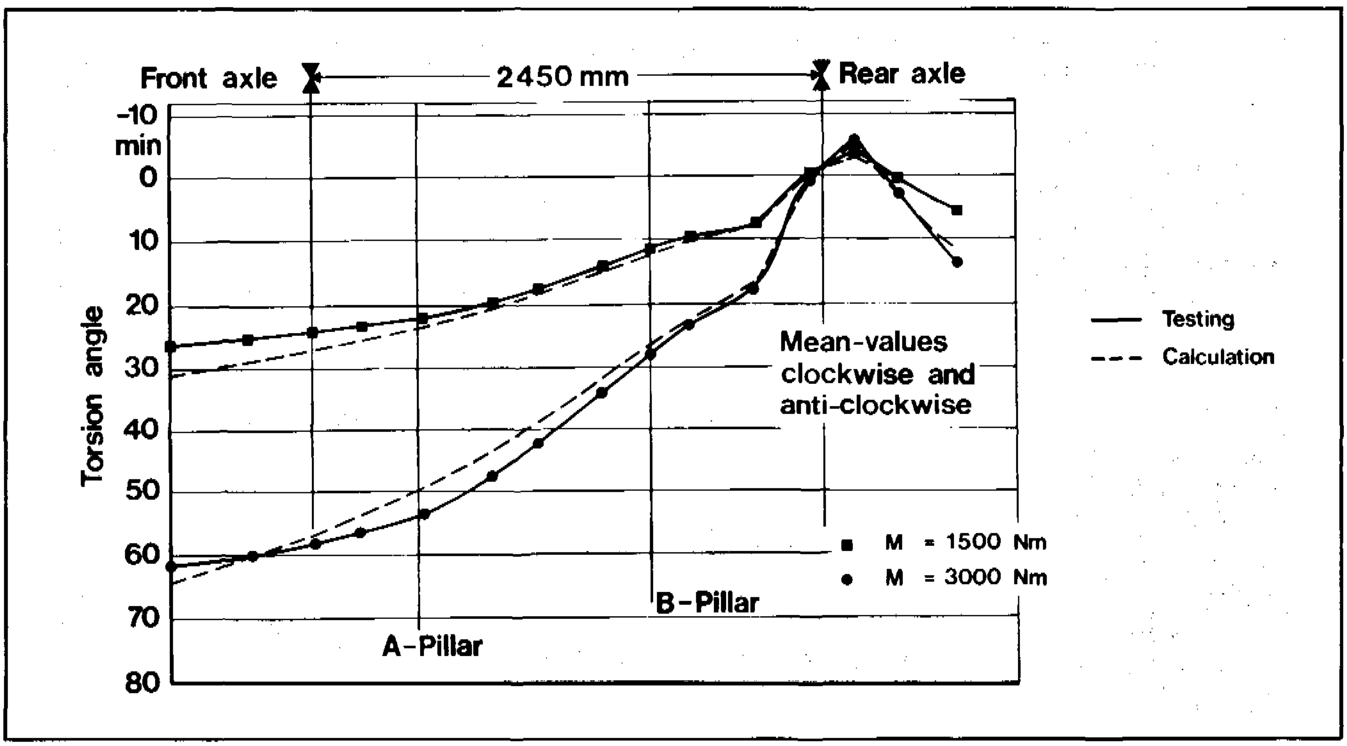

Figure 9b. Finite element analysis.

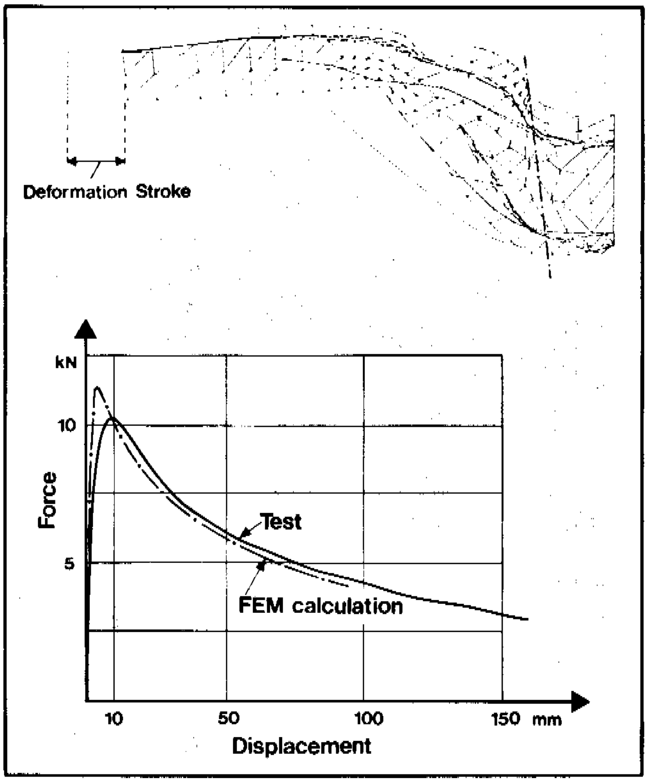

Figure 10. Finite element analysis for the front-beam.

Compared with vehicles with a high front end, the "flight path" of the dummy is different with the aerodynamic shape of the Auto 2000. This applies both to the kinematics of the dummy motion as well as to the contact time of the dummy on the front of the car. The initial impact is taken up by the front end which in case of pendulum test absorbs energy up to 2.5 mph. At higher speeds, the dummy comes into contact with the Sekuriflex windscreen. Figure 16 shows the contact between the car 2000 and the pedestrian dummy during the collision phase. Although the data measured at the dummies are well below the criteria specified for restrained vehicle occupants, a judgment about the performance in real world pedestrian accidents cannot be made at this time.

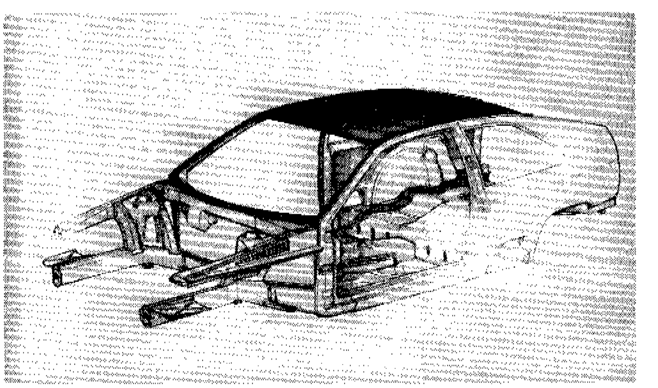

Figure 11. Body in white.

The tests and analyses of vehicle safety show that for a future vehicle concept designed along the lines of economy it is also possible to provide a reasonable degree of vehicle safety.

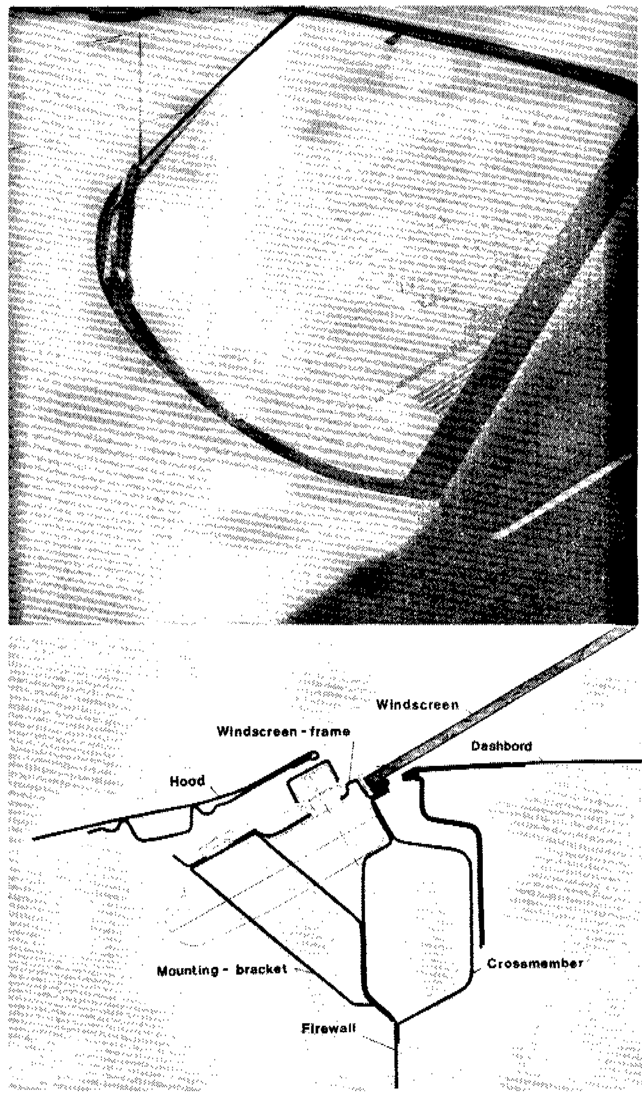

Figure 12. Hood/windscreen-design.

SUMMARY

The obligations incumbent on vehicle development should not just be seen in the field of vehicle safety. Along with the further increase in vehicle safety in the field of accident avoidance and mitigation of injuries, the requirements in the field of energy saving (manufacturing and operation), reduction of exhaust gas and noise emission

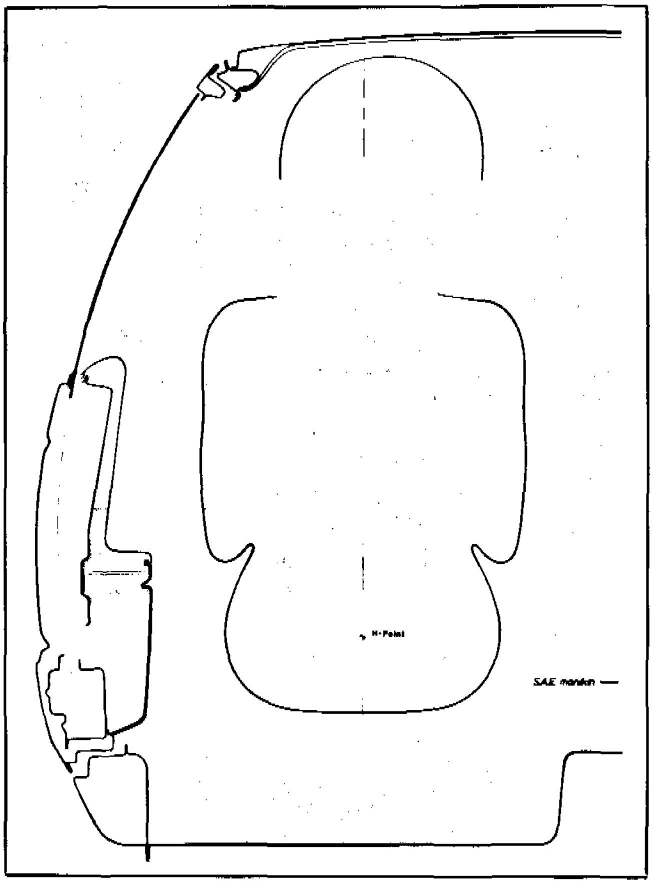

Figure 13. Door cross section.

Figure 14. Passive restraint system.

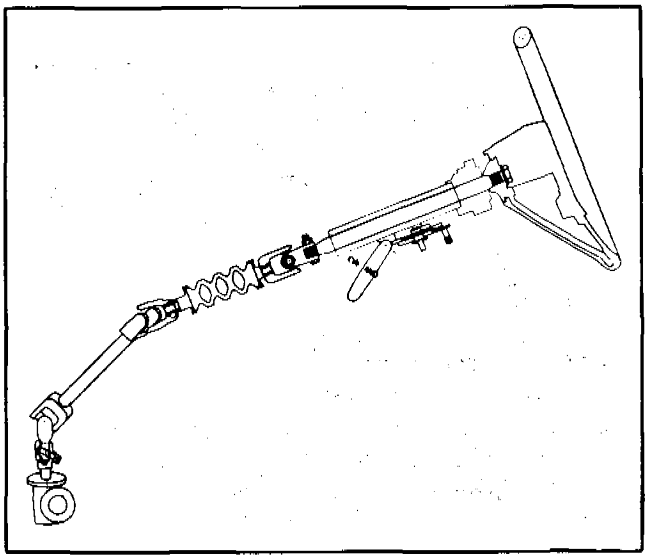

Figure 15. Safety-steering column.

Figure 16. Collision of the Volkswagen-Auto 2000 with a pedestrian dummy.

as well as new products and production technologies must be taken into account. For the fields of vehicle safety, it would appear apparent that along with further steps towards optimization in the field of accident avoidance, the assessment criteria for the behaviour of vehicles in a real crash in particular, but also in simulated accident tests will have to be reformulated. This applies in particular to the side collision, which represents a new area of emphasis for research in the field of vehicle safety.

REFERENCES

1. Seiffert, "VW-Auto 2000" Automobiltechnische Zeitschrift 9/81
2. Eib, Gaschler, "Der direkteinspritzende Dreizylinder-Dieselmotor des VW-Forschungsautos" Automobiltechnische Zeitschrift 10/81

3660

Aspects of Passive Safety in the Mercedes-Benz Research Car

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ABSTRACT

Under a national research programme, supported by the Federal Ministry of Research and Technology, test vehicles for a touring car were developed which had to take into equal account aspects of energy savings, economy, environmental protection and safety. An important partial objective of this programme was the design and testing of measures with the prospect of a further 30% reduction in injuries and deaths of road users in accidents involving cars.

Methods of improving passive safety emphasizing "protection of car occupants in head-on and side collisions and protection of pedestrians and cyclists" are demonstrated on the research car.

In countries with right-hand traffic, drivers are subject to the greatest risk of injury in head-on collisions due to forces acting mainly on the left side, seat use pattern and the added danger from pedals and steering. This is countered by reinforcement of the left side of the body and improved restraint systems for all seats.

Increased resistance of the passenger compartment to deformation under transverse load and correspondingly re-designed interior surfaces of the doors are suited to reduce the load on the occupants in side collisions. Furthermore, a number of measures are currently being tested with the research car for the protection of pedestrians and cyclists, whose percentage involvement in accidents gains increasing importance due to the growing number of cyclists and the substantial advances made in car occupant protection.

The continued lack of suitable measuring devices and extremely fragmentary studies on the correlation of laboratory measurements with actual injuries suffered present great difficulties for coping with the challenge effectively.

INTRODUCTION

In contrast to ESV/RSV development in the 1970's, with its extreme one-sided safety-oriented emphasis on occupant protection, the design of the Mercedes-Benz research car was influenced by a broader requirement profile guided by considerations of practical value and advantage to society (Fig. 1).

Measures designed to conserve energy and resources and improve environmental compatibility and economy were accorded equal significance with active and passive safety. This frequently resulted in a search for a balanced compromise between contrary demands—for example, more safety for car occupants *and* road users outside the car coupled with reduced weight and economic recycling.

While the total advantage to be derived was specified, the freedom allowed the participants to choose the major objectives within this scope was felt to be a beneficial feature of the research programme which enabled more realistic experiences and initiatives to be introduced.

An important objective of the demonstration of automotive engineering advances in the research car, the development of which was supported by the Federal Ministry of Research and Technology, was the reduction of deaths and injuries in accidents involving cars by 30%.

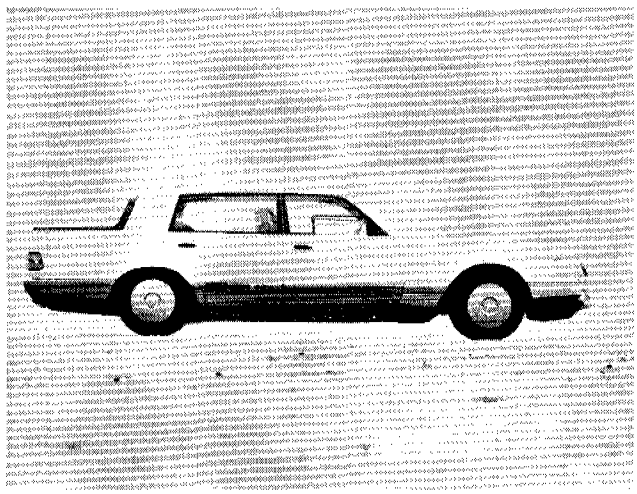

Figure 1. Mercedes-Benz research car.

As statistics show human error to be the cause of some 90% of all road accidents, measures to further improve passive safety can be expected to be more effective than improvements at the same effort and expense in the already highly developed active safety.

The new design features serve mainly the protection of car occupants in head-on and side collisions as well as the protection of pedestrians and cyclists, so that more than 80% of all injuries to persons in accidents involving cars are thus covered. The expected reduction in the consequential cost of injury on the basis of the familiar AIS scale is taken as the measure of progress. The better utilization of existing safety devices is not taken into account, moreover (for example, according to a BAST study a 30% higher rate of belt use corresponds to a 20% reduction in consequential cost of injury). In-depth case studies, an integral element of development and improvement of production vehicles at Daimler-Benz for many

years, are the precondition for achieving good results with the method selected (Fig. 2).

However, development work is rendered difficult by the lack of useful measuring equipment (side collision and pedestrian dummies) and extremely fragmentary research results on the correlation of measurable physical quantities from laboratory tests with the injuries suffered in accidents of comparable crash severity.

Passenger Protection in Head-on Collisions

Head-on collisions represent 60% of the car accidents with injury to passengers. They are by far the most frequent type of accident and entail a high risk of injury to vehicle occupants owing to the great changes in velocity. All endeavours to reduce these risks require reliable data on the frequency, severity and cause for a statistically relevant large number of vehicle collisions.

Figure 3 shows the distribution of head-on collisions—in the form of cumulative frequency curves—as a function of the energy equivalent speed EES, which characterizes the nature and extent of the deformation of the vehicle and thus the severity of the accident.

Two hundred forty frontal collisions causing at least one serious injury to or death of a passenger (MAIS 3^+) are taken into account. The EES was defined in connection with the reconstruction of highway accidents and has proven a far better descriptor of accident severity than the often used change of velocity Δ v.

From the distribution curves in Figure 3 we can conclude:

- 60% of all serious to fatal injuries occur in the speed range with EES $\leq$ 50 km/h, mainly due to failure to use restraint systems.
- More than 50% of all frontal collisions with serious injuries involve the left-hand side of the vehicle in countries with right-hand traffic. This suggests a similar frequency on the right-hand side in countries where driving is on the left.

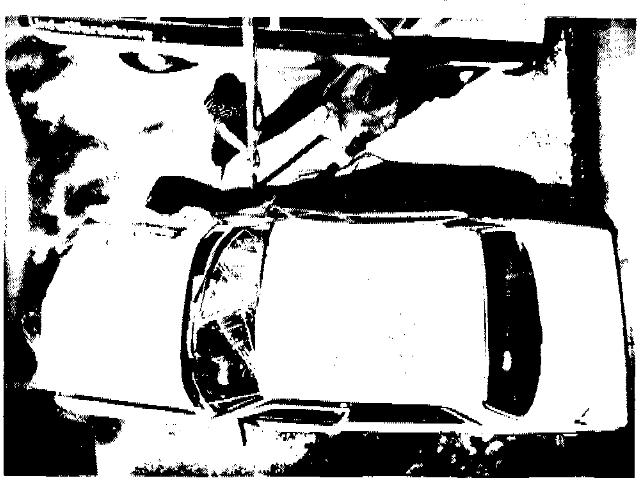

Figure 2. Accident investigation team on scene.

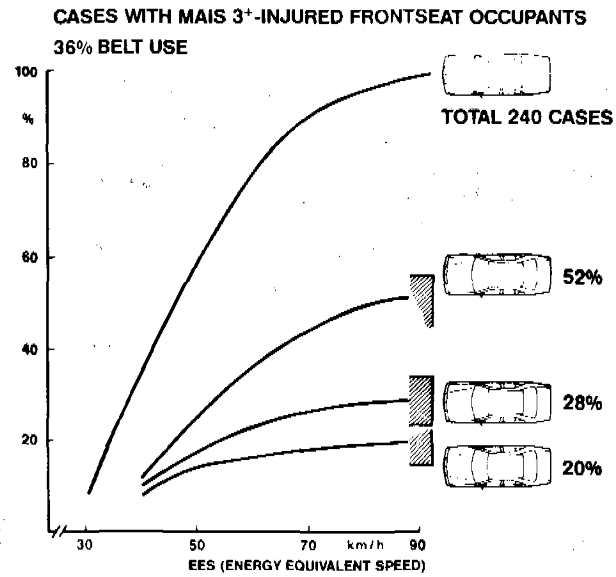

Figure 3. Distribution of head-on collisions.

- Only about 25% conform to the legally prescribed 0° barrier collision (3% of symmetric deformations occur in crashes against trees or poles).
- In the speed range 40 $\leq$ EES $\leq$ 60 km/h a sharp increase of cumulative frequency is recognized, caused mainly by collisions on the left-hand side.
- Speeds of EES > 80 km/h are hardly relevant statistically because of glance-off and the small number of cases.

The analysis of the head-on collisions shows that the drivers are subjected to the greatest risk of injury. This can be explained by the additional danger coming from the pedals and steering, the preponderance of left-hand offset collisions and the frequency of seat occupancy (driver : frontpassenger : back seat = 4 : 2 : 1).

Consequently, improved occupant protection for the driver's seat in head-on collisions must be accorded special significance in terms of efficiency (benefit/cost/weight requirement). Special attention should be given to an aspect of left-hand collisions, particularly involving glance-off, in future accident evaluations and new vehicle designs (Fig. 4).

Serious injuries, which in most cases determined the maximum injury severity (MAIS), to the lower extremities were found in the study of 82 *belt-wearing* drivers whose cars collided in the left-hand offset mode. Due to the high intrusion speeds in the footwell and the smaller change of velocity Δv this trend is augmented in collisions involving glance-off ($\Delta v \leq 0.7$ EES).

In addition to relatively minor head and thorax injuries specific injuries to the lower extremities were observed due to "impact shocks" from EES = 40 km/h upwards.

The investigation of all *belt-wearing* occupants in head-on collisions led to similar results: Injury severity MAIS

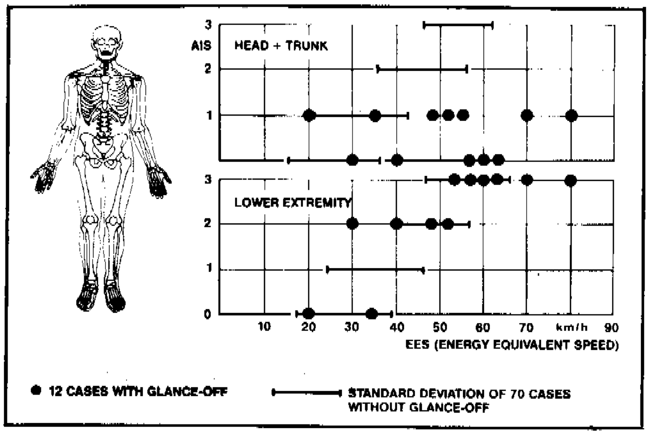

Figure 4. Injury severity of belted drivers.

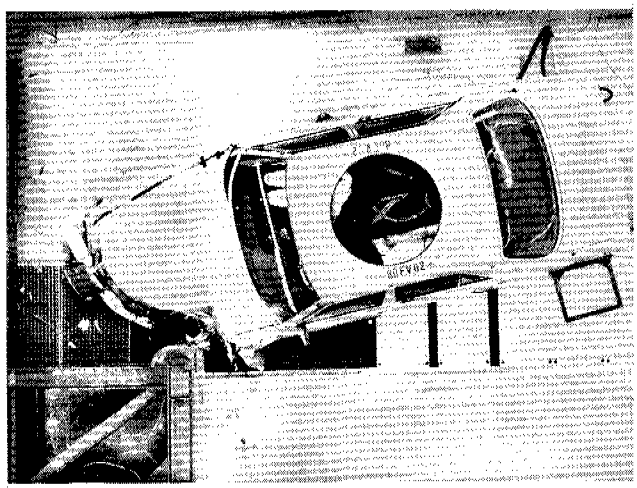

Figure 6. Frontal offset barrier test.

3-6 occurred with the following frequency: lower extremities 40%, trunk 27%, head 27%, upper extremities 6%.

The following passive-safety-enhancing elements are being tested in the Mercedes-Benz research car:

—Reinforced front end and passenger compartment structure on left-hand side (asymmetric)
—Modified arrangement of components in the engine compartment to reduce residual block length after compression through crash forces
—Improved coupling of the right-side front-end structure, which is not directly loaded in a left offset collision, with the left-hand side, by means of a high strength bumper support and the hood, which is hinged on the left and locked in two places
—Control of front wheel turn (because of influence on leg room!); disconnection of steering gear—steering wheel link dependent on displacement (Aramid element in steering shaft); and direction of pedals forwards when more severe deformation occurs
—Improved three-point belts on the front seats with all belt anchorages in the seat structure; buckles integrated in the rear cushion (Fig. 5)
—Two-stage automatic support through belt tensioners on all seats and airbag in the steering wheel
—Windscreen made of laminated glass with anti-shatter film
—New type of child restraint system as integral part of the rear seat, adaptable as regards age and interchangeability.

Figure 5. Front seats with integrated three-point belts.

As test procedure the frontal collision at 55 km/h with a solid obstacle, offset to the left, with 40% overlap of the vehicle width was selected (Fig. 6).

Results:

First tests with modified production cars including evaluations on the Bendix-Accelerator have already given some positive results. For example, despite the extreme test condition the passenger compartment remained intact as a survival space while acceleration was appreciably reduced (a = 20 g instead of 33 g) and steering displacement lessened and occupants could be freed without difficulty (door opening forces < 50 N).

Through measures applied to the restraint system, the following values for load on occupants were obtained for driver and front passenger in comparison with the production cars (Fig. 7).

Protection of Occupants in Side Collisions

A study of side collisions as to type of deformation, direction of impact, speed and severity of injury is not yet available. A small number of cases but a large variety of parameters make conclusive judgments difficult. The great risk of injury in side collisions is brought about by the extent and shape of the intrusion, the intrusion speed

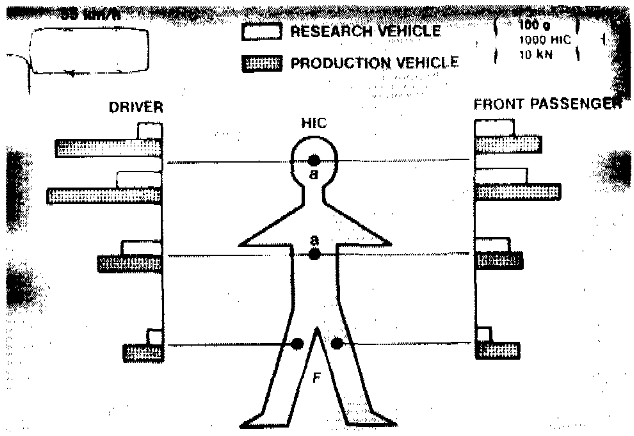

Figure 7. Dummy loads in front offset barrier tests.

of the impacted sidewall structure relative to the occupants and the limited capacity of the structural members and body panelling to absorb energy.

The risk of injury to the occupants can—as shown in Figure 8—be correlated with certain parts of the vehicle and can be determined from the frequency of contacts and the severity of the injuries using factors proportional to the consequential cost of injury.

Based on the results of the 222 side collisions with 336 injured passengers investigated by us we conclude:

—The most frequent cause of injury and thus the greatest risk of injury is attributable to the interior surfaces of the doors.
—The most serious injuries are attributable to objects outside the passenger compartment, chiefly because of contact with the head due to the breakage of prestressed glass panes and intrusions.
—A similarly high risk exists in the head impact area: doorposts, side roof frame and window frames, the latter particularly in conjunction with broken side windows.

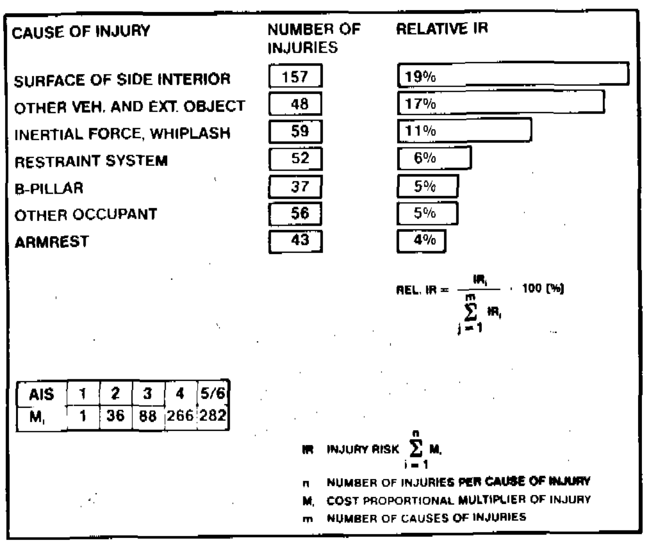

Figure 8. Cause and risk of injuries in side impacts.

The following elements for enhancing occupant protection in side collisions are being tested in the Mercedes-Benz research car (Fig. 9):

—Claw type overlap between all doors, the lower sections of which are reinforced, and the side members, transversely reinforced with interior plates; additional overlap of front doors at the reinforced bases of the centre pillars (bumper contact area!)
—Tension-compression connections in the doors between upper hinges and door latches
—Transverse stiffening of the passenger compartment through floor cross member including transmission tunnel bridge, recessed bulkhead and load-bearing seat structures (protective zones)

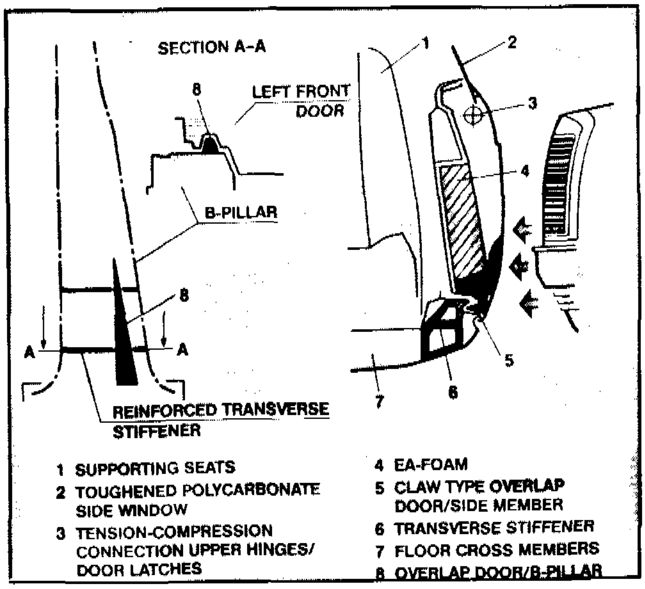

Figure 9. Improved occupant protection in lateral collisions.

—Expanded hip impact zones on all doors with approx. 80 mm thick energy absorbing foam members between inside and outside panels on the front doors
—All side windows made of Polycarbonate with high impact strength, firmly glued to the window frame
—Sandwiched prefab headliner with energy absorbing foam and Kevlar surface layer which yields fairly well under pressure in the head contact area
—All belt anchorages on the seat separated from the sidewall structure which takes the direct impact.

The measures were to be tested in impact tests with the moving barrier in accordance with ISO/TC 22/SC 10 striking the standing research car at 45 km/h at an angle of 90°. Results of the tests are not yet available.

Protection of Pedestrians and Cyclists

The number of injured and killed pedestrians shows a slightly declining trend, particularly relative to the increased mileages of cars. By contrast, a sharp rise in injuries and deaths to motorized cyclists can be noted. Their accident balance, still little analyzed at this time, is difficult to influence by measures applied to cars owing to the large share of intrinsic energy, the higher riding position and the wide dispersion of contact points.

The degree to which external road users are endangered is represented in the case studies at hand by the injury risk ascertained in relation to contact areas on the vehicle (Fig. 10).

The greatest risk of injury to pedestrians stems from contact with the vehicle front, injury mechanisms of which have been adequately researched. For cyclists only few preliminary study results are available. In comparison to pedestrians the large percentage of side contacts is conspicuous.

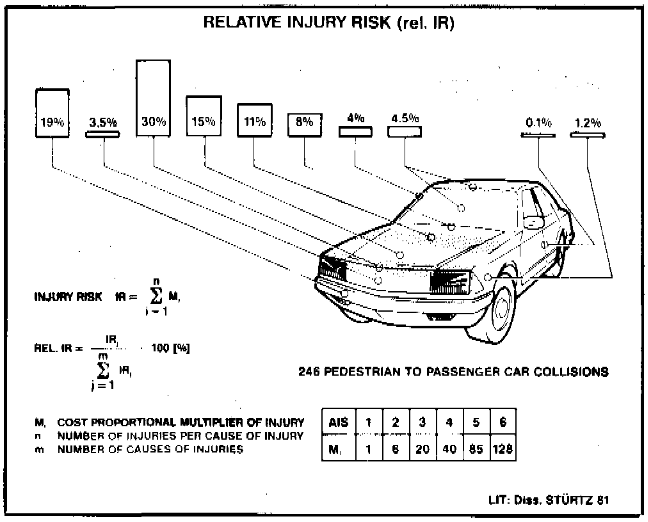

Figure 10. Causes and risk of injuries with car collisions to pedestrians.

The following injury-reducing measures, which mostly benefit also cyclists, are being tested on the Mercedes-Benz research car:

—Bumpers with energy-absorbing foam facing in front of the basebeam and Polyurethane spoiler with lower leg contact area moved downwards
—Soft face with radiator grille of fibre-reinforced polyurethane and yielding headlamp lenses of Polymethylmethacrylate.
—Fenders and complete panelling of A-pillars made of Polyurethane
—Hood edges and sealing hood / engine capsule / accessories partition with low resistance to deformation under vertical loading
—More deeply set nose contour (children) and completely recessed windscreen wipers
—Two-shell roof frame construction without roll-finished edge and projecting trim to reduce risk of injury to cyclists.

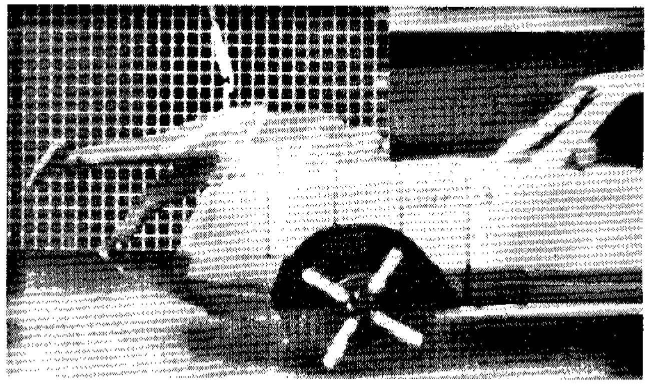
Figure 11. Car to pedestrian test.

As suitable test method a combination of pendulum tests on frequently impacted structural elements and model calculations is recommended. The latter serve to ascertain contact points and test parameters in the development phase of new vehicles.

In the absence of adequate experience with this method of optimization, dummy tests with the CCMC pedestrian position will be performed as a transitional arrangement (Fig. 11).

Results:

In Figure 12 first results of tests with a relatively frequent impact speed in city traffic of 25 km/h are shown. According to the results, all measurable load values with the exception of the head values for the child dummy could be reduced. The higher head load despite the soft nose is traceable to the front edge of the hood (conflicting targets load-bearing hood/head impact zone). Generally speaking, these test results should be viewed with caution due to only inadequate modification of the dummies and because measurements of this kind only partially reflect the risk of injury.

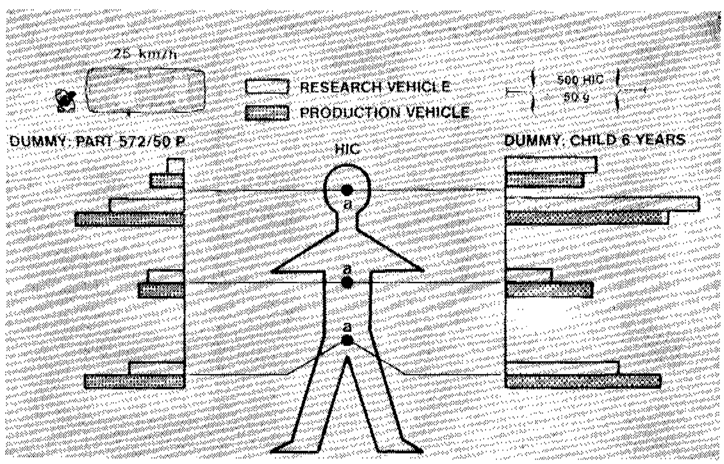

Figure 12. Dummy loads in pedestrian tests.

Influence of Research Results on Production Cars:

The research programme has accelerated the demonstration of some new steps suited to improve further on safety, economy and environmental compatibility of passenger cars. The profound examination of the demonstrated engineering solutions is still pending. Only those measures—even partially modified—may be found on future production cars which will be in strict correspondence with our standards regarding function, reliability and quality. To achieve economically justified results towards improved protection of road traffic participants, increased willingness of car occupants to use existing means for protection is a prerequisite.

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Study of Devices Designed to Improve Safety Belt Performance

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INTRODUCTION

Safety belt efficiency in head-on collisions has been confirmed by multidisciplinary analysis of actual accidents. However, this efficiency is limited, and wearing of a safety belt is not a guarantee of protection against impacts of any violence whatsoever. If the reader refers to a recent accidentology analysis performed by the Peugeot-Renault association, restraining improvement in the event of head-on collisions remains an essential priority. In fact, according to this survey, and in the hypothesis in which belts are worn at a rate of 100%, head-on collisions will still cause as many deaths as all other collisions configurations combined.

In a head-on collision, there are three main reasons why wearing a seat belt does not prevent death or severe injury:

—The occupant strikes an element of the compartment violently. This is due to an excessive movement of the occupant inside the compartment, and is favorized by a high intrusion level.
—The threshold of resistance of the occupant's thorax is exceeded, subsequent to excessively high forces in the shoulder belt.
—The occupant "submarined."

For the first two reasons cited, improvement in seat belts involves the resolution of a dilemma, increasing retention without increasing belt solicitations. The solution to this problem is known, and consists in improving coupling (or ride down effect), i.e., obtaining a better immediate coupling of the occupant to the vehicle, so as to use the stopping distance of the vehicle to the best possible advantage.

With a standard three-point belt, the part of the occupant energy dissipated by coupling is relatively low. Moreover, this is all the lower if the impact occurs at a high mean deceleration, i.e., over a short stopping distance. In the case of an orthogonal head-on collision, the occupant energy dissipated by the coupling is of the order of 25 to 35%.

Of the several factors which limit the share of coupling, two are regularly mentioned: first of all, the belt wearing slack, and secondly, movement of the webbing resulting from tightening of the strap reserve on the retractor spool (spool out effect).

Over recent years, devices to suppress these factors have been under study. Strap pretension devices concern wearing slack and, in part, movement. The belt locking devices are intended to suppress movement.

Renault is convinced that an improvement in coupling is still a highly interesting factor and, since 1970, has conducted studies in this field. In a previous paper, Renault presented its work concerning pretensioners (11).

Up to the present, the interest of web locking devices was cancelled out by systematic breaking of the straps due to the locking clamps or claws. Recently, research in this field was renewed, due to the availability of newly designed devices located at the retractor.

This paper is devoted to an examination of the progress actually due to these devices, omitting aspects relative to comfort. Renault considers that comfort cannot be neglected, and all the more so since unwinding and rewinding problems, together with difficulties in correctly adjusting the pressure on the thorax, are to be feared. However, in agreement with belt manufacturers, it has been admitted that the state of progress of the prototypes used does not, at least for the moment, enable an objective judgment to be made concerning the final performances of such devices in this field.

DEVICES TESTED

Presentation of Devices

In the present state of the technique, devices located at the D. ring were not retained due to breaking of the webbing at the clamping device.

Five different types of lockers located at the retractor were or are being tested.

These are broken down into two classes, according to their operating principle.

Type A

The web locker is independent of the retractor. Locking results from deceleration of the compartment. Deceleration causes movement of a flyweight, which actuates the locking device. In the open position, both locking clamps are open, and allow the strap to slide freely. This principle has no adverse effect on comfort.

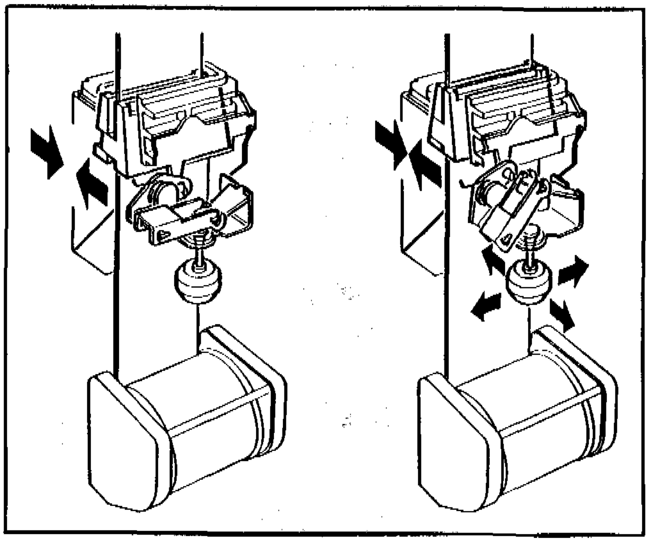

Figure 1. Web locker A.

Type B

The locking device is located under the retractor. Locking results from forces in the strap. Once the retractor has been locked, any pull on the strap causes the locking clamps to close in. The clamping pressure increases with belt webbing tension. When the roller is not locked, the clamps cannot close; this is the open position. With this principle, there will be a decrease in comfort if the device has not been carefully designed.

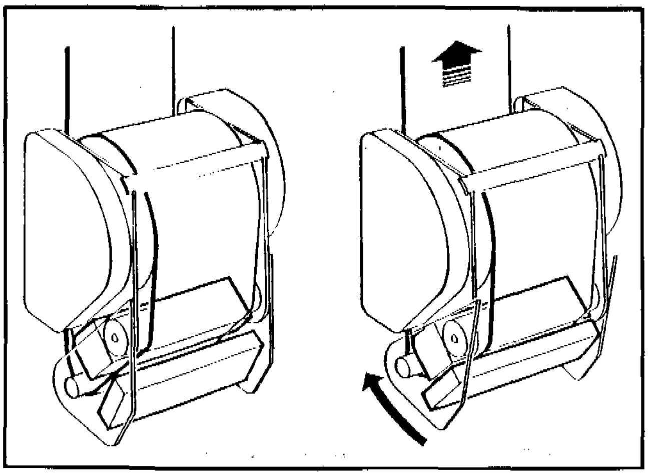

Figure 2. Web locker B.

Operation Validation

Webbing ruptures

Our work has demonstrated that the breaking resistance of the belt as a whole was not decreased with respect to that of a standard three-point belt.

During particularly stringent catapult tests, designed to approach the resistance limits of the safety belt, the percentage breakages, with or without a locker, were not significantly different. In 20% of the cases, breaking occurred with a three-point standard belt, and in 24% of cases with the locker. All breaks were located on the strap, the return loop or at the sliding buckle. Whatever the type of locker tested, there were never any traces of incipient tearing of the strap at the clamping device.

No breakages occurred during the barrier collision tests using the locker.

Spool out reduction

The use of a locker considerably reduces movement due to tightening of the webbing around the retractor spool.

This movement obviously increases with the length of the strap wound, the severity of the collision and the mass of the dummy.

Table 1. Average results of 18 sled tests with production cars (50 km/h - 0°).

	Conventional Retractor	Weblocker A	Weblocker B
Film spool (mm)	146	16,5	54
Head displacement (mm)	655	640	625
γ_L chest (g — 3 ms)	47	44	42
F shoulder belt (daN)	690	730	860

One gives, hereinafter, the mean travel values at the outlet from the retractor, obtained over 40 sled tests, performed under identical conditions; i.e., speed 50 kph, deceleration pulse for R.20 against 0° barrier, length of strap wound 800 mm, 12% elongation polyester strap, Hybrid 2 dummy. With a standard three-point belt, the mean spool out is 170 mm. For tests using a locker, the movement is reduced to 20, 30, 50 and 60 mm, depending on the prototype locker used.

The type A locker gave noticeably better performances than the type B. During subsequent tests, this was confirmed (see Tables 1 and 2). This advantage seems to be a logical consequence of the operating principle, which enables locking as soon as the flyweight moves. For the type B prototypes, clamping calls for locking of the retractor, then strap movement while the clamps close in.

LOCKERS ASSOCIATED WITH A STANDARD THREE-POINT BELT

0° Collision Configuration

Test program

—18 sled tests on R.18 body

The test conditions were as follows: speed 50 kph; R.18 deceleration law against 0° wall at 50 km per hr; dashboard, windshield and steering column removed; series production three-point belt with or without locker, H2 dummy installed in seat track mid-position. Six tests were performed using a conventional retractor, six with a type A locker and six with a type B locker.

—3 collisions against barrier with complete R.18 vehicle

The conditions were as follows: speed 50 kph, orthogonal barrier, H2 dummies installed in the seat track mid-position, three-point series production belt with or without locker. One collision was performed with a conventional retractor, one with locker A and one with locker B.

Results

Locker efficiency was estimated by measuring the characteristic restraining parameters, i.e.:

—Head movement within the compartment. This measurement was not retained when a head impact occurred.
—The driver HIC and the impact speed of the head, for barrier collisions. The HICs obtained without head impact are not characteristic of potential injuries, and were therefore not taken into consideration (however, time over 80 g's has always been mentioned).
—Thorax 3 ms deceleration.
—Force in the shoulder belt at the shoulder.
—Femur forces.
—"Submarining."

The results obtained call for the following comments (see Tables 1 and 2).

Head forward movement

Sled tests show only a slight reduction in head forward movement: 15 mm for the type A locker and 30 mm for

Table 2. Results of crash tests with production cars (50 km/h — 0°).

	Conventional Retractor		Weblocker A		Weblocker B	
	Driver	Passenger	Driver	Passenger	Driver	Passenger
Film spool (mm)	90	105	8	0	40	45
Head displacement (mm)	—	615	—	625	—	595
HIC (relative values)	100	—	116	—	62	—
t for γ head > 80 g (en ms)	0,8	0	8,7	0	0,8	0
Head impact speed (ms)	15	—	13	—	13	—
γ_L chest (g — 3ms) (ms)	57	50	44	39	45	43
γ_L Pelvis (g — 3 ms) (ms)	44	36	45	35	52	45
F shoulder belt (daN)	535	540	680	630	810	780
Femur load left (daN)	100	260	80	360	120	200
Femur load right (daN)	240	140	220	170	390	180

the type B locker. During barrier collision tests, an increase in head forward movement of 10 mm was observed with locker A, and a decrease of 20 mm with locker B. These differences remain of the same order of magnitude as those imputable to dispersions, and it would seem justified to conclude that no noticeable gain has been provided by the lockers.

In spite of the absence of head forward movement reduction, a certain reduction in shoulder forward movement was, however, noted. This contradiction can be explained by kinematic modifications. In particular, we observed that the use of a locker increases rotation of the thorax with respect to the shoulder strap—shoulder contact point. Strongly restrained by the shoulder strap at the shoulder, the dummy tends to turn towards the door. This twist explains the decrease in shoulder forward movement, without a decrease in head forward movement.

HIC and head impact speed

With respect to the series production three-point belt test, driver HIC increased by 17% with the type A locker, and decreased by 35% with the type B locker. These important differences do not, however, indicate a ranking of efficiency. These results from a minor modification of the kinematics. In one case, head-steering wheel impact took place at the hub, and the other at the rim.

The head impact speed was slightly decreased by the use of a locker. This gain may be the result of better restraining of the dummy at the shoulder. Because of the HICs obtained, it should, however, be noted that this gain does not provide a sufficient remedy to the differences in head impact location.

Forces in strap and head and thorax deceleration

Measurement of the force in the shoulder strap at the shoulder is a difficult operation. The results showed relatively high dispersions, and, considered isolatedly, the figures given should be considered with reserve.

However, for the overall tests, it is undeniable that the use of a locker is accompanied by an increase in forces in the shoulder strap; this can be estimated as between 5 and 15%.

It seems possible to explain this increase as follows: the use of a locker increases the overall stiffness of the safety belt, but does not noticeably increase that part of dummy energy dissipated due to coupling with the vehicle. Mainly, the share of this coupling is limited by the existence of occupant-belt slack. Tightening of the strap on the retractor spool influences this slack, but is not a preponderant element. The wearing of the belt, the stiffness of the seat cushion and deformation of the occupant forms the major part. This observation has been justified by a detailed energy study which it is not possible to develop here. At most, on the deceleration curves recorded during the barrier collision tests, it is possible to observe that the actual start of restraining of the dummy is hardly effected by the presence of a locker (see Fig. 3). It should be stated that this result, as observed for high mean deceleration collisions is not necessarily obtained for lower mean deceleration collisions. Now, it should be noted that accidentologists consider the latter more representative of accidentological reality.

On average, the use of a locker entails a slight increase in the thorax 3 ms deceleration criterion. Due to increase of the force in the shoulder strap, it is probable that this decrease results from an increase in rotation of the thorax as already mentioned. Therefore, this cannot be considered as an actual benefit in safety.

"Submarining"

The use of a locker seems to increase the tendency to "submarine." This phenomenon is closely related to the design of the overall restraining system. Also, and although the use of a locker has not excessively downgraded performances of the vehicle used for these tests, this problem should, in our opinion, be taken into consideration before making a decision to install a locker on a given vehicle.

Femur force

On the vehicle used, the values obtained with the three-point, series production belt were low, and this criterion cannot, therefore, be a discriminating factor in this type of collision.

30° configuration

Test program—7 collisions at 65 kph (30° left)

The (oblique) configuration is generally considered as more representative of actual accidents than an orthogonal collision. A study intended to quantize the efficiency of lockers in terms of actual safety must therefore involve certain tests in this configuration. The 30° left impact using a complete R.18 vehicle was retained. (In this configuration, the vehicle collided with the barrier from the left-hand side, the wall being inclined by 30° with respect to the longitudinal axis of the vehicle, see Figure 4.) Moreover, and in order to obtain extreme severity conditions, the collision speed was 65 kph. Under these conditions of severity, results are generally dispersed, and it was therefore necessary to conduct several collisions, i.e., three with a series production, three-point belt, and four with lockers.

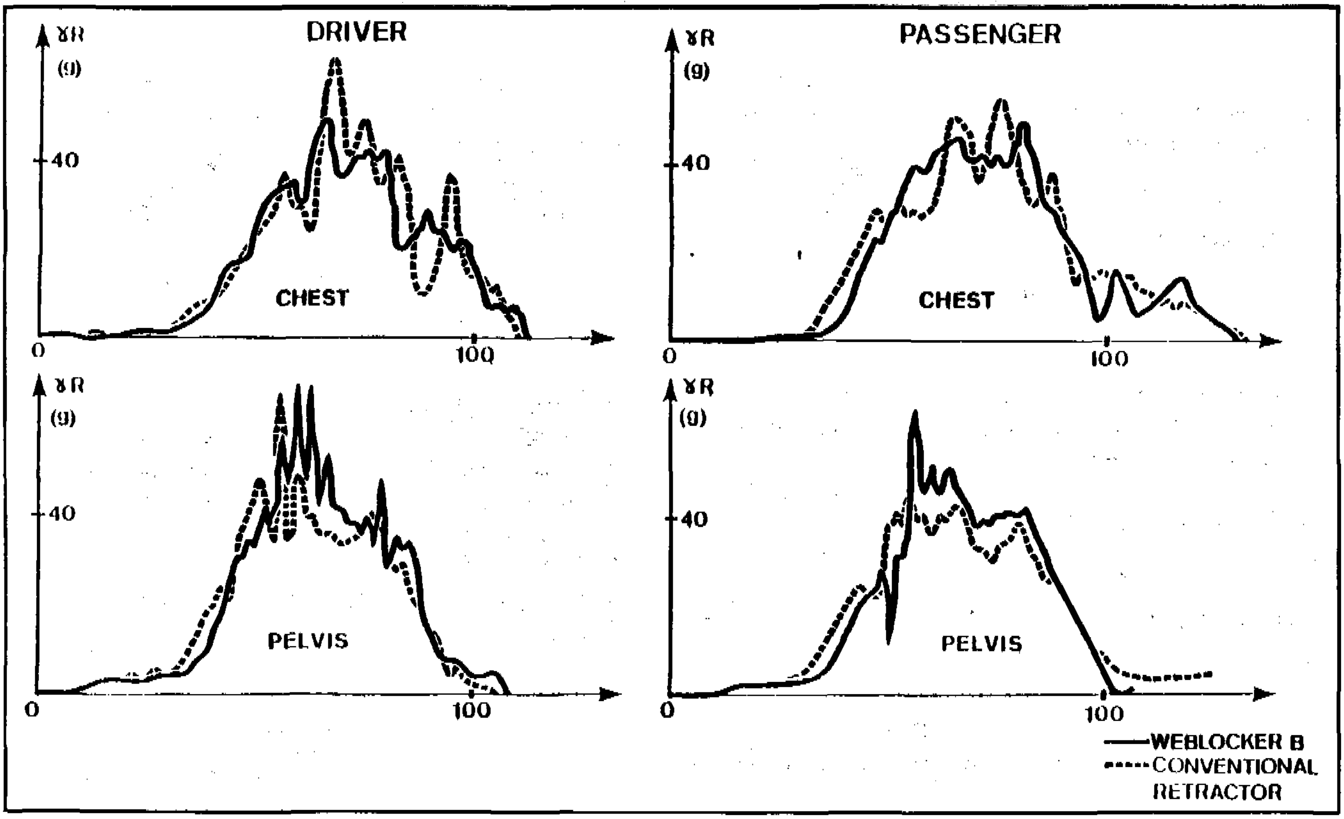

Figure 3. Chest and pelvis deceleration pulses.

Results

Injury criteria

The mean values obtained are combined in Table 3.

For the driver, and with the exception of the shoulder strap force, the use of a locker causes a general decrease in injury criteria. This decrease is obvious for HIC and femur forces, the mean values dropping by almost half.

In our opinion, the differences in HIC are once again due to a modification of the kinematic. This point is developed below.

Conversely, a single, more efficient restraint seems to explain the decrease in femur forces. Due to the order of magnitude of the values, the decrease obtained can be considered as particularly interesting. In fact, and if it is admitted that the mean human tolerance corresponds to a value of 1,000 daN, this signifies that it was possible to avoid dangerous impacts.

Table 3. Average results of 7 crash tests with production cars (65 km/h — 30°G).

	Conventional Retractor		Weblocker	
	Driver	Passenger	Driver	Passenger
Film spool (mm)	97,5	123	24	25
HIC (s)	1580	—	907	—
t for γ Head > 80 g (ms)	13,3	6,6	2,4	4,6
γ_R chest (g — 3 ms) (ms)	58	42	47	44
γ_R Pelvis (g — 3 ms) (ms)	69	58	60	52
Femur load left (daN)	432	510	160	223
Femur load right (daN)	1.038	213	495	196
F shoulder belt (daN)	580	785	725	785

For the passenger, the results are globally positive. However, the gains obtained are much less pronounced than for the driver, and cannot be considered as actually representative in terms of real safety. This is all the more clear if kinematics are taken into account.

Kinematic analysis

With respect to the 0° collision, this type of impact is dissymmetric. Simultaneously to the transverse movement of the vehicle to the right, there is a transverse movement of the dummies to the left. See Fig. 4.

This transverse movement calls for separate analysis of driver and passenger restraint.

Driver

Driver movement to the left, without locker,

—favorizes a correct position of the shoulder strap on the shoulder
—decreases thorax rotation
—moves the head impact towards the outside of the steering wheel, the impact location itself being shared between the rim and the hub.

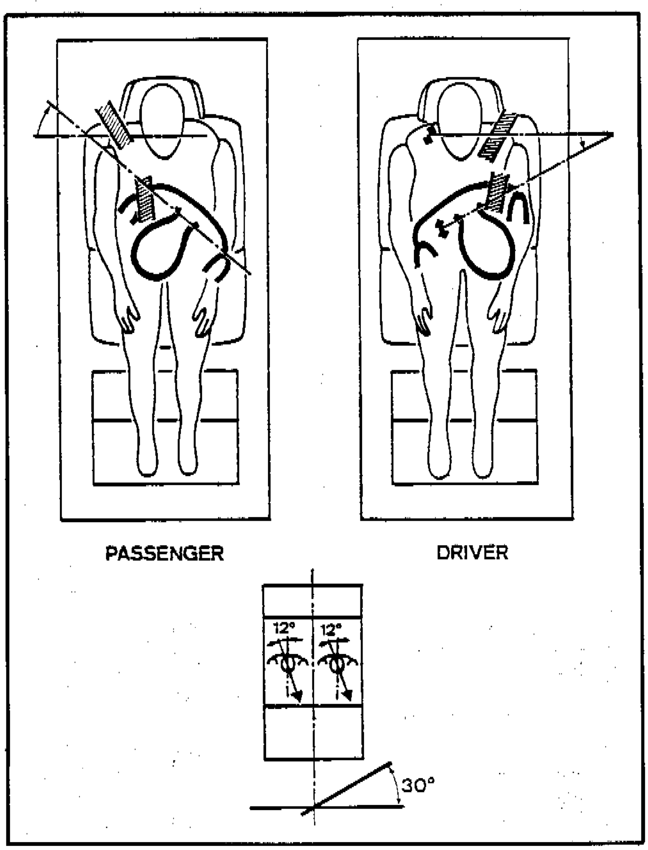

Figure 4. 30° angled barrier test at 65 km/h.

Using a locker, while increasing thorax rotation, also accentuates lateral movement of the head. The consequences of this are to move the impact point of the head completely on the steering wheel rim, *thus reducing collision severity.*

Passenger

Without a locker, movement to the left of the passenger causes slippage of the belt on the shoulder; the strap, which catches in the articulation of the arm, produces important rotation of the thorax. The dummy has a tendency to escape from the belt.

The use of a locker accentuates thorax rotation, thus increasing the risk of escape. If this escape possibility, which was highlighted using an H2 dummy, is obtained with an actual occupant, it can be considered that the use of a locker under these conditions is useless, and even dangerous.

LOCKERS ASSOCIATED WITH AN OPTIMIZED THREE-POINT BELT

Parameters Modified

Allowing for previously acquired information, optimization concerned:

—the position of the three belt attachment points
—the percentage elongation of the strap (6, 12, 17%)
—the seat cushion stiffness and geometry.

The *only* objective sought was to improve efficiency of the lockers. To achieve this, efforts have been made to:

—limit rotation of the thorax
—accentuate shoulder restraining
—avoid the risk of "submarining."

Test Program

Over an initial stage, twenty sled tests were performed to study the effect of each of these parameters. In order to judge the effect of the modifications on locker efficiency, each configuration was tested once without the locker, and once with. Only the principal conclusions are mentioned here, so as not to complicate this paper.

The position of the attachment point is, by far, the most discriminating parameter. However, it seems preferable to use a strap of 6% elongation, with a relatively stiff seat cushion.

The position of each of the 3 anchorage points has a notable effect, but it was only by raising the shoulder strap point that it was possible to fully monitor rotation of the thorax.

Subsequent to this study, the following optimum configuration was retained:

—shoulder strap point raised by 100 mm
—outside lap belt point advanced by 100 mm
—inside lap belt point back by 100 mm and lowered by 50 mm
—6% elongation strap
—seat cushion reinforced.

After sled testing, this configuration was subjected to two 50 km/h orthogonal barrier collisions, using a complete R.18 automobile, one with conventional retractors and the other with lockers.

Results

Results obtained during the catapult and wall tests are given in Tables 4 and 5 respectively.

The basic conclusion that can be drawn is that optimization of the various items involving restraining as a function of locker presence has, as expected, increased the efficiency of the locker as far as the occupant movement is concerned.

With the sled, it was possible to obtain a head travel of 500 mm. This represents a gain:

—of 155 mm, with respect to the reference tests (baseline car + conventional retractor)
—of 130 mm with respect to tests using the locker only (baseline car + locker)
—of 95 mm with respect to the modified car test (modified car + conventional retractor).

Table 4. Results of sled tests with modified cars (50 km/h – 0°).

	Conventional Retractor	Weblocker A
Spool film (mm)	80	0
Head displacement (mm)	595	500
γ_L chest (g – 3 ms) (ms)	47	52
γ_L Pelvis (g – 3 ms) (ms)	36	37
F shoulder belt (daN)	N.A.	720

Here, it is worth noting that the use of a locker with a standard three-point belt gave a reduction of only 15 to 30 mm on average, depending on the type of locker.

For the barrier test, a head travel on the passenger side of 520 mm was obtained. This represents a gain:

—of the order of 100 mm with respect to collisions using the standard three-point belt. It should be remembered that, under these conditions, the use of a locker did not provide any noticeable gain;
—of 55 mm, with respect to the collision in the optimized configuration with a conventional retractor.

In the optimized configuration, and for barrier impacts, an important decrease in driver HIC was noted with

Table 5. Results of crash test with modified cars (50 km/h – 0°).

	Conventional Retractor		Weblocker A	
	Driver	Passenger	Driver	Passenger
Film spool (mm)	95	130	0	0
Head displacement	—	575	—	520
HIC relative values standard belt	75	—	54	—
t for γ head > 80 g (ms)	2,9	0	1,5	0
Head impact speed (ms)	14	—	11,7	—
γ_L chest (g – 3 ms) (ms)	49	42	40	35
γ_L Pelvis (g – 3 ms) (ms)	48	34	41	37
F shoulder belt (daN)	770	760	710	720
F pelvis belt (daN)	770	760	860	830
Femur load left	125	160	170	150
Femur load right	155	150	120	180

respect to the value obtained using the series production vehicle. This decrease can be explained by the different head impact locations. In both cases, impact occurred against the top of the steering wheel. The difference between these two tests may result from the difference between the two impact speeds. However, it should be noted that the values obtained are both below what is considered to be the tolerable threshold. The difference obtained therefore does not necessarily signify that injuries can be avoided.

As far as the other criteria are concerned, the results do not seem to question the conclusions obtained subsequent to tests performed with a standard three-point belt.

CONCLUSION

This study has shown that several retractor located belt locking devices which operate correctly are at present available on the market. Use of these considerably reduces strap movement at the outlet from the retractor, without noticeably increasing the risk of overall rupture of the safety belt.

The effects on restraining, which are imputable to the use of lockers of this type, are complex and difficult to estimate. However, some major points can be highlighted.

The use of a locker does not increase coupling sensitivity, and, in particular, this applies to a high mean deceleration collision. Suppression of spool out increases the overall stiffness of the restraining device. Solicitations on the occupants due to the forces developed on the belt are therefore conserved or even increased.

By "stiffening" the restraining device, a locker can increase retention. However, and allowing for the operation of a standard three-point belt, this gain in stiffness does not necessarily result in a reduction of the travel of the dummy inside the passenger compartment. To obtain positive results, optimization of the restraining device may be necessary. While potentially obtainable, the limits of an optimization of this type should be noted.

a. The geometric position of the attachments has been optimized for a given model size and a given seat adjustment. In other cases, this may be inefficient or even dangerous.
b. The developed optimization was tested for orthogonal collisions only, and it is not certain that this will be efficient in other collision configurations. For example, and according to our study, suppression of model rotation in the event of a 65 km per hour 30°L collision would render the impact of the driver's head against the steering column more severe.
c. For this optimization, only the efficiency criterion was taken into account. Now, it should be noted that the newly developed belt geometry is not compatible with the various criteria which a restraining device must meet. In particular, this applies to comfort. The shoulder strap is too high at neck level. It should also be noted that the new outside attachment point of the lap belt is no longer located in the zone mandated by the standards.

As far as the fundamental object of this study is concerned, i.e., examination of progress in actual safety provided by the use of such devices, the state of progress of our work indicates contradictory results which are difficult to estimate. However, if the various corporal segments involved in head-on collisions are treated separately, several trends become clear.

Lower members

In our study, the use of a locker can, in some cases, avoid dangerous solicitations of the femur, and cannot be considered as unfavorable. The gain involved is difficult to estimate. Moreover, it must be considered that the severity of injuries on the femur segment is potentially less important than to other segments.

Abdomen

"Submarining," implying loading of the soft parts of the abdomen, on the one hand, and the spinal column, on the other, due to the lap belt can be the origin of severe injuries. Therefore, this phenomenon cannot be neglected. The use of a locker seems to increase this risk. However, prior to installing a locker on a given vehicle, it would be at least desirable that this does not lead to unacceptable "submarining."

Thorax

Injuries to the thorax result either from the safety belt itself, or interaction with the steering column. As far as injuries caused by the belt alone are concerned, it would seem preferable to consider the shoulderstrap force at the shoulder, instead of the thorax 3 ms deceleration criterion. Since injuries are a function of the occupant's age, and knowing that the lower age groups are over-represented in accidents, it is legitimate to have efficient restraint, limiting travel and implying a tolerably high shoulder force for young occupants. However, the use of a locker notably increases this force, and it is impossible not to fear supplementary injuries to the thorax.

Our study does not provide a response as far as injuries associated with interaction with the steering column are concerned.

Head

The majority of head injuries, if not all, result from direct impact against the steering column, the dashboard and the front pillars, etc. The results obtained call for differentiation between driver and passenger seats.

—Driver's side

The noticeable feature is that the use of a locker has not enabled avoidance of existing impacts. Has severity been decreased? We know that this depends mainly on the characteristics of the zone actually impacted.

Our study shows that important differences in HIC are all correlated to different points of impact. This point, which is subject to very small variations, is impossible to monitor, and then only in a purely experimental configuration. Therefore, our results cannot be considered as an actual benefit in safety.

—Passenger side

As the vehicle used and the belt equipping it prevent any impact with the dashboard in the types of tests conducted, the results obtained cannot be discriminant. The slight reduction in head travel might, however, have been decisive on another vehicle.

This study is not complete. Renault is continuing its research. Tests, which have not yet been analysed, have been conducted for a lower mean deceleration. Moreover, a further optimization of the restraining system has been concerned, this time allowing for all criteria. It would also be desirable to conduct some tests with cadavers. In fact, some points raised in this study could be strongly correlated to the inadequacy of the Hybrid 2 dummy. Mainly, this involves the nonrepresentativity of the pelvis, the shoulder and thorax stiffness, which can respectively influence "submarining" aspects, slippage of the belt at the shoulder and rotation of the dummy. Also, it would be of interest to conduct a severe head-on collision between two vehicles, leading to a certain intrusion into the compartment.

Without trying to anticipate future results, it is, however, to be feared that antagonistic effects exist between improvement in restraining, on the one hand, and an increase in belt solicitations on the other. In this case, the use of a locker cannot be considered an absolute measure, but approached as a possible solution of an existing problem for a given vehicle and restraining device.

BIBLIOGRAPHY

1. Sacreste et al.: Laboratoire de Physiologie et de Biomécanique PSA/Renault—Tolérance thoracique des porteurs de ceintures de sécurité. J. Traumatologie 1980 Tl No. 2, pp. 105–113.
2. Thomas et al.: Laboratoire de Physiologie et de Biomécanique PSA/Renault—Influence de l'âge et du niveau d'effort de retenue sur la gravité des lésions thoraciques subies par les occupants ceintures en accidents réels. Proceedings of the 4th IRCOBI, September 1979.
3. NHTSA—Automobile occupant crash protection. Progress Report No. 3, July 1980.
4. Heinrich Hontschik et al.—Necessities and possibilities of improving the protective effect of three-point seat belts. 21st STAPP CAR CRASH CONFERENCE.
5. M. Ramet and O. Cesari—Behavior of restrained dummies and cadavers in frontal impacts. Proceedings of 4th IRCOBI, September 1979.
6. D. Adomeit et al.—Evaluation methods for the biomechanical quality of restraint systems during frontal impact. 21st STAPP CAR CRASH CONFERENCE.
7. D. Adomeit and A. Heger—Motion sequence criteria and design proposals for restraint devices in order to avoid unfavorable biomechanic conditions and submarining. 19th STAPP CAR CRASH CONFERENCE 751146.
8. L.G. Svensson—Means for effective improvement of the three-point seat belt in frontal crashes. 22nd STAPP CAR CRASH CONFERENCE 780898.
9. G. Danese—A research study for an energy absorbing sliding seat. 5th International Technical Conference on Experimental Safety Vehicles, p. 699.
10. H. Stanley et al.—Part 572 crash test dummy response and the effects of shoulder belt location and impact vector direction. 8th International Technical Conference on Experimental Safety Vehicles, p. 417.
11. M. P. Bereau—Amélioration des ceintures de sécurité par utilisation des dispositifs pyrotechniques de rétraction. Ingénieurs de l'Automobile No. 3, March 1979.
12. G. Hoffman et al.—The influence of preloading on the efficiency of belt systems. ISATA 1978.
13. R. Weissner—A comparison of advanced belt systems regarding their effectiveness. SAI 1978 PAPER 780414.
14. M. Dejeammes et al.—Improvement of the automatic belt: the possible efficiency of the pyrotechnical retractor. 8th International Technical Conference on Experimental Safety Vehicles, p. 379.

A Lightweight Two-Passenger Automobile Combining Improved Crashworthiness, Good Performance, and Excellent Fuel Economy

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ABSTRACT

The Viking Six Integrated Research Vehicle was designed under contract to the National Highway Traffic Safety Administration of the Department of Transportation to demonstrate that it is possible to obtain superior fuel economy and performance without compromising passenger safety. The Viking Six has achieved occupant survival in a 41.2 mph barrier crash, fuel economy of 40.4 mph city and 66.6 mph highway, and has met 1982 exhaust emission standards. It can accelerate from 0-60 in less than 9 seconds and shows outstanding stability on corners and in crosswinds.

INTRODUCTION

The Viking One through Five series of experimental vehicles have demonstrated ability to achieve extremely high fuel economy and the ability to meet stringent exhaust emission standards. The Viking Six vehicle breaks new ground because a high degree of crashworthiness and occupant safety has been achieved without compromising exhaust emissions or fuel economy.

SAFETY FEATURES

Crashworthy Structure

Viking Six was designed to see if it would be possible to build an ultralight (1320 lb, 600 kg) fuel efficient vehicle capable of providing safety at least as good as that provided by full sized cars. Its performance in a crash test at Dynamic Science in Arizona on May 29, 1980 showed an ability to provide survivability for the occupants in a 41.2 mph (66 kph) crash. In order to provide good crashworthiness in such a vehicle many unusual design steps were taken. To make sure that the occupants would not be crushed in the crash event the central monocoque chassis section was made extremely stiff as shown in Figure 1 with 1.5 mm to 2 mm 7075 T-6 sheet and hat section riveted together. This structure was obviously stiff enough as it only suffered a 4 mm permanent deformation after the crash event. The front and rear chassis sections were designed to crush at much lower loadings to provide a manageable crash pulse. To this end the front and rear chassis panels were made from 6061 T-3 .75 mm thick. The nose section of the structure ahead of the toeboard was filled with aluminum honeycomb material. (Fig. 2.) On the advice of Mr. Sol Davis of Dynamic Science it was decided to use aluminum honeycomb material with a crush strength of 100 psi (7 kg per cm^2) over an area of 400 sq. in. (2581 cm^2) for a 40,000 lb (18,182 kg) force through the available 29.5 in. (75 mm) crush stroke of the front end of the car.

Passive Restraint Airbelts

Although the original design of the car had called for a passive belt design the only pyrotechnic inflator available at this time mandated an active belt system for the crash test. (Fig. 4.) Late in 1980 Mr. M. Fitzpatrick of Fitzpatrick Engineering designed and static tested an "in-belt gas generator" which Vehicle Research Institute personnel have installed in a functional passive restraint air belt system on the second iteration of the Viking Six design. (Fig. 3.)

Once the problem of the in-belt inflator was solved it became possible to complete the passive restraint design originally intended. Unfortunately if we were to use the force limiting system developed for the first crash test we would have to devise some system for automatic decoupling when the hatch is raised for occupant entry or egress. A simple peg-in-hole system independent of the main hatch latching system solved the problem and the belt end was riveted up to the hatch with aluminum rivets that shear off at about 200 lb force. (Fig. 5.) A notch is cut into the forward face of the peg so that relative motion during the crash sequence will shear the rivets before the 2200 lb force limiters started to stroke ensuring that there would be no excessive g loading at the beginning of the stroke.

Gas Generator

Figure 6 shows the gas generator chosen. It is manufactured by Thiokol and weighs only 6 oz fully loaded for each occupant as opposed to 7.6 lb for the former gas generator used in the crash test. Although the in-belt gas generator has only 12 gms of propellant per occupant vs 57 gms per occupant in the old system, the gas would be much hotter at 1600 degrees Fahrenheit (871 degrees Celsius) as compared with 600 degrees Fahrenheit (315 degrees Celsius) of the previous system which would help to bridge the gap. Also assisting in this regard was the

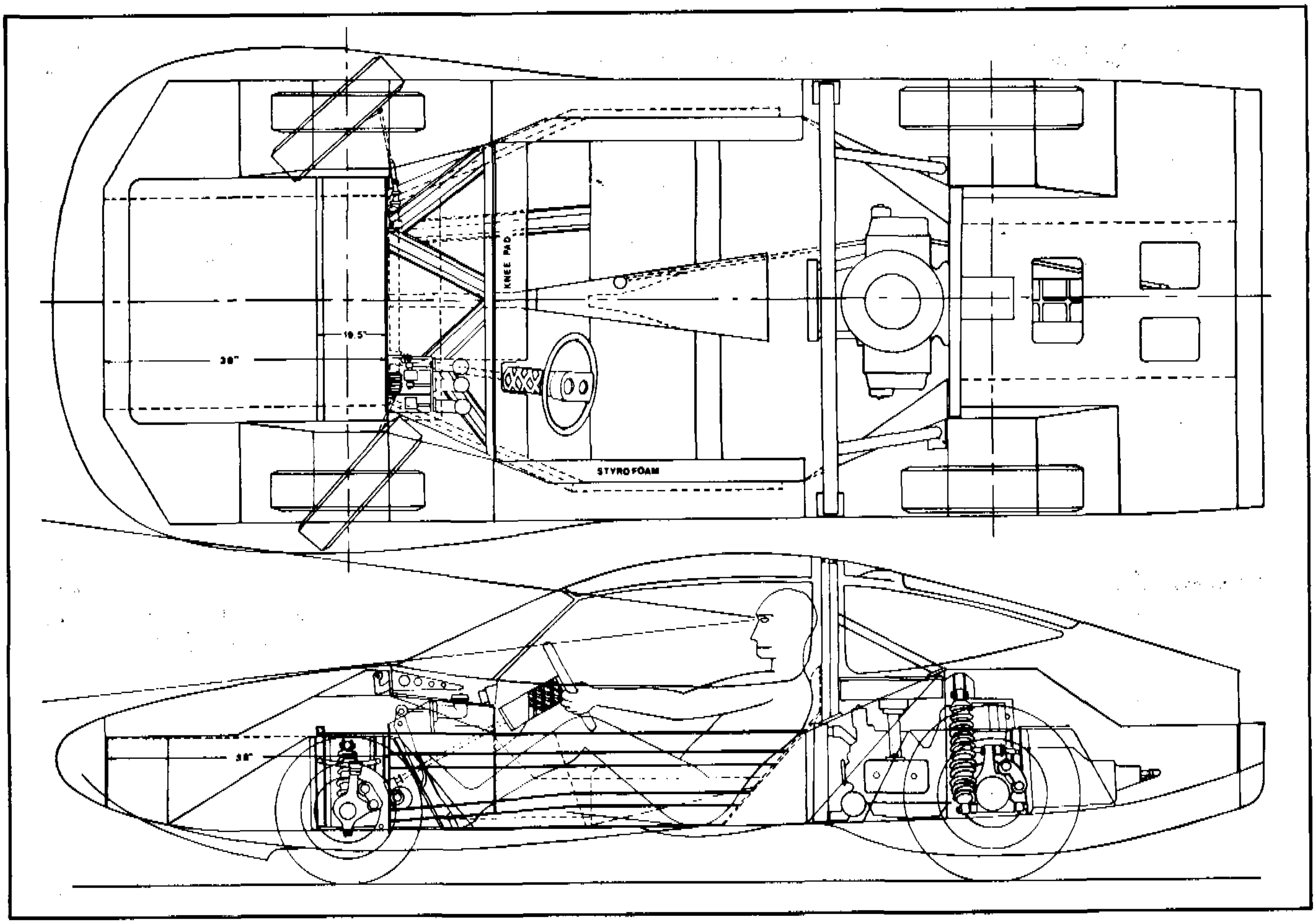

Figure 1. Viking Six chassis drawings.

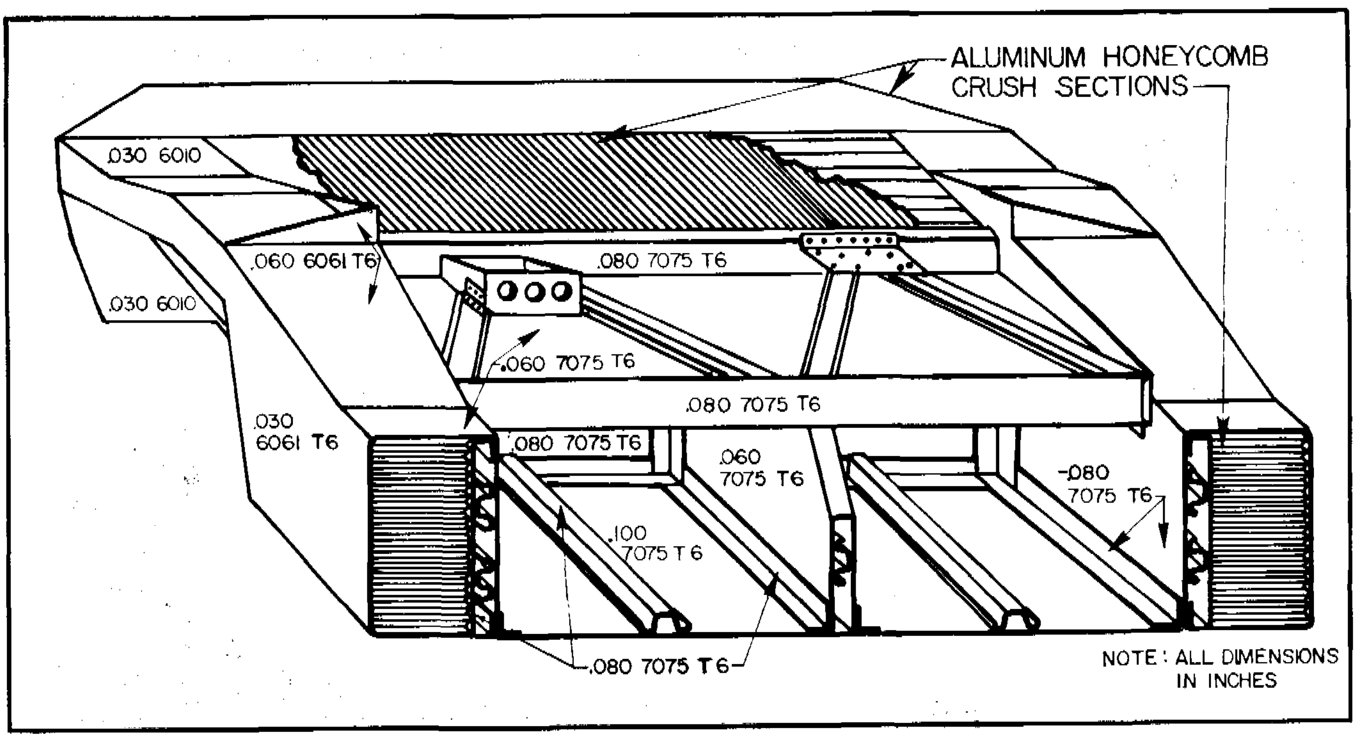

Figure 2. Front chassis pictorial.

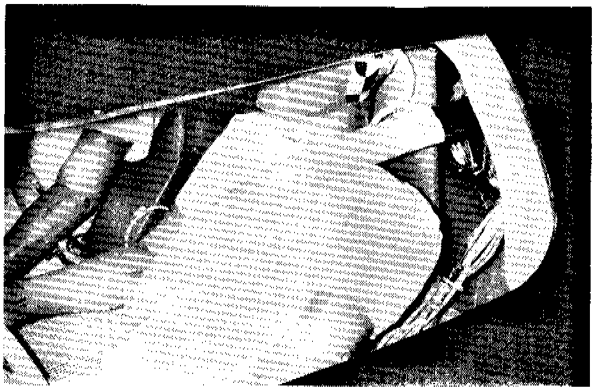

Figure 3. Belts on dummies.

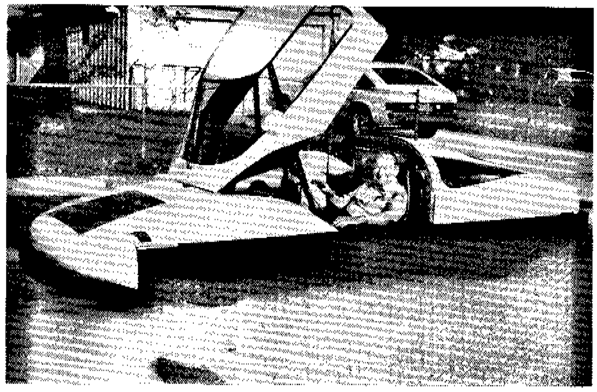

Figure 4. Viking Six MK II seat belts.

new airbelt design which was configured to have the airbelt volume in only the area required for proper performance. As airbelt inflation is used primarily to prevent forward rotation of the head almost all of the available volume within the airbelt was devoted to supporting the head.

As a result of a number of static tests and mathematical analyses Fitzpatrick concluded that a 550 cu. in. volume airbelt loaded with 12 gms of propellant activated 20 ms into the crash event should provide performance equivalent to the crash test performed on the first Viking Six vehicle.

FITZPATRICK ENGINEERING REPORT

As Mr. M. Fitzpatrick had the primary responsibility for restraint system design the following excerpt from his final report to the NHTSA is presented here.

RESTRAINT SYSTEM DESIGN

At the conclusion of the four sled tests Fitzpatrick Engineering settled on a total restraint system design which was judged to have the most potential for meeting the Federal Motor Vehicle Safety Standards (FMVSS) 208 injury criteria in a frontal barrier crash of 40 mph. The 40 mph impact velocity was chosen based upon sled test results as well as predicted behavior of the vehicle structure in the crash.

Gas Generator

The gas generator chosen for use as the inflation source for the airbelt systems was a generator originally manufactured for installation in a steering wheel hub and used with a driver airbag system. The gas generator was supplied by Thiokol and loaded with 115 grams of DLZ 113 gas generant (50 gms of pellets 0.120 in. (3 mm) thick

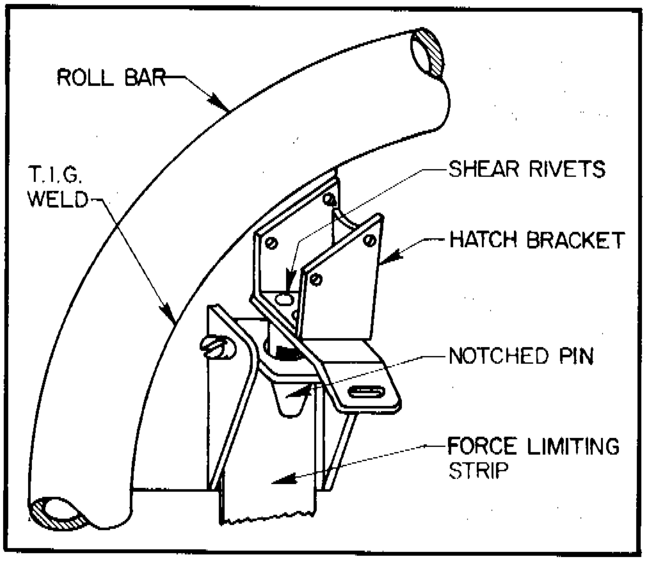

Figure 5. Belt decoupler drawing.

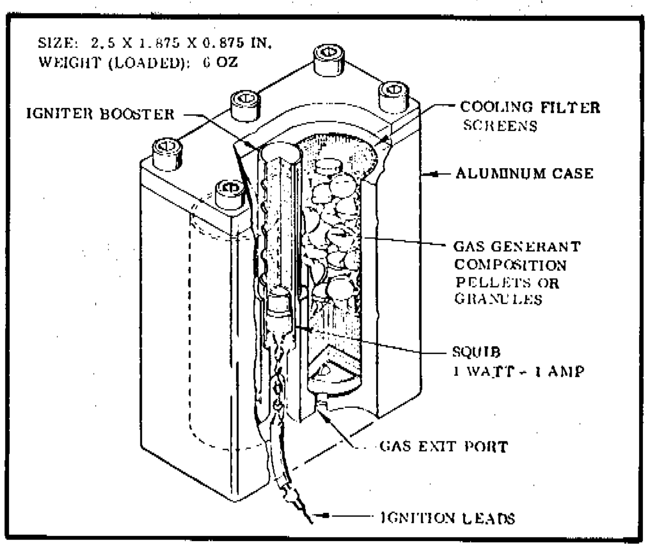

Figure 6. In-belt gas generator.

and 65 gms of pellets 0.060 in. (1.5 mm) thick). The igniter charge was 3 gms of UIZ-172 with 12 gms of $FeSO_4$ as a neutralizer. The cooling screen was 0.7 in. (18 mm), 21 strand Gold with a 2-12 mesh and 3-40 mesh filter screen.

The gas generator is bolted to a gas distribution manifold with two three-quarter inch (19 mm) I.D. exhaust parts which distributes one-half of the total flow to each of the two airbelt systems as shown in Figure 6. This type of gas generation distribution system was based upon that used in the Calspan RSV as modified by Fitzpatrick Engineering.

Airbelt

The airbelt design was based upon a design by Fitzpatrick Engineering and Calspan for the Calspan RSV. Certain changes to this basic design were necessary prior to using it in the Viking Six. To be consistent with desired anchor point locations in the Viking Six, the inflatable portion of the belt was shortened. Also, due to the fact that no force limiting belt webbing was readily available, standard nylon webbing was used with the idea that a mechanical force limiter could be implemented later if desired. (Fig. 7.) The retractor used with the airbelt system was a VW Rabbit retractor. A Honda pivot loop became necessary in the final design iteration.

Seats

Due to the nature of the seat design which has very little padding and the rather high rearward angle in which the occupants recline in order for the vehicle to have as little air resistance as possible, we became concerned early in the program that the occupants might receive excessive g loads up through the spine. In an effort to attenuate these g loads, a crushable, aluminum honeycomb block of 24 psi (1.7 kg per cm^2) crush strength (part #38-5052-.0007-1.0) and 45 sq. in. (290 cm^2) area was placed under the driver and passenger seats for the test. Unfortunately, due to lack of headroom, it was not possible to place the honeycomb under the seat; space only exists under the seat leading edge.

During sled testing we noticed that the best overall trajectory control and underseat honeycomb crush for the occupants was maintained if we allowed certain rivets that connected the seat body to the floor bracket to shear, thereby allowing the seats to rotate forward and stay with the occupants. (Fig. 8.) This rivet shearing concept was retained for the crash test.

Knee Restraint

Since the airbelt was a two-point design (torso belt only as shown in Figure 4), some form of lower body restraint was necessary. Originally, W.W.U. had installed a VW Rabbit knee bolster in the Viking Six; however, it was determined during sled testing that it was simply too "hard" for integration into the Viking Six structure; so it was discarded in favor of a new knee restraint designed specifically for the Viking Six. (Fig. 10.)

Force Limiter

Due to the fact that the crash pulse of the Viking Six could only be estimated since no crash history for this vehicle exists, and due to our desire to maximize the stroke efficiency of the airbelt system, Fitzpatrick Engineering designed a mechanical force limiter for use with airbelt systems. (Fig. 7.)

For the Viking Six crash test an energy absorber system composed of a tape width of 0.75 in. (19 mm) a tape thickness of 0.071 in. (1.8 mm), and a roller diameter of 0.250 in. (6 mm) was used for both the driver and passenger systems. The rollers and tapes were lubricated with grease before the test.

Anchor Point Locations

With an airbelt design it is very important to locate the belt anchors so that the belt passes across the chest

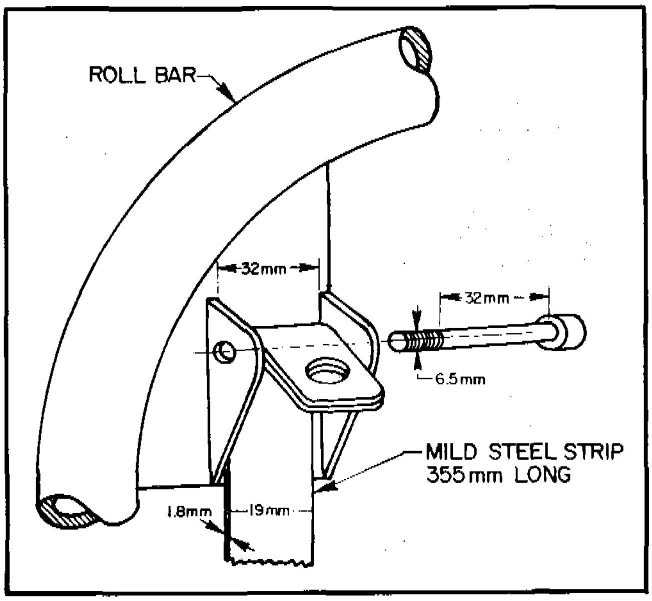

Figure 7. Force limiter.

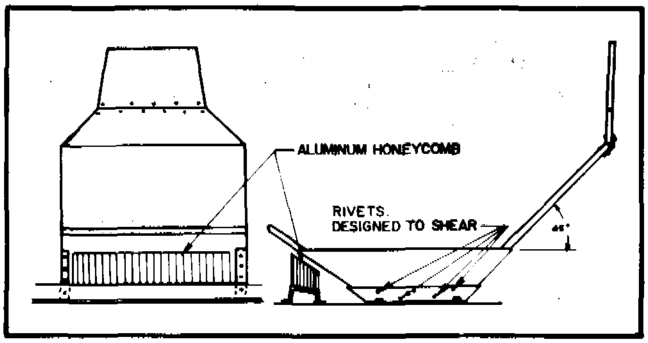

Figure 8. Seat shearing rivets.

in a manner where proper head support will be maintained as the head rotates forward during the crash. Additionally, the anchors must be located so the belt force transmission angles are as efficient as possible. In order to accomplish this it was necessary to move the lower anchor 3 in. (76 mm) rearward to the bulkhead immediately behind the seats and to move the upper anchor upward and inboard a total of 8¾ in. (222 mm) on the roll bar from the original W.W.U. positions.

Pre-Test Configuration

Figures 9 through 12 show the pertinent restraint system dimensions in schematic form. In addition, the anchor point locations mentioned above are shown.

For this test, 50th percentile Part 572 dummies were used in both the driver and passenger positions. Since we wanted to be sure that the test velocity was at least 40.0 mph (64 kph), we chose a test "window" for velocity of 41 ± 1 mph. Any velocity outside this range would result in an aborted test. The vehicle front end energy absorber selected for this test was 75 psi (34 kg) crush strength aluminum honeycomb which was expected to exhibit a static crush of approximately 22.5 in. (572 mm).

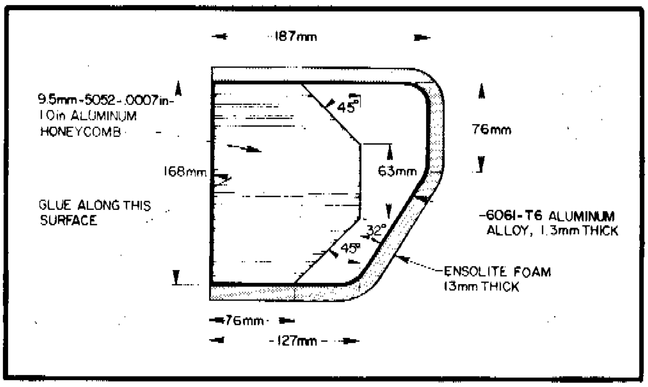

Figure 9. Viking Six knee restraints.

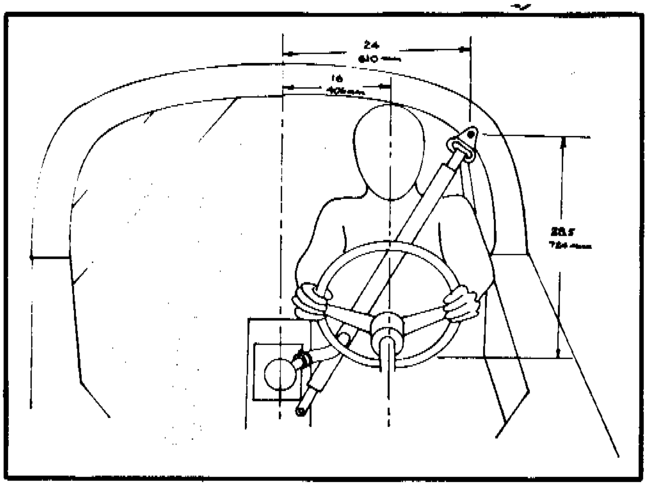

Figure 10. Viking Six belt set up, front view.

TEST RESULTS

The Viking Six crash test was conducted by Dynamic Science on May 29, 1980. The actual crash velocity was 41.2 mph (66 kph) with a rebound velocity estimated at 3 mph (5 kph). Sensing time for airbelt actuation was selected and verified at 11 ms.

As is evident from Table 1, all the measured injury parameters are well below the FMVSS 208 injury criteria limits. We believe these results are especially pertinent since they show that it *is* possible to design a very small car and still protect the vehicle occupants within established injury guidelines even at velocities greater than required by present standards. Admittedly only one impact mode was tested here; however, we believe in a program where more development and testing were possible, these results could be extended to other accident modes as well.

The seats performed pretty much as expected in that

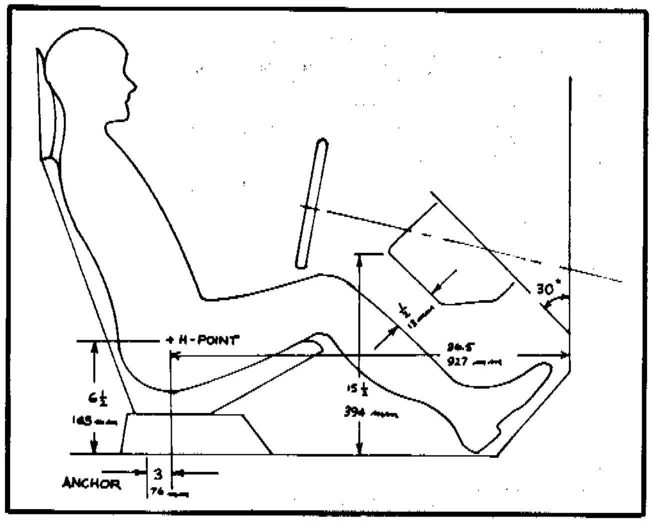

Figure 11. Viking Six belt set up, side view.

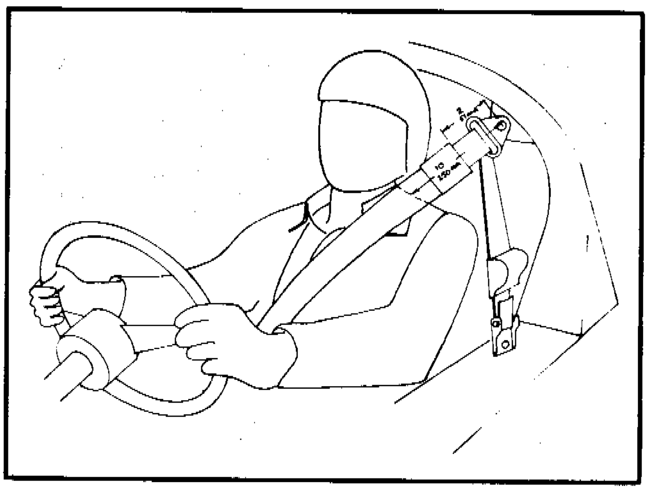

Figure 12. Viking Six belt set up 3/4 view.

Table 1. Injury measures received for the driver and passenger.

	Driver	Passenger	"208" Std.
HIC	*552	286	1000
Pk. Res. Chest G's (−3 ms)	44	51	60
Pk. Vert. Chest G's (−3 ms)	24	24	NA
Pk. Femur Loads Left	1031	1080	2250
Right	1130	819	2250
*Roll bar hit dummy on side of head controlling HIC			

the rivets previously discussed sheared according to plan. However, not quite as much honeycomb was crushed under the seat pans as desired. The reason for this is that some other rivets holding the plate to which the under seat honeycomb had been bonded, sheared allowing the honeycomb to slide partially out from under the seat pans. Perhaps if this had not happened, the chest vertical g component would have been a little less than the 24 g's actually measured.

There was very little knee restraint crush for either the driver or the passenger (0-½ in., 13 mm) as the upward tilt to the seat pan effectively prevented the lower body from translating very far and absorbed, through bending and crushing the honeycomb, most of the lower body energy. Sled test #2 on the driver side was the sled test in which the seat and the knee restraint were configured most nearly like this test and exhibited nearly identical results in that, here too, the knee penetration was only about ½ in. (13 mm).

Perhaps if the vehicle was designed to have slightly more headroom, the occupants could be seated more nearly erect and absorb more of the lower body energy through the knee restraint rather than the seat pan. This should help lower the chest vertical g's which are a little higher than we think is necessary.

The crash pulse g's were fairly high in the beginning of the crash. However in spite of the fact that these g's peaked at approximately 56 g's and were quite high for a relatively long time resulting in a very short crash pulse duration of only 72 ms, the force limiter operation effectively limited body g's to rather low values.

One might wonder, given the severe roll bar bending that occurred, whether the roll bar may have added to the force limiting thereby resulting in chest g levels that were artificially low. We wondered about this, too, but close inspection of the films and data show that roll bar bending did not begin until approximately 85 ms and was over at 90 ms, very late in the event and much later than peak chest g's were experienced. This is corroborated by the g "spike" on the dummy's head at 90 ms when contacted by the roll bar at maximum roll bar rotation and by the sudden drop off in chest longitudinal g's for both the driver and passenger at approximately 85 ms.

Film and data analysis show that peak chest g's and force limiter stroke were over when the roll bar collapsed. The dummy and vehicle had both stopped moving forward when this event happened. Here again, one might wonder why the roll bar collapsed when the belts which were loading the roll bar had reached their peak loads sometime before and were now much lower as evidenced by the drop off in chest g's. The answer, we feel, lies in two related facts. First, the rivet failure at the roll bar base that led to its collapse, probably started earlier in the impact event without any apparent movement of the roll bar. However, as the rivets continued to tear out of the sheet aluminum, a point was reached—rather late in the event—where the roll bar strength was now less than the force applied even though the force was now much reduced. (Fig. 14.) Secondly, there may have been another contributing factor to roll bar collapse. The buckling of the structure immediately aft of the roll bar may have dumped its load into the roll bar base structure. If so, this would also tend to explain the late failure of the roll bar, significantly after the peak belt loads were experienced.

The driver side force limiter stroked approximately 3 in. (76 mm), 2 in. (51 mm) normal stroke plus 1 in. (25 mm) weld tearing at the point where the force limiter tape attached to the retractor. The passenger side force limiter stroked 6 in. (152 mm) in normal fashion.

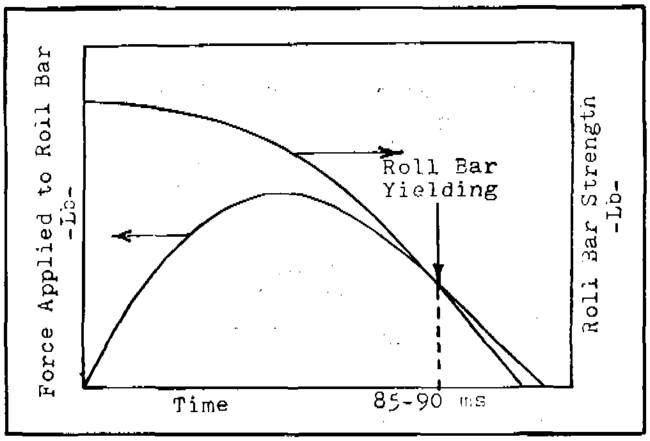

Figure 13. Roll bar deformation.

The reason for the difference in total stroke for the two systems is not entirely clear; however, it may be that the honeycomb on the passenger side being a little less securely fastened (due to riveting space restrictions) due to fewer rivets, allowed the honeycomb to slip out from under the seat earlier in the crash event. If so, this would mean that less energy would be absorbed necessitating more stroke by the upper torso force limiter.

The crush of the vehicle front end was qualitatively much different than anticipated; although quantitatively the crash pulse g levels were not a great deal different than expected with the exception that the peak levels were somewhat higher. The reason we say the crush was different than anticipated is that rather than crushing accordian fashion the remaining half over-rode the correctly crushed section and was incompletely crushed. As it turned out however, the rest of the vehicle structure absorbed more energy than anticipated, which apparently helped offset the odd crush behavior of the aluminum honeycomb itself.

There was significant pitching of the vehicle late in the crash event; however, we believe the center-of-gravity of the vehicle was artificially high due to instrumentation mounting locations being generally much higher than normal vehicle C.G. In addition, we do not believe that pitching is necessarily detrimental to the occupants as it adds more overground stroke in which to bring the occupants to rest and does not appreciably affect vertical g-levels "seen" by the occupants as it occurs over a relatively long time period late in the impact event.

Static crush of the vehicle was estimated at 18-19 in. (460–480 mm) while dynamic crush measured from the films was approximately 25-26 in. (650 mm). This is quite a difference indicating that the vehicle may have had a fairly high rebound velocity. The actual rebound velocity is a little difficult to establish however. This is because the vehicle accelerometers underwent such gross movements and rotations due to severe buckling in areas where the accelerometers were mounted. For example, of the three compartment-mounted accelerometer traces only one showed a return to zero in vehicle velocity when integrated. The other two showed a residual vehicle velocity of 6–8 mph (10–13 kpm) in the original direction of travel which is clearly impossible. Film analysis shows the vehicle rebound velocity to be approximately 3 mph (5 kph) for a total vehicle "delta V" of 44 mph (70 kph).

SIDE IMPACT

Analysis of force and acceleration suffered by the impacted car during a side crash make it apparent that it is not feasible to provide a side crush zone wide enough to absorb the energy released when the striking vehicle impacts at 40 mph (60 kph) (30 inches (76 mm) would be required on each side of the car). If a measure of safety is to be provided then the side of the vehicle must be made stiff enough to force the striking car to provide nearly all of the ride down distance through crush in its nose.

The Viking Six used side boxes 6 in. (152 mm) by 13 in. (330 mm) in cross section made from 7075 T-6 aluminum sheet 115 mm thick reinforced at critical points with 2 mm thick 7075 T-6 hat section. A transverse panel of 7075 T-6 1.5 mm thick behind the seats anchors the rear end of the box while the upper dash panel structure provides a front transverse stiffener as well as providing a reaction point for the knee bar. A tranverse member under the front edge of the seats further stiffens the middle of the structure. Additional stiffening is provided by aluminum honeycomb bonded to the face skins with expoxy adhesive. The inner surface of the side tanks had a 500 mm thick layer of rigid polyurethane foam covered with 13 mm of ensolite foam. The entire cab is skinned with dark brown vinyl upholstery material.

The windshield is mounted well forward of the driver to give maximum ride down space for the occupants' heads during a crash when they are riding forward in their belts, which are stroking the force limiters previously described. Other benefits of the forward mounted windshield are that the angle of vision subtended by the A pillars is very small and the degree of sunshielding makes separate sun visors unnecessary.

WEIGHT SAVING

Extensive use of aluminum played an important part in weight reduction. Not only were all major castings for engine, transmission, steering, suspension, and brakes made from aluminum alloy, but also the chassis lower body monocoque tubs were made from aluminum sheet. All of the parts cast in the Vehicle Research Institute (VRI) were cast from 356A-T6 alloy with strontium modification to improve grain structure. The parts were heat treated to T-6 or T-61 to improve strength and machinability. (Fig. 14.)

The center monocoque was made from 7075 T-6 alloy 0.080 in. (2 mm) for the critical toeboard which serves

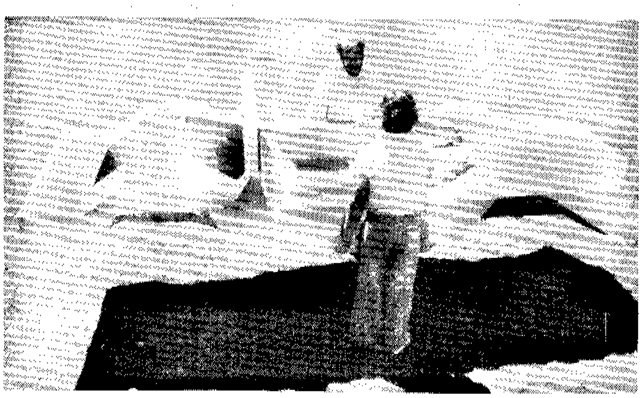

Figure 14. Viking Six chassis.

as the reaction member for the aluminum honeycomb deformable section in the nose of the car. Localized longitudinal and transverse stiffening was provided by corner reinforcement angle sections and 0.060 in. (1.5 mm) 7075 T-6 alloy hat sections. The forward and rear bays were made from 0.050 in. (1.2 mm) 6061 T-4 sheet to form a structure strong enough and stiff enough to carry normal usage loads but able to deform at a survivable rate during a crash. The overall weight of the hull was kept to 225 lb (102 kg). Previous experience with Viking Four aluminum aerodynamic skin and Viking Five's glass reinforced polyester matrix body led us to believe that there is not a lot to choose between the two materials for one off prototypes in terms of weight, and the glass reinforced polyester skin is far easier to build. As a matter of record it does seem that bringing a body up to show quality with liberal quantities of filler material has more effect on body skin weight than the initial material chosen. As a consequence we attempted to make aircraft quality body skins from fiberglass. The body skins for both cars were initially very light (220 lb, 90.7 kg) and the panels used on the crash test car had very little filler. The second fuel economy, emission, and performance car suffered from a misunderstanding with the campus janitor service. They took it upon themselves to destroy some of the body plugs and mold before the final body parts were fabricated. As a consequence the show car on display in Japan weighs about 50 lb (22.6 kg) more than planned.

SUSPENSION AND BRAKE MATERIALS

Suspension components were specially fabricated to save unsprung mass for improved ride and roadholding. The wishbones for the unequal length nonparallel system were made from 0.040 in. (1 mm) thick 4130 chrome-moly steel tubing 0.750 in. (19 mm) in diameter. The suspension system makes use of coil springs wrapped around the shock absorbers, forged steel spindles and uprights at the front, mount forged aluminum 6061 T-6 steering arms. (Figs. 15 and 16.) Aluminum discs with copper-iron metal spray surfaces were cast and machined for front and rear. The front units have given no trouble, but the more heavily loaded rear units have actually melted the aluminum from the middle of the iron-aluminum-iron sandwich. As a consequence the experimental discs have been replaced with cast iron units. The front wheel diameter was kept as small as possible for several reasons. The elimination of bumps in the upper body to allow for the wheel travel of larger wheels improves aerodynamics. Smaller intrustion into the car center at full lock make it possible to fit a good aluminum deformable structure. Smaller skirts could be put over the front wheels at full lock which saves frontal area.

BODY DESIGN

Styling

The styling of Viking Six was based on the premise that a smooth aerodynamic form could provide an attractive appearance. The rounded elastomeric urethane five mph bumper provides a curved surface unlikely to injure a pedestrian struck in a low speed impact. (Fig. 17.) In fact the 40 degree sloping windshield would be likely to deflect a person clear over the vehicle with a minimum second impact injury. The headlights were set

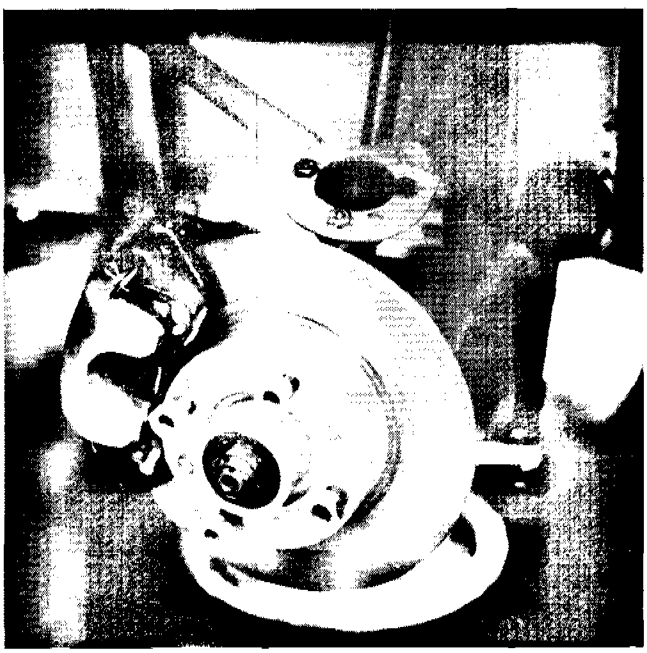

Figure 15. Front suspension.

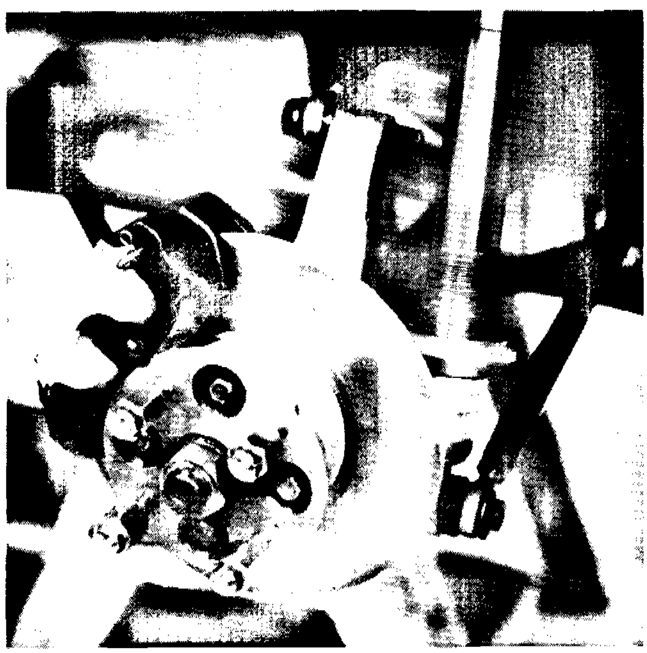

Figure 16. Rear suspension.

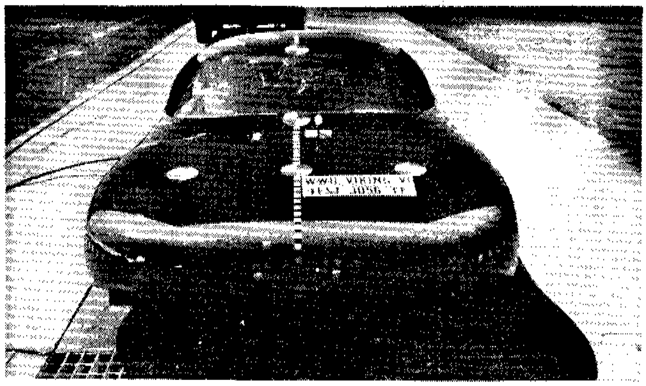

Figure 17. Viking Six MK I.

well back from the front so that they will be out of the 5 mph bumper strike zone and because the front of the car is low enough that the most forward part of the body high enough to meet the Federal headlight height regulations is almost at the leading edge of the windshield.

Headlight Cover

Early in the design program it was decided that good aerodynamic form would be required to give the expected fuel economy. Initial wind tunnel tests on one-eighth scale model indicated that a drag coefficient (Cd) of .26 would be possible on the already low frontal area of 15.1 sq. (1.4 sq. meter). Subsequent coast down tests and rolling drag measurements done at the California Subaru Engineering Center indicate that the actual Cd is closer to .21. Removal of the headlight cover panel increases the Cd to .25 and increases wind noise from a very low level to more normal levels. Fuel economy could be expected to be noticeably poorer on a highway driving cycle. The panel used is a flat wrap panel of hard abrasive-resistant polycarbonate. During the first year of use the panel has been remarkably free from scratches, but a demister-defroster system will be necessary for some conditions. During a snowstorm in the mountain passes of Oregon the headlight range was seriously compromised by snow build-up. The flexible light cover does provide an excellent cushion for a struck pedestrian, however.

Ventilation

A NACA Duct in the center of the hood feeds a duct which contains the heater-defroster core and axial flow fan. Although the need for such a duct inlet shape is not really necessary on such a low speed vehicle it does add an aerodynamic styling appeal.

Other Design Features

A single wiper centrally mounted wiped sufficient area to give good forward vision. It parks in the center of the screen in a manner that minimizes aerodynamic drag. The A pillars are extremely thin (1½ inches, 38 mm) to maximize forward vision. The line of the windscreen top and bottom continues into the compound curved side windows. The windscreen is made from safety plate so that a windshield wiper will not scratch it, but all other windows were made from scratch resistant hard surfaced polycarbonate to save weight. The hatch for occupant access hinges at the forward edge and is counterbalanced with gas struts to make it virtually effortless to lift. The flush fitting exterior door handles are pressed at the upper edge to make the lower surface pop out for easy lifting of the hatch.

Inflatable air belts are attached to the top of the B pillar on the hatch edge so that the engagement pin releases when the hatch is unlatched and the belts rise out of the way when the hatch rises to allow entry or exit. The steering column tilts upward to provide easy access for the driver who must step over a relatively high sill. (Fig. 18.)

Aerodynamics

The rear view mirror sits on a long airfoil-shaped strut to minimize aerodynamic interference drag. The mirror itself is enclosed in a streamlined pod and is adjustable from inside the car.

An unusual feature of the car is that all four wheels are enclosed to reduce aerodynamic drag. Although one might suppose that the enclosed front wheels would require either a narrow front track or an increased turning circle such is not the case. The car has a 30-ft (9 m) turning circle. The underbody is sloped upwards towards the rear to reduce aerodynamic lift and the windshield is given pronounced curvature in plan form to direct air to the sides of the vehicle, not over its roof where it would contribute to a high velocity low pressure area on the top surface of the vehicle. Cooling air is taken in through a NACA Duct in the center of the underpan where it is ducted through the radiator and into the engine compartment. The exit duct for engine compartment air is through a clear polycarbonate duct behind the drivers head (the one place the driver cannot see anyway) and out through an aircraft style exit vent in the roof in a

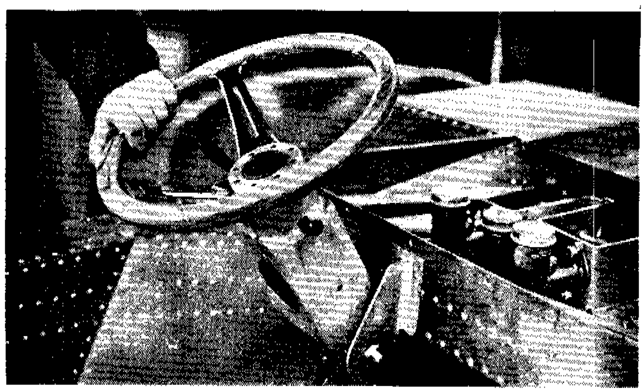

Figure 18. Tilt Steering Wheel.

natural low pressure zone. (Fig. 19.) When the car is operating at normal speeds natural air flow is sufficient to cool the engine. At idle, convection currents cool the engine. There are some conditions when the thermostat controlled electric fan is required however. When crawling up a steep grade in heavy traffic, the fan comes on to cool the engine.

Aerodynamic stability was a matter of some concern as the center of gravity of the vehicle is well to the back and the lateral center of pressure of well streamlined vehicles tends to be well forward. As a result the nose section of the car is quite low and has well-rounded contours. The rear sections are quite slab sided and the rear wheel skirts drop to within several inches of the ground. The net result of moving the center of lateral effort aft and fitting the rear end with tires of much larger footprint than those of the front gives very satisfactory crosswind performance. All turn signals and repeater lamps are fitted flush with the body to further reduce aerodynamic drag. The rear lamps are mounted just ahead of the rear clear polycarbonate cover to maximize rearward vision in parking maneuvers. In fact the driver can actually see the rear bumper when backing up.

COMPONENT ACCESSIBILITY

It was considered desirable to provide easy access to all mechanical, electrical, and plumbing components of the vehicle. The rear body panel tilts back on hinges at the extreme rear of the body providing good access to the engine. By simply removing the easily accessible hinge pins the entire rear aerodynamic skin comes off the car. As there are no electrical connections to this panel, removal is very easy. A number of easily accessible cap screws that hold down the transaxle cover can be removed and the entire powertrain is exposed and can be worked on from above rather than below. The battery is easily accessible in the extreme right rear section of the chassis.

When the hatch is lifted and the instrument backing panel lifted off (no fasteners), all of the instruments and associated wiring is exposed for easy servicing. In addition, the three clutch and brake master cylinders are exposed. When the cover to the tunnel between the seats is uncovered the switches and attendant wiring are exposed. The seat belt retractors and shift linkage also lurk in this tunnel. Removal of the front wheels does present a problem however. The car must be jacked up so the wheel nuts are exposed and the wheel will only come out of its well when pointed straight ahead.

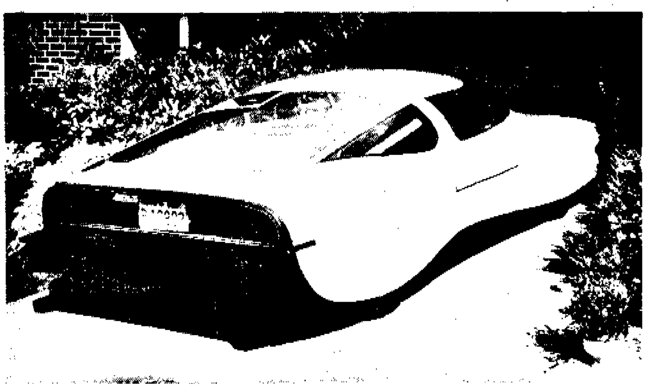

Figure 19. Viking Six MK II.

Seats

Finding seats that will fit into this low built car that can be adjusted to fit a 95th percentile male and a 5th percentile female without incurring a weight penalty proved to be a problem. Finally it became necessary to design and construct special seats. The seat chassis was made from 2024 T-6 aluminum skinned balsa core material riveted together with doublers at high stress areas. The seats were then upholstered in conventional materials. The adjustment mechanism is unique. It was determined that the best driving position for a tall person was a steep reclining position, while best vision and comfort for a short driver was achieved by providing a more upright driving position with the seat closer to the dashboard. The 105 degree angle between the seat back and seat bottom is maintained at all times. Standard seat rails were mounted outboard of the seats to give the lowest possible seating position, while the seat angle adjustment was provided by means of an adjustable aluminum wedge controlled by a simple knob on the floor.

Luggage Space

Although Viking Six does not have a great deal of luggage space it was sufficient to carry luggage for two weeks for two people to California and back from the VRI Research Laboratory in Washington State. The rear hatch pivots around its rear attachment hinges to provide access to the luggage space. The insulation fitted around the exhaust system to provide early catalyst light off serves to keep the luggage compartment at the satisfactory temperature in 25 degrees Celsius.

ENGINE EFFICIENCY IMPROVEMENT

At the beginning of the research project a search was made for a lightweight engine of good efficiency and smoothness able to meet exhaust emission standards. Engines of less than four cylinders were rejected because it was not thought that adequate smoothness and refinement would be available from such powerplants. The Subaru 1600 cc aluminum engine was chosen because of its light weight (185 lb, 84 kg), boxer layout, and its proven ability to meet exhaust emission standards. Unfortunately the engine has somewhat too much displacement for best fuel economy. It was decided to use Eaton valve disablers on the intake and exhaust valves on the front cylinders of each bank so that the driver can switch off two cylinders in situations not needing high power output. Although the front two cylinders are motoring there is very little power loss because pumping losses are almost eliminated as the valves are closed. The energy required to compress the air in the cylinder is almost entirely recovered on the expansion stroke. The remaining two cylinders are able to function at much higher Brake Mean Effective Pressure (BMEP) which provided improved thermal efficiency. (Fig. 20.)

Because of low vehicle drag a low numerical final drive ratio can be used with large diameter wheels and tires. At a given vehicle speed in top gear the engine will operate at reduced rpm and increased throttle opening which reduces pumping losses.

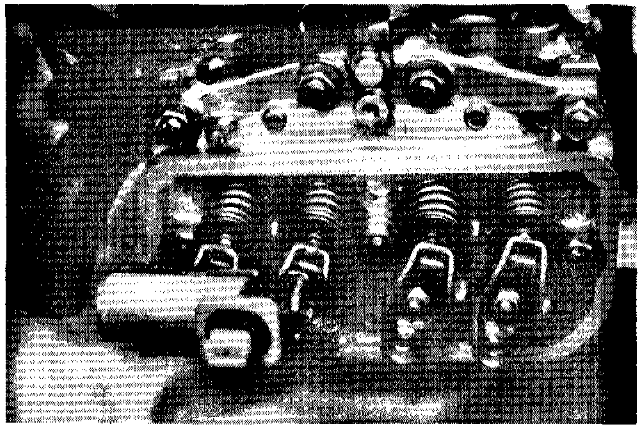

Figure 20. Valve disablers.

FUEL ECONOMY

One of the prime objectives of this integrated research safety vehicle was to improve vehicle fuel efficiency without compromising safety goals. Improvements in engine efficiency, aerodynamic drag, and weight reduction all played a part in the demonstrated high mileage of the vehicle. On an EPA city test 40.4 mpg (5.84 liter per 100 km) was achieved and a highway figure of 66.6 mpg (3.55 liters per 100 km) was achieved. Gravimetric data showed that even better results could be obtained with further engine optimization.

PERFORMANCE AND HANDLING

Although acceleration, braking, and handling were not the highest priorities for the Viking Six program, VRI personnel have a long standing personal interest in these aspects of vehicle design. The basic suspension system utilizes coil-over shock absorber units located by a long and short arm nonparallel wishbone system at each end. The roll center at the front is 50 mm above ground level, while the rear roll center is 100 mm above ground level. The virtual swing arm length both front and rear is 190 mm. Camber gain at 3 degree roll maintains the outer wheel perpendicular to the road surface. The tire footprint at each end of the vehicle is high for the load carried and in direct proportion to it.

Nine-inch disc brakes are used at each wheel with aluminum brake calipers. Two master cylinders are used with a balance beam mounted integral with the pedal so that a simple screw adjustment can adjust the percentage braking each end of the vehicle receives. At this writing the unit is not servo controlled by weight in the trunk.

At this time only acceleration and coast down tests have been run on the car. It has achieved a 8.95 s time from 0-60 mph (0-96 kph) and a time of 16.8 s for the standing start quarter mile. This writer has driven the car down the freeways from Bellingham, Washington to Santa Ana, California and back up the coast of California, Oregon, and Washington and can report that the car is

Table 2. Steady state fuel economy 1,625 pound inertia—3.2 hp.

Speed (MPH)	Gear Used	Time Min: Sec 7	Fuel Used (gms)	MPG	Liters / 100 Km
50 (4 Cyl)	5th	2:56.98	100 gms	68.4	3.45
50 (2 Cyl)	5th	3:39.76	100 gms	84.9	2.78
55 (4 Cyl)	5th	2:46.09	100 gms	70.6	3.35
55 (2 Cyl)	5th	2:45.91	100 gms	70.6	3.35
45 (4 Cyl)	5th	3:07.43	100 gms	65.1	3.63
45 (2 Cyl)	5th	3:45.39	100 gms	78.7	3.07

$$\text{Fuel Consumption (MPG)} = \frac{\text{Speed (MPH)} \times \text{Time (Min)} \times 46.37}{\text{Fuel Used (gms)}}$$

Table 3. Exhaust emission data.

Test Date	Test Type	Emission Data HC	CO	NO_x	Fuel Economy CO_2	CB
3 25 82	CVS — H	.09	.89	.86	202.4	43.4
3 27 82	CVS — CH	.25	1.13	.89	237.5	36.9
3 29 82	CVS — CH	.25	6.62	1.23	208.2	40.4
3 29 82	HFET	.05	2.51	1.42	129.0	66.6

comfortable and surefooted on all types of roads. In fact the car compares favorably in roadworthiness to a Chevrolet Corvette and Lotus Europa.

EXHAUST EMISSIONS

Viking Six was tested for exhaust emissions at the Subaru Technical Center in Santa Ana. After some preliminary work to dial in the best compromise for fuel economy and exhaust emissions the following results were posted.

SUMMARY

Viking Six met the 1982 exhaust emission requirements without a feedback loop carburetor or fuel injection. This is a graphic example of what a reduction in weight and aerodynamic drag can do to reduce emissions and improve fuel economy while limiting hardware costs.

Fuel economy could be improved still further by using a smaller displacement engine optimized for a car of this weight. We plan to try a 1300 cc engine of the same type in the near future.

A very significant conclusion based on the results of this program indicates that it is indeed possible to protect occupants in a very small lightweight vehicle in a crash situation. The work done with in belt inflator shows that effective passive restraint air belt systems are viable and show promise of combining the best features of air bags and belts albeit at a high cost. Further work with the front crush zone suggests that with suitable redesign the aluminum honeycomb may not be necessary. (Fig. 21.)

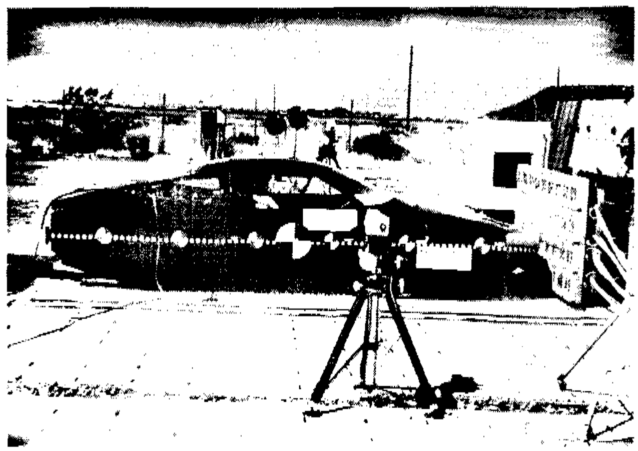

Figure 21. Dynamic science crash test.

Section 4: Panel Discussion on ESV/RSV Development

Mr. John Furness, Chairman, United Kingdom

Panel Member Statements

MICHAEL M. FINKELSTEIN
United States

The purpose of the initial experimental safety vehicle program was to test, on an experimental basis, new ideas of automotive safety incorporated in a vehicle which has been designed, fabricated, and tested as a total system. The basic objectives of the program were to determine the technical feasibility of making significant safety performance improvements in motor vehicles, to stimulate public awareness of the long-term social and economic advantages to be gained from the savings of lives and injuries resulting from advanced auto safety design, to encourage the industry to increase their efforts in auto safety design, and finally, to establish the technical base for the development of improved motor vehicle safety standards. How well have we, this confederation of concerned nations, done in the past 12 years? Have we accomplished our initial objectives, or is there work yet to be done?

I believe this international cooperative program has been perhaps not in the way originally envisioned successful. Automobiles produced today are safer, more fuel efficient, less polluting, and more economical to maintain than those manufactured only a few years ago. Automotive technology has made impressive advances. Questions of how much of this was related to ESV/RSV is a subject that no two individuals would agree on.

The technology of the ESV/RSV includes among other items the relocation of fuel tanks over the rear axle, the integration of restraint systems with structure crash performance, the application of advanced electronics including the miniprocessor, diagnostic displays and information displays, application of lightweight material in improved structures, improved restraint systems, the use of computer simulations of advanced design concepts, the construction of advanced safety testing facilities, and finally the creation of a new awareness of safety performance as a design requirement.

How many of these advances were the product of the ESV/RSV or how much was proved by this project is interesting to consider since we are not able to fully determine sources of technology changes.

Over the years, we have come to know each other better and now work together in cooperative research efforts. We share technical progress through personal contacts and through international forums such as this Conference where we gather to exchange research results and discuss mutual safety problems. Our research and knowledge in automotive safety, like our ESV/RSV performance specifications, have matured and grown. I believe our progress has exceeded our most optimistic expectations of 12 years ago. Indeed, as one participant once stated, "The real result of the ESV program may well be not the questions answered, but the questions asked but yet unanswered."

To try to find answers to the questions yet unanswered we in the United States are in the process of analyzing all available accident data to determine the principal causes of death and injuries in traffic accidents. The results of this analysis in the crashworthiness area have already been presented during the SAE Conference of last February. The same detailed analysis is now in progress for the accident avoidance area, and the results of this work will be presented at the SAE Conference in February/March 1983. The "easy" solutions to improved safety performance are already known and have been or are being implemented. Future improvement will require hard cost/benefit analysis, detailed economic impact analysis, and conclusive research results.

The United States has no near-term plans for the construction of additional complete experimental vehicle systems. Our plans now are, based on the analysis mentioned above, to turn our attention to the subsystems which our analysis has indicated are a major contributor to death and injury. In parallel with this subsystem research we will continue our supporting research in accident data analysis, biomechanics, and human factors. The possibilities for an *immediate* and *dramatic* reduction in traffic fatalities do not exist in the vehicle safety design area but in a change in social behavior patterns such as increased belt usage and a reduction in the number of drunk drivers. These areas are receiving major attention as our highest priority programs.

However, we know that improvements in the safety design of vehicles still require our serious attention: improvements in the front and side structure; improvements in braking and handling, lighting and visibility; improvements in the interior compartment, steering column, and glazing; improvements in restraint systems; further advances in material substitution to reduce weight and improve safety and fuel economy; more incorporation of advanced electronics for improved driver displays, warnings, and improved engine/transmission performance. Improved safety designs in all of these areas and many others can result in a significant contribution to a reduction in deaths and injuries. I personally believe that our knowledge and engineering expertise have advanced to the point where we can accomplish these improvements without weight or fuel economy penalties. Our engineers must be allowed to practice their trade and apply their knowledge.

For the automotive engineer to introduce this new available technology requires serious management support. As new designs are developed in response to consumer demands, many tradeoffs are required. The impact of the introduction of advanced automotive technology is considerable. The manufacturing process must change, new suppliers are required, new test and reliability procedures must be developed to mention only a few; however, in this the space age and in this the safety, environment, and fuel economy age we must accept the challenge. The technology is available; our task is to transfer this technology into production cars.

As we enter this age of the world car, as we fine tune our research programs, and as we work together in this common effort, I believe that the international ESV program was the initiative from which we started and the base from which we can now advance.

Panel Discussion on ESV/RSV Development: Panel member statement for EEVC

PROF. DR. BERTIL ALDMAN
Sweden

The European Experimental Vehicles Committee has followed closely and with great interest the ESV/RSV programme in all its phases of development. Over the years it has been possible to note how the basic philosophy behind this programme has gradually penetrated into the general discussions among legislators, car manufacturers, and researchers in Europe. Of particular interest in this context is of course the principle that safety should be built into cars from the beginning and not added afterwards.

Traditionally in Europe a number of regulations and directives have been applied, which have mainly been design or construction standards often related to component testing. During the last decade, however, attempts have been made to arrive at performance standards with a more global concept of the vehicle, its occupants, and other road users.

When EEVC in 1974 presented its report "The Future for Car Safety in Europe" at the fifth ESV Conference in London the basic approach was that eventually a few full scale car tests should be used to demonstrate that a desired level of safety for the occupants had been achieved. The approval would be based upon a set of requirements related to human tolerance levels and the kinematic response of appropriate anthropomorphic test dummies.

However, a working group, set up by EEVC, presented a report at the sixth ESV Conference which revealed gaps in the knowledge of biomechanics and lack of biofidelity in current test dummies. EEVC then aided the Commission of the European Economic Community in setting up a coherent Biomechanics Programme to tackle these problems. It has monitored very closely the realization of this programme and in particular that part of it which has dealt with the closing of the gaps in our knowledge about human tolerance levels.

For the development of a suitable side impact dummy intended for legislative testing and for research puproses EEVC formed an ad hoc group with the responsibility to draft desirable requirements and lay down provisional performance specifications for such a dummy. Liaison was established with NHTSA and the group monitored the development work carried out within the framework of the EEC Biomechanics Programme. The work resulted in a number of new dummies whose components interface with contiguous parts of the Hybrid II dummy. This enabled comparative testing of one American and three

European complete side impact dummies to be carried out. It is expected that this ongoing project will eventually lead to the formulation of an acceptable performance specification for a side impact dummy to be used for legislative purposes.

Two other EEVC working groups, reporting at this conference, have addressed the problem of testing to check occupant protection in side impacts and the protection of pedestrians when impacted by the front structures of cars. These problems will continue to be monitored by the committee through its working groups. It is hoped that more light will be shed on the problem of optimizing the frontal car structures to reduce their aggressivity in pedestrian collisions and to increase their compatibility with other cars in side impacts. The results are not expected to be available until late 1983 and late 1984 respectively.

Over the last few years many countries in Europe have seen a considerable increase in the number and usage of bicycles. Many of these are lighter and capable of higher speeds than earlier models were. This creates more conflicts with other road user categories. The most frequent serious accidents for two-wheelers being those where an impact with a car takes place. At the initiative of The Netherlands the EEVC main committee recently decided to set up a new working group to tackle the safety of bicycles and in particular this problem. The group will mainly be concerned with bicycles and the light type of mopeds which resemble bicycles in their main construction. Heavier mopeds and motorcycles will not be studied by this group.

The task of the group will be to study available data on accidents and injuries to riders of light two-wheelers in Europe. Particular interest should be given to the sex and age distribution of the victims since bicycles are becoming more popular to adults than they used to be. The group shall make recommendations including priorities for action for bicycles and the vehicles striking them in order to reduce the severity of such accidents and injuries. The group itself will give priority to the possible influence on the safety of bicyclists from certain already proposed measures, so that changes to the car can be considered with respect to the benefit of all non-occupant road users as well as to the occupants of the vehicle. It is expected that the results from these studies will be available in 1984.

During the period of time over which the ESV/RSV programme has developed into its present state, it has been of great interest to watch how the concern of researchers, car manufacturers, and legislators in Europe gradually has changed. It has turned from components for safety, such as the safety belt or the air bag, to larger systems including seats and other structures in the car. In this context also luggage and fellow occupants are of interest as interaction may occur in some types of accidents. Finally the entire vehicle has been taken into consideration not only in a few specified situations but in all its aspects of safety in a variety of accident situations for both occupants and other road users. The interest also embraces the normal driving conditions where problems related to fuel conservation and reduction of noise and pollution are being discussed.

The EEVC sees this as a logical line of development for Europe and the lead times necessary for the car manufacturers to make their products conform with the new ideas have to be added to those needed for the researchers and the testing institutes who have to learn to handle the more complex test situations. In this latter context the ESV/RSV programme has been beneficial to all concerned in this field.

Panel Statement ESV/RSV Development

P. VON MANTEUFFEL
Federal Republic of Germany

This morning members of the German delegation reported on our recent research car project. Other reports by our delegation will cover work in the areas of side collisions, field performance of an automatic restraint system, modifications of an integrated research vehicle for improved crashworthiness, a statistical analysis of the influence of vehicle size on safety, injury risks at higher test speeds as well as questions of terminology and definitions of passive safety and compatibility.

Besides the work to enhance safety within the individual companies themselves German car manufacturers and some vendors have combined their research efforts and—some ten years ago—formed the "Research Association on Automobile Technology (FAT)."

Of the 24 reports on research projects hitherto published, 11 deal with various aspects of automotive and traffic safety. One of our speakers here in Kyoto will report on the status of a particular project dealing with dummy/cadaver comparison in head-on collisions.

For our following panel discussion I would like to raise a few topics of general interest, and I shall put them forth partly in the form of a hypothesis.

1. Hypothesis No. 1 is the following: The decade of spectacular presentations of complete ESVs/RSVs is over.

Insight into the technological means to improve particularly passive safety has been tremendous. In this respect I agree completely with Mike Finkelstein. Actual safety progress on production cars, however—working under the constraint of cost/benefit aspects—is harder to achieve. Is this so?

2. My second hypothesis offered for discussion is as follows: The days of safety devices with high benefit/cost ratios on production cars (such as the safety belt) are over. Air bags and antilock brake systems are much more expensive and statistically less effective. Would you agree, then, that safety progress on production cars can be expected to gently level off, that technical improvements will, in future, rather have to rely on the effects of many detail advancements?
3. Harmonization/Trade Barriers:
   One of the most important aspects in international automobile design, manufacture, and trade is the harmonization of regulations. We welcome particularly the positive attitude which NHTSA is taking toward this common goal. At the same time industry cannot be content with the actual progress achieved in this field as of today.
   In spite of these efforts, the tendency to invent new automobile regulations and approval methods thus obstructing trade is, in many countries, increasing. How can we create a forum for a broad harmonization program?
4. Another subject I would like to offer for discussion is the minimum/maximum philosophy of standards which to me seems endangered. Generally, in a given testing discipline, either a certain minimum value must be reached or exceeded, or a certain maximum value may not be exceeded.
   A heavy strike against the basics of this philosophy was, in my opinion, the 35 mph crash test program in the U.S. Similar elements of violation of the minimum/maximum philosophy can today be found elsewhere, also in Germany.
   I believe it is important to accept the fact that a maximum standard is simply an upper limit. Engineers create different technical solutions which give certain performance readings below the limit value thus introducing the element of competition. From there on market forces should take over. I frankly believe that unless this is recognized, the maximum/minimum philosophy of setting standards is endangered.
5. Fifth, I should like to touch upon the question of how to continue these ESV conferences.
   As much as we see these conferences as a forum to exchange views between government and industry of various nations, and because our delegation has always contributed very actively to this exchange, we dare to appeal to this assembly to discuss its own future plans.
   If it is true that the years of design of complete ESVs are over, and this was my first hypothesis, should we not contemplate to reorganize this exchange of views by embedding the reports on safety work into other existing regular conferences (such as, for example, next week's FISITA) where safety is regularly on the agenda?
   Again I say this not without bowing before DOT/NHTSA and our Japanese hosts for staging this and the preceding conferences.

Our efforts for safer road vehicles must not be regarded as the one and only means to improve road safety. Driver behavior, improved roads, and organization of traffic are other important factors. A concerted safety effort requires careful assessment of all factors, including the driver, in a totalistic approach.

Most important of all we must increase the general public awareness of road safety aspects. In Germany, unfortunately, some people presently seem to be more concerned about 11,000 trees when an airport runway or a road is to be built than about 11,000 road fatalities.

Finally, let me close with a request to our Japanese panel member, Goto-san, to please, if appropriate, describe the key elements of the highly successful Japanese road safety program.

Thank you for your patience.

Panel Statement on ESV/RSV Development

I. D. NEILSON
United Kingdom

In the United Kingdom the distribution of fatalities in road accidents is different from that for many other countries. Under 40% are killed in cars, whilst pedestrians account for 33%, and pedal and motor cyclists 25%. About 14% of fatalities are in accidents involving a Heavy Goods Vehicle. The relatively high numbers of motorcyclist casualties and of accidents involving Heavy Goods Vehicles are the reasons why safety developments for these vehicles have been studied for some years. There have been both a UK demonstration safety motorcycle and an articulated vehicle. It is good to be able to report that there have been many positive results from these developments. Sintered pads for disc brakes for motorcycles are now in large scale production. Antilock brakes are almost developed for motorcycles and are being increasingly adopted for both the semi-trailers and the tractor units of articulated vehicles. Two-wheeler riders are becoming increasingly conscious of the need to use lights or wear conspicuous garments. Heavy Goods Vehicles will be required to have sideguards and underrun protection at the rear, and a standard for spray suppression is being discussed urgently in the British Standards Institution which it is intended will become mandatory if a satisfactory conclusion is reached.

There has been little obvious progress towards improving the safety of cars but research and development for cars as well as for other vehicles is continuing in the United Kingdom. An impetus is being given by the belated introduction of the compulsory wearing of seat belts and of restrictions on the positioning of unrestrained children. We are glad that the long development of child safety seats and related items has been recognized by one of the NHTSA Awards at this Conference.

Looking to the future, one outcome of all the work on vehicle safety Research and Development seems likely to be the adoption of antilock braking for motorcycles as well as for articulated vehicles. Car design will incorporate protection for pedestrians as well as for occupants in side impacts. Protection of the occupants of small cars in frontal impacts can be improved but the will to do so is required. The present question for vehicle safety legislation is whether progress can be made by updating current minimum standards or whether Crashworthiness Ratings of cars can be introduced to the extent that car purchasers consider the quality of the safety offered in the new cars available to them. If so, they would encourage improved safety through the pressures of the market place.

Panel Discussion on ESV/RSV Development

ENZO FRANCHINI,
Italy

The ESV program has developed through distinct phases that have assumed different characteristics over the years.

- —The first phase began with the definition of an experimental safety vehicle that would meet extremely severe requirements. On the one hand it led to models not suitable for production and moreover excessively heavy; on the other hand to Fiat ESVs having a limited weight but a cost increased by 40 per cent.
- —The second phase defined a research safety vehicle with less severe requirements aiming at its producibility. Even if less heavy models were developed, in the light of the 1973 energy crisis weight and consumption resulted to be prohibitive.
- —The third phase has begun in the recent past in which the energy crisis, combined with the economic crisis, has put industries, in particular the automobile industry, in serious difficulties.

These difficulties concern numbers of interacting problems such as consumption reduction (hence energy waste), weight reduction (hence cost), low pollution and acceptable safety.

The solution lies in innovation. Innovation in structure and engine design, materials and electronics applied to motorcar, production technology.

Today the automobile industry is making extensive research and investing large amounts of money in those fields. The recent Italian accomplishments, Fiat VSS and Alfa Romeo Svar, are mentioned in the Italian Government status report.

Industry's efforts call for cooperation by governments in the field of economics and in the field of regulations. These must be such as not to cause disadvantages in certain areas (e.g., weight, consumption, cost) with the purpose of giving advantages in others (e.g., pollution and safety). Regulations must not be antithetical in their aims, but it is necessary that they have a realistic and thought-out basis.

Panel Discussion on ESV/RSV Development

DOMINQUE CESARI,
France

During the last decade, the number of traffic accident victims decreased while the vehicle miles traveled increased. A great part of this improvement is certainly due to consequences of ESV/RSV program which allowed the rapid introduction of safety research results into production cars.

However, traffic accidents still remain a serious problem for the industrialized countries; and it is, therefore, necessary to continue our research efforts to reduce their very serious consequences.

Future programs should mainly address specific improvements in subsystems without necessarily developing complete prototypes of full scale cars. The field of work is extremely broad, and I would now like to discuss the topics which we feel are most important.

The French Government recently decided to set up an accident investigation program which would deal with severe and fatal traffic accidents. This program will be principally concerned with vehicle crashes in the field of active safety.

During the past few years, car design has been improved to reduce fuel consumption. In this connection, there are in France at this moment two projects for the design of cars which use less than 3 liters of gasoline to travel 100 kilometers. These cars will have interior space similar to present cars, but they will be much lighter. Due to the importance of the loading of these cars compared to their curb weight, it is necessary to accomplish the gain in fuel consumption without decreasing their safety performance.

In the same way, the manufacture of future cars will more and more involve new materials. These new materials have a behavior during impact which is not fully understood. This behavior must be determined to establish protection levels for occupants and other road users.

France has participated in the establishment of an integrated test procedure for frontal impact and contributed to the definition of a test procedure for side impact proposed by the European Experimental Vehicles Committee. The results of this work will be presented during this Conference. We think that an integrated test procedure is a good way to improve the safety of cars; however, there are problems with its applications which must be resolved.

In the same field, it would be interesting to make an evaluation of the gain in safety as a result of the integrated test procedure in frontal impact. The problems in dealing with integrated tests concern the behavior of dummy improvements, and improvements in our knowledge of injury mechanisms and human tolerance in order to choose realistic protection criteria.

Another specific improvement one can think of is restraint systems design. The protection offered by safety belts could be increased by improving their performances during accidents and by increasing their acceptability to users.

In the field of side impact protection, injury mechanisms are presently known and specific solutions are proposed by the car industry, but evaluation methods are still uncertain.

Finally we think that international cooperation is necessary to proceed more quickly and more efficiently. This is especially true in the field of biomechanical research and dummy improvement.

Panel Statement: A Future Plan for the ESV/RSV Program

KENICHI GOTO,
Japan

I have the pleasure of speaking to you about my private views on the future plans for the ESV and RSV program. In the first place, it is necessary to review the progress of the program to date. The development of Experimental Safety Vehicles began in 1970 with the announcement of the ESV program. Although there might be some debatable points, I think that the specifications were epochmaking in the safety design of vehicles. In order to satisfy these specifications, auto manufacturers in the participating countries, after major design efforts, finished the evaluation tests of ESV's in 1974. It should be pointed out, however, that the manufacturers could not develop safety vehicles capable of fully meeting all the safety requirements. The major question pertained to body weight. Vehicle weight had to be increased to reinforce structure strength. An alternative solution was conceived to the effect that impact energy could be absorbed by the vehicle body without reinforcing the structure strength. The design characteristics of the past which put emphasis on improving operational durability on bad roads were advanced taking into consideration the absorption of impact energy. This was a great achievement of the ESV program.

Based on the results of ESV program, the RSV program was initiated to develop a production car applicable to the mid-1980's. The results of this program have been presented during the Eighth and current Ninth ESV Conferences. I have some doubts about the success of the RSV program. I suppose that the types of vehicle produced after Phase 2 were developed by putting emphasis on the specifications for crashworthiness. Such a vehicle should not be evaluated as a model of production cars for the mid-1980's. In my opinion, the RSV program was not successful, whereas the ESV program was successful.

The IVS program was introduced as a follow-on program to ESV and RSV. The current status of this program is unknown. My comments on the IVS program are that it should not aim at developing a safety vehicle but at developing a vehicle of the future. Automobiles should be designed on a well balanced basis covering all requirements, not just safety. The IVS program calls for more specification items than for the RSV. I assume that the large manufacturers are obliged to develop and complete an IVS. Furthermore, they have to expedite the development of their own production models capable of competing in the current innovative age. In these circumstances, manufacturers may be reluctant to develop an IVS. Then, what should we do? I would like to suggest that fundamental studies on problems relating to safety be encouraged. Although it is attractive work to complete an IVS as early as possible, I fear that the RSV program experience may be repeated.

I have two concerns regarding the IVS program. The first concern is that the program supports rulemaking and the other concern is that the program still places emphasis on vehicle performance during collision. As to the first concern, I understand that rulemaking is an easy way to enforce the application of safety requirements. The manufacturers are not in a position to easily adopt safety devices since these devices are difficult to market. However, the persons engaging in safety problem have as their final object the reduction of injuries in vehicle accidents and not in rulemaking. My second concern addresses the possibility of the occurrence of an accident where crashworthiness is required. With these points in mind, I would like to stress that accident prevention should be emphasized rather than crashworthiness. I agree with the current NHTSA program addressing the prevention of accidents involving drunk drivers. As is often pointed out, the safety problem consists of the automobile, the human, and the environment. In consideration of what is most important in these factors, I would like to say that emphasis should also be placed on the other problems relating to the automobile.

The best way to reduce injuries in vehicle accidents is to investigate the causes of accidents and then to find a way to remove the causes.

In conclusion, I propose that if we are to continue the International Technical Conference on ESVs hereafter, the first thing we should do is to clarify the role of these conferences and change the name to the International Technical Conference on Automotive Safety. Thank you.