REPORT ON THE SECOND INTERNATIONAL TECHNICAL CONFERENCE ON EXPERIMENTAL SAFETY VEHICLES

SINDELFINGEN, GERMANY: OCT. 26TH THRU 29TH, 1971

DEPARTMENT OF TRANSPORTATION National Highway Traffic Safety Administration

SECOND INTERNATIONAL ESV CONFERENCE

Report on the Second International Technical Conference on Experimental Safety Vehicles

NATO CDSM

OTAN CCMS

Sponsor: U.S. Department of Transportation
Hosts: The Government of the Federal Republic of Germany
The Daimler Benz A.G.
Held at: The Stadthalle
Sindelfingen, Germany
October 26-29, 1971

DEPARTMENT OF TRANSPORTATION

National Highway
Traffic Safety
Administration

THE SECRETARY OF TRANSPORTATION
WASHINGTON, D.C. 20590

OCT 25 1971

Ladies and Gentlemen:

I am happy to welcome you to the Second International Technical Conference on Experimental Safety Vehicles which is being hosted by the Federal Minister of Transport Georg Leber. I hope your stay will be both a pleasant and a rewarding one.

The enclosed agenda and list of conference participants indicate that the material to be presented and the discussions to follow should be extremely informative and interesting. Indeed, assembled here in Stuttgart for this conference are the world's foremost automotive engineers devoting their attention specifically to the development of safer automobiles. I congratulate you for your membership in such a distinguished group.

For the ladies that may be accompanying, Daimler-Benz, which has offered its facilities for the conference and helped us arrange so many important details, has also included an excellent program which we are sure will prove enjoyable and entertaining.

Again, I extend a welcome and look forward to meeting with each of you during the conference.

John Volpe

G r u ß w o r t

Verehrte Teilnehmer
an der Zweiten Internationalen Technischen Konferenz über Experimentier-Sicherheitsfahrzeuge in Stuttgart!

Die Sicherheit des Straßenverkehrs ist eine der großen Sorgen, die jeden Verkehrsminister bewegt. Ich begrüße es daher sehr, daß einer der Hauptfaktoren des Unfallgeschehens, der Personenkraftwagen, hier an seiner Wiegestätte hinsichtlich der Erfordernisse, die heute an seine Sicherheit zu stellen sind, neu überdacht wird. Ich verspreche mir von dieser fachlich bedeutsamen Konferenz wertvolle neue Erkenntnisse über das zur durchgreifenden Erhöhung der Sicherheit des Automobils technisch Notwendige und wirtschaftlich Mögliche.

Der National Highway Traffic Safety Administration im Verkehrsministerium der Vereinigten Staaten von Amerika danke ich für die fachliche Ausgestaltung der Konferenz, der Daimler Benz AG für die ausgezeichnete Vorbereitung und Durchführung.

Ich wünsche der Konferenz einen fruchtbaren Verlauf und allen Teilnehmern neben fachlichem Gewinn einen angenehmen Aufenthalt im Schwabenland.

Georg Leber
Bundesminister für Verkehr
und für das Post u. Fernmeldewesen

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Foreword

This report of the proceedings of the Second International Technical Conference on Experimental Safety Vehicles was prepared by the Office of Experimental Safety Vehicle Programs, National Highway Traffic Safety Administration, United States Department of Transportation.

The report includes the conference opening remarks, status reports by governmental representatives, the formal technical presentations by the automotive industries participating, the technical papers presented during the parallel seminars on "Crashworthiness" and "Accident Avoidance," and summations and concluding remarks by the United States and the Federal Republic of Germany.

For clarity and because of some translation difficulties a certain amount of editing was necessary. Apologies are therefore offered where the transcription is not exact.

Agenda

Tuesday, October 26	0830-0930	Registration at Stadthalle
	0930-1015	Conference Opening
	1015-1130	Reports by Governmental representatives on the nature, scope and status of their ESV programs: United States Germany Japan United Kingdom Italy France Netherlands Sweden Belgium
	1130-1200	Transfer from the Stadthalle to the Daimler-Benz A.G. Plant — Sindelfingen
	1200-1300	Inspection of exhibits (building 18)
	1300-1400	Luncheon at Daimler-Benz
	1400-1430	Return to the Stadthalle
	1430-1530	U.S. Technical Presentation, Part I — Fairchild Industries
	1530-1630	U.S. Technical Presentation, Part II — AMF Incorporated
	1630-1730	Question and Answer Period
	1730-1800	Press Conference
	1800-1900	Reception — Stadthalle, Sindelfingen Hosted by the United States
Wednesday, October 27	0900-1000	U.S. Technical Presentation, Part III — General Motors Corporation
	1000-1100	U.S. Technical Presentation, Part IV — Ford Motor Company
	1100-1230	Technical Presentation, Federal Republic of Germany
	1230-1400	Luncheon at Stadthalle, Sindelfingen
	1400-1500	Technical Presentation, United Kingdom
	1500-1630	Technical Presentation, Japan
	1630-1730	Question and Answer Period
	2000	Daimler-Benz A.G. Reception at Ludwigsburg Castle

Thursday, October 28	0900-1030	Technical Presentation, Italy
	1030-1130	Technical Presentation, France
	1130-1230	Other Technical Presentations
	1230-1300	Discussion
	1300-1430	Luncheon – Stadthalle, Sindelfingen
	1430-1800	PARALLEL SEMINARS
		Crashworthiness Seminar
		(Detailed agenda to be provided at conference)
		Accident Avoidance Seminar
		(Detailed agenda to be provided at conference)
	1800-1900	Reception – Stadthalle, Sindelfingen
		Hosted by the Federal Republic of Germany
Friday, October 29	1000-1030	Summation, Crashworthiness Seminar
	1030-1100	Summation, Accident Avoidance Seminar
	1100-1130	Concluding Remarks:
		United States
		Federal Republic of Germany
	1200-1300	Luncheon – Stadthalle, Sindelfingen

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SECTION 1

PART 1 CONFERENCE OPENING

INTRODUCTION BY THE CHAIRMAN OF THE SECOND INTERNATIONAL TECHNICAL CONFERENCE ON EXPERIMENTAL SAFETY VEHICLES

MR. JOHN A. EDWARDS

Associate Administrator for Research and Development
National Highway Traffic Safety Administration
United States Department of Transportation

Good morning ladies and gentlemen, it is my pleasure to serve as your chairman for this Second International Technical Conference on Experimental Safety Vehicles. To open our meeting it is my honor to introduce our host Dr. Joachim Zahn, Chairman of the Executive Board, Daimler-Benz Company.

SECTION 1

PART 2 INTRODUCTORY REMARKS

DR. JOACHIM ZAHN

Chairman of the Executive Board,
the Daimler-Benz Company

Mr. Secretary,
Herr Minister,
Dr. Randers,
Ladies and Gentlemen,

I should like to welcome you most cordially to Sindelfingen, a town whose history dates back for centuries, and a town whose name has for many years now been associated with the automobile. We felt it was a great honor, not only for Sindelfingen, but also for us, when we heard that the German Ministry of Transport and the U.S. Department of Transportation had selected Sindelfingen as the location for this conference.

We of the house of Daimler-Benz were all the more pleased to help with the arrangements for the conference, since as you know, safety has been one of the primary and guiding principles of our work for many years – and a great deal of that work has gone on right here in Sindelfingen.

It is also a special pleasure for me to welcome the international automobile industry, as well as the many members of the press corps. I would like to thank all of you for accepting the invitation.

You are here today as the world's leading automotive authorities, and you are here to discuss a subject which is one of the great challenges confronting society.

There are two aspects of this conference which I would particularly like to mention in the time available to me:

First, I find it a welcome state of affairs when representatives of many governments can sit together with private industry, at the invitation of two of the governments, to work out – or at least to take the preliminary steps toward – joint solutions in an atmosphere of international cooperation.

These solutions can provide the basis for the legislation in an area which is so vital to our industry – and even more important, is so vital to those persons who use our products.

Furthermore, it seems indeed significant that such a large number of experts from the fields of both science and industry are gathered here. Because we are here for a task which extends far beyond the economic and technical goals of the usual kind.

The basic subject of this conference is the safety of the automobile. I believe I can say at this time – and this conference is living proof of what I am saying – that the world's automotive industry is ready and willing to help find the answer to the problems involved, even though it is aware of the fact that this can only be accomplished with great financial involvement.

The subject of automotive safety has met with great response, indeed at times with a great emotional response, from the public. Many critical opinions have been voiced on the subject of motorization as such, but at the same time, the development of individual transportation has been regarded as a symbol of progress and proof of a higher standard of living.

The specific subject of this conference deals with what is without a doubt one of the critical aspects of the automobile as a product of modern technology. The question of safety is one of a general complex of problems which sets tasks of the first order for all of us who are concerned with this product.

The task which is set for us here is to find the most comprehensive solutions: that is, to find the most favorable solutions in the sense of a synthesis of what is necessary or desirable in the field of safety, what is technically feasible within reasonable means, and what is also economically justifiable.

One question which is bound to assume considerable significance in this and other conferences to come is that of manufacturing automobiles which will be safe, yet at the same time will remain within the economic reach of all people. This is an aspect of high social significance.

The gentlemen of the automobile industry who are present here and who are personally engaged with the problem of safety will appreciate the fact that we are all endeavoring to find solutions. We are trying, free of emotions and on the basis of rational research and precise scientific knowledge, to find solutions which are technically feasible and attainable within a reasonable period of time. These are goals to be fitted into an over-all technical concept. For I am certain that proposing goals which would prove unfeasible or which might result in negative effects in other fields would not serve our common aims.

It is in our common interest to set goals and deadlines which promote our aims in the long run, and thereby avoid setbacks which could also possibly discredit our efforts.

At a time when in many cases in the field of international trade a trend towards disintegration has become apparent, the international character of this conference is something to be particularly welcomed, and I am sure it has been greeted by everyone in our industry. This also holds true from an economic point of view, for not only has the automobile contributed toward promoting world trade, but by stimulating competition it has contributed to the general prosperity. But worldwide competition, if it is to continue, is only possible if exchange of technical know-how and equal starting conditions continue to exist.

This applies not only in the economic sense, but also in the technological when we consider the extreme importance the subject of safety will have for our entire future technological development.

I should therefore again like to thank the governments represented here for their initiative in tackling this problem, which concerns us all, as a joint effort. I once again extend a cordial welcome to all of you and I hope that your work here will be fruitful.

DR. GUNNAR RANDERS

Assistant Secretary General and Chairman of the Committee on Challenges of Modern Society, CCMS, NATO

NATO's CCMS will be celebrating the second anniversary of its creation next week. This is not ordinarily a long time in the history of an international organisation. It is the time usually needed for decorating the headquarters, appointing the key staff, moving into the new buildings, and hoisting the flags outside. The CCMS – the Committee on the Challenges of Modern Society – does not have headquarters. It also has no staff. The two years could therefore not be used for building headquarters and appointing staff. Instead, there exist today half a dozen living and active projects attacking specially-selected problems which threaten to destroy the pleasure and satisfaction of living in a highly developed society in an age of advanced technology. These half a dozen projects show that it is possible to work internationally in a new fashion, different from the old concept of international organisations, which necessarily seemed to imply bureaucracy and formality.

It may sound as a sad complaint when I say that the CCMS has no headquarters and no staff. However, it is the result of a well-designed policy. Experience over many years of international cooperation in the world has shown that the best substantive work in technology as well as in fields of research and development is done by national institutions and national laboratories. The idea of a modern international collaboration is therefore not to replace or duplicate national work, but to induce nations themselves to combine their abilities and coordinate the work of their institutions. In the CCMS, this procedure is called the pilot country approach. As most of you know, this means that each subject which is attacked by the CCMS, will have to be undertaken with one nation as the responsible leader. This pilot nation has the responsibility for the preparatory work and all possible studies that are necessary before a recommendation is formally brought to the Committee itself. The studies, the research, the regional specialist meetings, the report writing – all of this must be organised by the pilot nation. Since the pilot nation task is a voluntary task by the nation, one is always sure that interest and drive are present in the leadership. Our meeting here today is a typical example of this drive and leadership.

Eighteen months ago we had one of the first big international pilot project meetings in Milford, Michigan. This meeting was also devoted to the safety of automobiles, and at that meeting I had the pleasure, for the first time, of meeting Secretary Volpe of the US Department of Transportation. At the time, the CCMS was only a few months old and it was necessary for Secretary Volpe to explain carefully to the audience the strong support which the U.S. President gave to the work of the CCMS and to express the wish that it would be possible for an organisation like NATO to do useful work in a field which is normally considered rather different from the ordinary field of work of that organisation. It was also necessary for myself to explain why and how NATO was being used, together with other international organisations, in order to improve the deteriorating conditions which we are facing in the daily lives of human beings in the advanced world. Today, I believe, it is unnecessary to repeat both the fact that there is support for the CCMS and the explanations for why NATO can do certain things more rapidly and efficiently than many other organisations. In the meantime, most people have seen a rather surprising growth of activities, including preparations for air pollution management in Ankara, Frankfurt and St. Louis, agreement on ending of oil spills in the oceans, recommendations on flood control measures, earth quake protection, and design of pollution-free automobile engines. The speed with which these projects have grown and the determination with which they are pursued, have made people aware of the CCMS during this short period to the extent that it is today undoubtedly considered one of the most active agents in this area in our part of the world.

The agenda of the present meeting reminds one at first sight of a meeting of a sub-committee of the UN. Nine nations are giving reports on the work of their experimental safety vehicles. There are two striking features in this agenda: one is that the question of safety of automobiles is looked upon for the first time from a completely different philosophical angle than before. At earlier times, safety was something which was added here and there after cars were designed for beauty, sales appeal and speed. The philosophy of the present project is to begin with safety, and then find out whether the car can move and whether it can be sold. I have heard that the participants in this action are of the opinion that it should well be possible to combine these features. The other striking fact is that these problems are attacked by all the major automobile manufacturing industries simultaneously and jointly. This is what makes the approach dead serious, because however good intentions one may have, hardly anything could come out of safety features which would be adopted only in one country without regard to the fine balance of competitiveness between nations.

The safety car project has a third peculiarity: as a major ingredient in the road safety pilot project it has pioneered a new type of pilot nation procedure, namely one in which the results of the undertaking may very well appear in practice before any recommendations are brought formally before the CCMS and the NATO Council. Since the actively-interested members of the automobile industry and the governmental representatives of transportation ministries take part already at the pilot project stage, it is highly likely that the desired improvements will be brought about as a direct result of the pilot development itself, and that it will be quite unnecessary to wait for formal agreements in the NATO Council. This is one of the valuable contributions which the leaders of the Road Safety project has made to the whole CCMS, and by this they have helped not only progress in their own field, but indirectly in many of the other fields of work of the CCMS. On behalf of NATO and the CCMS I want to express our satisfaction and gratitude with the way this project is being advanced.

THE HONORABLE JOHN A. VOLPE

Secretary,
United States Department of Transportation

Today marks the start of the Second International Technical Conference on Experimental Safety Vehicles.

The purpose is clear – to stimulate the design and development of safer vehicles. The need is also clear, painfully so – to stem the continuing tragedy of traffic deaths, crippling, and costly destruction of property in absolutely senseless crashes on highways throughout the world.

And the response to this need here in Stuttgart is most gratifying, with hundreds of the world's leading automotive engineers assembled to describe progress and exchange viewpoints on this one theme of how to design vehicles with the saving of life principally in mind.

This meeting relates to a number of bi-lateral co-operative agreements on ESV development which I have had the privilege of signing this past year with the Federal Republic of Germany, Japan, United Kingdom, Italy, and, most recently, France. All are of vital importance in pursuing our common goal of safer vehicles. The first such agreement was signed by me and my very good friend Minister Georg Leber in Bonn, not quite a year ago. I might note – if you will allow me a brief informality – that both Minister Leber and I are former bricklayers. So it is appropriate that the two of us were involved in "placing the foundation" for international ESV agreements. My Government is indebted to the Federal Republic of Germany, not only as the host of this fine meeting, but also our first ESV partner.

Each of the bi-lateral agreements is, of course, on a government to government basis with every government backed up by its automotive industry. In our case, I am proud of the support we are receiving from our fine ESV contractors in the United States – Fairchild Industries, American Machine and Foundry, General Motors, and Ford Motor Company. I also recognize the support that other nations are receiving from their companies. Today, our thanks go to the German automotive industry, Daimler-Benz in particular, for providing these magnificent facilities and the other arrangements for the Conference.

We could hardly start this meeting on cooperative ESV developments without mentioning that it is a vital part of our Road Safety Pilot Study for NATO's Committee on the Challenges of Modern Society. However, our pilot study includes a number of other projects which also demonstrate the broad scope of cooperation and international interest in road safety.

– *Canada* is leading our project in alcohol and driving safety.

– *The Netherlands* is leading the accident investigation project.

– *Italy* is directing the effort on emergency medical response to aid traffic victims.

– *France* is heading the work on road hazard identification and correction.

– *The Federal Republic of Germany* is leading the motor vehicle inspection project.

– *Belgium* has recently started work on pedestrian safety.

I am no less gratified by the broad range of leadership and participation in these other safety projects in our CCMS pilot study as I am with the support of ESV developments.

The Road Safety Pilot Study itself is only one of a number of CCMS pilot studies. Others – headed by various NATO Allies – are directed at a broad array of environmental matters: inland water pollution, ocean pollution, air pollution, disaster assistance, work satisfaction in a technological era, scientific knowledge and decision making, environment and the study of regional development, cities and urban transportation. Last year, in Brussels, it was my privilege to present a resolution on behalf of my Government aimed at eliminating ocean pollution from intentional oil spills. We are delighted that the recommendations were approved and that this serious threat to the environment will be abated.

All of this activity stems from a proposal by President Nixon, less than four months after he took office, that NATO broaden its programs to environmental and social problems. The far-ranging interest in solving environmental problems generated by CCMS in less than two years after NATO acted on the President's bold suggestion is almost unparalleled in the operation of multilateral forums. It demonstrates that the modern industrialized nations **can** work together effectively and rapidly on environmental problems that challenge us all.

Which leads me back to the subject of our Conference today.

I consider the ESV program an excellent opportunity for modern automotive technology and engineering know-how. It shows what can be done to produce safer designs. The blunt challenge that participating governments have posed to their automotive industries is simply put: "What can you do to design a really safe car if, from the very start of the design thinking, safety is the over-riding goal?"

The challenge, however, goes far beyond safety. "Can you design – from the ground up – a car that meets very high levels of safety and still have good engine performance, low exhaust emissions, attractive styling, and, above all, be adaptable into mass production vehicles at a price that people can afford to pay?"

The last issue – the price that people can afford to pay – is particularly important to me. As I have said over and over again, and repeat here – **safety must never become a luxury item available only to the rich.**

These are only a few of the technical dimensions of the challenge. I am sure that you have already encountered many more in coming to grips with the actual design of an ESV as a total system. I trust that these will be fully discussed in the next several days here.

There is still another type of challenge to be met in this worldwide program of ESV developments. This is how best to accomplish the rapid exchange of ESV technology and the lessons learned throughout. All of us are dedicated to saving lives through safer vehicle design. But it would be naive to fail to recognize as well the economic overtones in the ESV programs. My Government, for one, fully intends to have the ESV's lead the way to higher levels of safety in **production** vehicles. Thus, we recognize the difficult problem of ESV manufacturers, even under contracts to their governments, in deciding how best to exchange ESV technology with others and not compromise their competitive positions in the near-term marketplace.

I do not believe that there are any clear cut answers here, but it is my hope that out of the cooperative ESV programs sponsored by governments, methods will evolve for exchanging new safety developments far more rapidly than now is accomplished in the purely industrial operations in the commercial marketplace.

In this regard, I am pleased to learn from Doug Toms' fine staff of engineers representing my Nation in the international ESV program, that even in the short time that these programs have been in effect, there has been a marked increase in the openness of the information exchange. This will be clearly demonstrated here in the next several days.

I am sure that even more openness in information exchange will be apparent when the Third International ESV Conference takes place. I am especially pleased to announce that this will take place in June of 1972 in conjunction with the U.S. International Transportation Exposition, Transpo 72 to be held at Dulles International Airport near Washington, D.C.

In these technical conferences and in the exchange of engineering plant visits, joint observation of testing programs, and possible exchange of prototype vehicles, we are charting new methods for more rapidly sharing our separate advances in vehicle safety. But even as we thus broaden the scope of international cooperation in ESV developments, I can assure you that we continue to fully subscribe to the free enterprise system, highlighted by intensive competition with appropriate economic rewards for the winners. As described in the guidelines that I, with a support opinion from our Attorney General, have announced, we want to promote intensive competition in the early stages of seeking new safety breakthroughs, but we also want equally intensive cooperation in sharing the new technology as rapidly as it develops, and in full detail as well.

I cannot overemphasize the importance that my Government places upon a full, two-way exchange of ESV information. Toward this end, we recently established a public information file through which the latest ESV technological advances will be made available to anyone interested in the development of safer vehicles. All information will be placed in this ESV public file as soon as my Department receives it, unless specifically forbidden to do so by the manufacturers or the foreign governments supplying this information. Necessary measures will be taken for the protection of patent rights that result from the ESV programs. I call upon all participating governments to join us in persuading everyone working on new ESV safety developments to make the results of their progress publicly available as rapidly as possible.

Thus, the United States policy in the international ESV program focuses on three major objectives:

– To stimulate the development of new vehicle safety technology.

– To promote full cooperation in sharing the new technology on a continuing basis as rapidly as it develops, and

– To incorporate the safety features demonstrated by the prototype ESV's into requirements for mass production vehicles that reflect worldwide needs and research experience.

This is a competition in the fullest sense of the word.

But it is a competition of worldwide automotive engineering skills and talent aligned on one side against a common foe of death and destruction on all of our highways.

Working together in the fine spirit of cooperation shown in this meeting, I am confident that we will win.

Thank you.

THE HONORABLE GEORG LEBER

Bundis-Minister of Transport, Federal Republic of Germany

This conference, which begins today here in Stuttgart, brings the motor car symbolically back to the place of its birth, in order that it may be developed once again, so to speak. What happens to it may be compared to what happens to a grown-up man who has always thought of himself as being perfect and who now all of a sudden has to go back to school. Here a development had begun one day, which has changed life in this world in many respects. The old engine-propelled coach so much smiled at in those days, the privilege of a well-to-do class during the twenties and the thirties of this century, has become an object for everyday use, a useful article for millions of people.

This development has positive and less positive sides. Let us be careful not to pass a rash and one-sided judgment, as do so many in this world. I am one of those who without reservation consider the automobile as a progress for mankind. But he who sees only the positive side of the motor car and not also dedicates a good deal of energy to contemplating its negative effects, will in the long run even discriminate progress as such. It is one of the characteristics of human nature that we easily get accustomed to the positive sides of progress and that we without much ado put up with its negative effects. The knowledge of the negative qualities of the motor car is often suppressed. It is easier for many to occupy themselves with the performance of modern automobiles than to meditate on the problems which they give rise to. All those who hold the automobile in high esteem must direct their special attention to this underestimation of these negative sides: every driver of a motor car, the automobile industry, and every politician concerned with transport policy whose task it is to protect the banks between which the motorized flood flows along. This is no easy job. If a river is not controlled and if it flows on in unharnessed freedom, it will destroy its banks and cause great damage to the country. The river must be tamed, the damage which it causes must be kept low, the damage must be checked so that the river can fully serve mankind in harnessed freedom. This can as a rule be easily done with rivers. Man will mutter and offer resistance to unpleasant decisions and measures. The motor car has to submit to the conditions of society and to adapt itself to what society expects of it. This must be so because otherwise a dissonance, a disharmony will have to be feared between society and progress which the motor car represents.

What we must achieve, upon what we must concentrate our energy, are three things: we need safe roads, we need safe drivers, and we need safe vehicles. We are incessantly searching for new methods for making the roads safer. But we have in the past dedicated too little effort to achieving a fundamentally new attitude towards the safety of the motor car. Our successes in the past, important and useful as they all were, may be compared to a crazy quilt. The smashing success, the ten-strike, the long step ahead, the all-embracing improvement in quality, which may also be called a renewal, has failed to happen with the automobile.

This conference shows that we are on the right track for a fundamental rethinking. The motor car as an object for everyday use is intended to serve us and to render this service without any danger to those who have to do with it, who are in contact with it, who live with it. This conference shows that the industrial countries and their respective automobile industries stand up to the demand for a ten-strike, for more safety in the motor car and in road traffic and that they in their laboratories, in their workshops, and with the help of their engineers are seeking for new methods to comply with this demand.

After these introductory remarks I should like to welcome you and to thank you for having come here to Federal Republic and that you have come together here in this assembly. I want to thank all those who have spoken in this first hour of the conference for all they have told us.

- Your house, Dr. Zahn, Daimler-Benz AG, has with prudence and devotion set up the frame necessary for the success of this conference and has taken upon themself the many troubles that that entails. This is also a positive contribution to traffic safety.
- Let me thank you, Prof. Randers, for that NATO does not limit its activity to external safety only. External safety and internal peace, peace on our roads, belong together and complement each other in an industrialized world. Only together can they form a sound basis for the march of the nations into a secured and happy future. Internal peace, however, means also that we strike the automobile off the arsenal of our weapons, that we do not live our lives armed with a motor car, that we deactivate this dangerous weapon, that we no more fly at each other, armed with the motor car, and inflict pain upon each other.
- I want to express my particular thanks to my esteemed colleague, Secretary Volpe, for having come here. The fact that he has come and has spoken to us is evidence of the great interest the United States of American takes in safety in road traffic, in more safety for the passenger car, and it proves also the great interest in the project, which is the actual object of this conference and to which it will be devoted for four days: the experimental safety vehicle.

  You, dear Secretary Volpe, have ventured to undertake what we are all grateful to you for. You have given a world-wide impulse to discover – in a scientific large-scale experiment – the greatest possible degree of safety for the occupants of motor vehicles. This is a truly humanitarian experiment which we have embarked upon together. We welcome this kind of action and the initiative you have taken. My personal opinion is: The contest for the better motor car should not in the first place be considered a contest for more horsepower, more chromium trim, and more glass, but a contest for more safety.

  You reminded us in your address, Secretary Volpe, that we on November 5, 1970 – that is a little less than one year ago – here in Bonn signed an agreement on joint action, just as a great number of agreements have been signed by you in the world. Today we have October 26, 1971 – not quite a year later – and we have not been idle in this country during that year. We are here in Stuttgart, not far from Daimler-Benz, who is still a bit coy about what they have developed in the course of these twelve months. Daimler-Benz behaves like good parents who have a well-educated and pretty young lady at home. One doesn't display her in the shop window, one keeps her back in modesty. I think the model Daimler-Benz has developed need not be ashamed of being looked at. The model may be inspected by all, I think, who want to do so.

Ladies and gentlemen, I don't want to philosophise here on the violation of human dignity by what happens day by day on our roads. Anyone who bears responsibility must be caused sleepless nights, when he sees, how little human life is valued in road traffic. The French writer Antoine de Saint-Exupery once said, 100,000 dead – that is nothing at all. 100,000 dead don't cause pain. 100,000 dead, that is but statistics. Somebody who leaves in the morning and does not return in the evening, causes much more pain than 100,000 in the statistics. And how many in our countries, how many times one somebody leaves in the morning and does not return in the evening. And how many times once in a day is sorrow and misery brought upon mankind. This is the obligation we have to face. That is why we in this country have understood the impulse to create a special experimental safety vehicle as a favourable opportunity to obtain a greater knowledge as regards the safety of the motor vehicle. Times change also here. There was once a time when people believed that new knowledge and experience concerning the construction of motor vehicles can be obtained on race tracks. Nothing or nothing much is nowadays to be gained from there for the technical development of the motor car. We must go back to the workshop with the automobile. At our request the German automobile industry has prepared a list of requirements, with the aid of which the individual manufacturers develop their prototypes. The work on the safety vehicle will bring very important information on the technical possibilities that there are for enhancing the safety of the automobile and of its occupants.

The research results will also raise many serious questions to legislation, when we will know what the overall results will be. We need not answer them here and today. But we may be sure we will see ourselves confronted with them, and the questions that have been raised will have to be answered, because to answer them is in the interest of man. We all know that what is feasible from the technical point of view is not always also what is justifiable from the economic point of view. Or more precise: the last percent of safety which we will strive for will in all probability be also the one which will pose the largest number of questions in the economic respect. But we must forge ahead also into that last percent of safety, be it only in order to know what problems are facing us. When we examine where the ratio of the advantages and the costs of safety is more favourable, then the legislator must take care that the advantages are correctly defined. A purely commercial definition would be wrong, for human life and health are no quantities to be defined by commercial terms, which, though reluctantly, must inevitably be sacrificed to traffic.

I plead for approaching also traffic safety more and more rationally and for making it the object of practical considerations. A compromise arrived at in this way must be an honest solution which takes into account what is financially possible for motorists with an average income. After all, 80% of all passenger cars are owned by employees and by people who do not belong to the class of big earners. And then many people are not driving a car only for their pleasure, but they use it on their way to work, and this possibility must be left to them also in the future, when they will drive a safer vehicle. On the other hand we must exact from the owner of a motor vehicle and we expect it of him that he, too, is prepared to make an adequate contribution to enhancing his own safety, which is at the same time an enhancement of motor vehicle safety on the whole. If he realizes that this will above all and in the first place serve to protect the motorist himself, he will be the more prepared to pay for his own safety the amount which is absolutely necessary.

A more thorough and improved investigation into accident causation, the sequence of events in an accident, and the consequences of accidents can and will in the future supply us with the necessary data for this cost-benefit analysis, particularly with respect to the effect of the forces set free in an accident on the human organism.

Here we stand only at the beginning of a development, which I hope is a promising one. I am confident, however. We have already taken the first step, the door is no longer closed. How wide we open it into a better and a new development, depends on us and on how much energy we spend on this project. The experimental safety vehicle is the starting point. Even if we cannot expect it to solve all the safety problems overnight, we must walk on this road until we come to its end, for it is the right road and it is an important road.

Much water will drift under the bridges of the Neckar before the results of our research can be applied in serial production. We must therefore not flag nor fail in our efforts in the search for new methods of making our conventional automobiles safer. We must go on working hard for the ten-strike which we are striving for. This is what I want to request of you, for this is a task which no one, no country can solve on its own. This is on the contrary a world-wide problem, and we should feel this to be a world-wide challenge.

Let me now wind up this address by quoting Henry Ford. I couldn't find anything better than what he had once said. His words were to this effect: "What is really the basic idea of industry? It is not in the first place to make money. The basic idea of industry exacts the creation of a useful conception and its multiplication into thousands and thousands, until all men benefit from it." Ladies and gentlemen, this is exactly the gamble. This is the idea which we should be obsessed with and for the multiplication of which into thousands and thousands, nay, into millions, we should strive – as soon as we have transferred the theoretical idea into practice. This ought to be the great task, to which we shall all face up.

I thank you for your attention and I wish all of us much success in our endeavours.

SECTION 1

PART 3

REPORTS BY GOVERNMENTAL REPRESENTATIVES ON THE NATURE AND STATUS OF THEIR EXPERIMENTAL SAFETY VEHICLE PROGRAMS

UNITED STATES

MR. JOHN A. EDWARDS

Associate Administrator for Research and Development, National Highway Traffic Safety Administration, United States Department of Transportation

Introduction

Ladies and gentlemen, it is my pleasure to serve as Chairman of this Second International Technical Conference on Experimental Safety Vehicles. I welcome you to Sindelfingen and invite your active participation during the next four days of technical presentations and seminar discussions. I wish to express my sincere appreciation to the Government of the Republic of Germany, the VDA and to the Daimler-Benz Company for their most gracious hospitality and for providing this superb facility for what I hope will be a most fruitful meeting. We appreciate the excellence of the arrangements and fully recognize the great deal of hard work that is required for a successful conference of this type.

Our meeting in Paris last January allowed us to get to know each other and began a candid dialogue which I know will continue here in Sindelfingen. Our discussions then necessarily were united on specifications, and the general intent of the ESV program. Since January, we have had independent discussions with all Governments and now look forward in these next few days to exchanging detailed progress reports on all ESV projects.

As pilot country, the United States is well aware of the concern of all participants over the implications of information exchange in this program such as the proper protection of proprietary information, patent right, and the question of anti-trust as it relates to this exchange. The United States Department of Justice in August 1971 provided guidance on the operation of this program by answering a number of specific questions posed by the Department of Transportation. I believe all of the participating countries have received a copy of this guidance. Without exploring it in further detail here, we believe the guidance received has provided reasonably flexible ground rules so that significant exchange of information may take place. Most important is that each country and industry participants, while discussing with each other in these formal meetings their various approaches to problems and development results, continue independently their Experimental Safety Vehicle research and development projects.

Let me now provide a quick summary of progress in the United States Experimental Safety Vehicle Program which will be expanded upon by each of our contractors today and tomorrow. Fairchild and AMF developments are on schedule for a Christmas Experimental Safety Vehicle delivery to the United States Government. In June, the Department of Transportation signed a contract for testing of these prototypes with Dynamic Science of Phoenix, Arizona in the amount of nearly one million dollars. This company has substantial experience in dynamic testing, has conducted many compliance tests for the Department of Transportation, and provides an outstanding combination of expertise, facilities, and climate to conduct these tests.

General Motors is on schedule for prototype delivery in October 1972 and will report their very substantial progress tomorrow. In July 1971 the Ford Motor Company entered into a one dollar contract with DOT for the development of a prototype design by December 1972. We are most happy to welcome Ford representatives to this international forum, and you will hear of their detailed progress tomorrow.

In May 1971, the Governments of Great Britain and Italy signed Memoranda of Understanding to exchange information on ESV developments with the United States. Just recently, on October 7, 1971, a similar agreement was signed between the French and United States Governments.

We welcome these Governments and their industries now as official participants in this endeavor.

Finally, an annex to the United States-Japanese agreement was recently signed by both Governments specifying in greater detail the kinds of information exchange to be implemented during the course of our program. It is our intention to use this annex as a basis for negotiating similar arrangements with the other countries and a copy of this annex will be made available to the Governments during this meeting. The annex calls for, among other things, the eventual exchange of systems, subsystems and total vehicles for test by reciprocating countries. I lay before you a sincere desire that as this program matures, such an exchange of test articles may take place between the United States and all participating countries.

Again, my sincere welcome to this Second International Conference on Experimental Safety Vehicles. I look forward to hearing the progress reports of each Government and industry representative.

THE FEDERAL REPUBLIC OF GERMANY

DR. OTTO LINDER

Ministerialdirektor, Federal Ministry of Transport, Federal Republic of Germany

The Federal Republic of Germany engaged relatively early in the project of the experiemental safety vehicle (ESV), which was started in the United States of America.

In August last year the Federal Minister of Transport, Mr. Georg Leber, and the German automobile industry came to the conclusion that the ESV project must be given due regard and the German conceptions of a safety vehicle of European dimensions should be worked out.

In December 1970 the German automobile industry presented a set of rules to the Federal Minister of Transport, a survey of the technical requirements to be made on an experimental safety passenger car. This set of rules will serve as a guideline for the work of all German manufacturers of passenger cars on experimental safety vehicles, no matter whether they build complete vehicles, as do Volkswagen and Daimler-Benz, or whether they are working on individual parts for the ESV, as do the rest of the German car manufacturers.

After we could be sure that in the Federal Republic of Germany complete experimental safety vehicles are being built, we concluded an agreement with the United States in November 1970 on the cooperation in the development of experimental safety vehicles, as a result of which first reciprocal visits have already taken place. This agreement will in the near future be complemented with respect to the manner and the scope of the reciprocal exchange of opinion and experience.

I am glad to be in a position to say that our automobile industry have not closed their minds to the necessity to avail themselves as much as possible of the chances offered by the ESV project for making the motor car safer. The high degree of own initiative of the German automobile manufacturers, which greatly advances their work, must particularly be welcomed.

It must be pointed out in this connection that the cooperation in this field between the Government and the automobile industry is of a different nature in the Federal Republic than in the United States. Whereas in the United States the Government themselves have taken the initiative and have accepted the responsibility for and the supervision of the work and have commissioned industry with carrying out the projects, in Germany another method has been decided upon on account of the different structure. In Germany the Federal Minister of Transport has invited industry – and that successfully – to create the preconditions for an experimental safety vehicle and to carry through its development and its construction. This kind of cooperation between Government and industry has proved a full success. I want to emphasize this particularly and to express our thanks to the German industry.

Daimler-Benz has developed an experimental safety vehicle on the basis of standard type vehicles and is now about to bring its qualities into line with the requirements of the set of rules.

The individual German firms will report on the state of their respective developments themselves. Volkswagen has developed components and is about to integrate these components into an overall system.

Such zeal is evidence of the willingness of the automobile industry and of the design engineers to carry the examination and the development of technical possibilities for the improvement of the safety of the passenger car as far as to such limit, where the sphere of reality ends and the impossible begins. If in this attempt a substantial portion of the efforts is spent on realizing that not all safety components will for a given additional expenditure yield an equivalent increase in safety, we would only welcome this fact.

In the course of the long history of automobile construction certain different basic conceptions have developed for the passenger car in Europe and in the United States, which are determined by a great variety of factors. It would be a miracle, if these differences in conception would not make themselves felt also in the ESV project.

So the German ideas on the requirements to be made on an experimental safety vehicle of European dimensions differ from those of the United States in the following matters:

- road behaviour
- room for survival of the passengers and
- the kinds of occupant retention device.

Moreover, the problem of mixed traffic of light and heavy vehicles causes us some trouble, as it has not yet been satisfactorily solved. Finally also the requirements with respect to rear-end and lateral collisions in comparison with the more serious head-on collisions should once again be fundamentally discussed.

I would welcome it if the pros and cons of these differences in the requirements to be made on the experimental safety vehicle could be discussed in detail in the course of this meeting and if a harmonization of the opinions could be reached.

On account of all these considerations, to which a great number of others will certainly be added at this conference in the course of the next days, we in the Federal Republic feel urged to thoroughly reconsider our set of rules. We suggest to deal with the "Requirements to be made on the experimental safety vehicle" in detail during the next seminar. Oral discussion of the problems is undoubtedly to be given preference over treatment in writing.

In spite of various technical differences of opinion in questions of detail between us and our American partners we can much to our pleasure say that both Government and industry in Germany energetically continue their work on the project ESV and that they endeavor to achieve the greatest possible international harmonization. We are convinced that this is an effective contribution to an improvement of the safety in road traffic.

JAPAN

MR. YOSHIO IGARASHI

Automobile Section, Heavy Industry Bureau, Ministry of International Trade and Industry

The Status Of The Japanese ESV Program

"The Experimental Safety Vehicle Development Project of Japan" is making steady progress and today I would like to report on the present situation and the future prospect of the Japanese project.

The Experimental Safety Vehicle development project of Japan started in November, 1970 when the United States-Japan memorandum was signed concerning cooperation on Experimental Safety Vehicle development. After the signature of the memorandum, the Japanese Government, Japan Automobile Manufacturers Association, Inc. (JAMA) and Japan Automobile Research Institute (JARI) worked collectively to establish the detailed specifications for the Japanese Experimental Safety Vehicle.

The technical expert group which consists jointly of members of the Japanese Government and representatives of automobile companies visited the United States and the Federal Republic of Germany in order to study the progress of the Experimental Safety Vehicle projects of these two countries as well as their approach to the development of specifications for their ESVs.

The results of these visits contributed considerably to the establishment of the Japanese Experimental Safety Vehicle specification. The work on the specification was completed in May, 1971 and the specification was officially adopted as a formal ESV specification by the Japanese Government (Ministry of International Trade and Industry and Ministry of Transport). Upon governmental approval of the specification copies were furnished to the United States Department of Transportation. We will cover detailed contents of this specification during the "Japanese Technical Presentation" scheduled for tomorrow.

The Ministry of International Trade and Industry and the Ministry of Transport jointly invited open proposal from the automboile companies interested in manufacturing a model car based upon the specification for the Japanese Experimental Safety Vehicle. After examination of the development programs offered to the government by several automobile companies, Toyota Motor Co., Ltd., Nissan Motor Co., Ltd. and Honda Motor Co., Ltd. were designated as the eligible participants in the Japanese ESV project. The details of each company's development approach will be discussed during tomorrow's Technical Presentation.

The manufacturing of a prototype car is scheduled to be completed by the end of 1973, with the exception of the Honda Motor Co., Ltd. which will require an additional year to complete. After the manufacture of the final prototypes, the test of the performance and the appraisal of the results will be made at and by the Japanese Automobile Research Institute.

We are considering the possibility of the exchange of experimental safety vehicle prototypes with other participating countries in this world-wide ESV development project, if this is necessary and desirable. The Japanese Government has decided to give subsidies to the Japanese Automobile Research Institute for the necessary expenses such as the construction of testing courses, the purchase of the final prototypes and the study and examination of the project.

Recently, the Japanese Government and the United States Government signed an annex to the above-mentioned United States-Japan memorandum which prescribes the actual methods of exchanging technical information on Experimental Safety Vehicles between governments. This exchange of technical information between the two countries has already begun in accordance with this annex. We hope that the technical information of the other participating countries will also be exchanged through similar procedures.

Finally, we would like to express our sincere respect and gratitude to the Government of the Federal Republic of Germany, the Society of German Automobile Industry and the United States Government for their efforts to hold this Second International Conference on Experimental Safety Vehicles. Thank you.

THE UNITED KINGDOM

MR. R. D. LISTER

Head of Vehicles Section, Road Research Laboratory, Department of Environment

British Safety Car Programme

The proposals contained in this outline programme are for a number of individual projects and studies to be carried out under the direction of the Road Research Laboratory with the aid of leading car and component manufacturers. Its aim is to develop car safety features in practical engineering forms and to incorporate them into designs of complete cars which can be used to demonstrate the latest ideas for accident prevention as well as occupant protection. The interaction and relative effectiveness of the various designs would also be considered.

It is not intended to dictate future styling except in so far as safety is affected but rather to ensure that manufacturers, with safety factors in mind, explore designs and production to meet advanced specifications for accident avoidance and injury prevention.

The programme is fluid; other items may be added as basic research progresses or a selection of the individual projects may be made.

The programme is in three phases:

- **Phase 1.** To issue a number of contracts to industry in the immediate future to design and produce specimens of various safety components and systems.
- **Phase 2.** Calls for the design production of prototypes incorporating various groups of safety features. Though basically conventional in layout, these cars should meet advanced safety requirements and demonstrate that the measures taken to do so can be incorporated in a car acceptable to the general public.
- **Phase 3.** Consideration will be given to more basic changes in car design and to advanced ideas in accident avoidance and will incorporate successful developments arising from Phase 2.

It is to be stressed at this stage that this development programme is to be a series of joint projects between RRL and manufacturers on the basis of support from government funds. For this reason it cannot be undertaken that all the projects listed below will be carried out though others may be added. Each project has to be acceptable to a car manufacturer or other appropriate firm in this country and also the firm's proposals, staff and facilities available and commercial situation, have to be acceptable to the British Government.

The Phase 1 contracts are planned to be completed within one to two years of placing each one and Phase 2 may be started before all Phase 1 items are completed.

Phase 1

Project 1

Passive safety belt layout in which belts are attached to doors; engineering of system into some current models.

It is planned that major car manufacturers should build passive safety belt systems in which the belts are attached to the car doors into some of their current models. The installations should be fully engineered so that the cars can be evaluated in everyday use and tested to see how far they comply with proposed dynamic test procedures.

Project 2

Development of belt and reel components for safety belts attached to doors.

Safety belt manufacturers are to be asked to develop belts for this application which have adequate life, low extensibility, suitable inertia lock arrangements, some means of emergency release after impact or belt failure and satisfactory means of installing the reel on to car seats or body structure.

Project 3

Design of frontal structure of small cars.

There are several design requirements and different levels of performance are possible for different sizes of car. For this reason and also because different design solutions may be proposed, several contracts may be negotiated. The main requirements are:

1. To design an energy absorbing front bumper or sub-structure to reduce injuries to lower limbs of pedestrians struck by it. The bumper should also cope with any other minor impacts without damage to other car components. The weight of the bumper to meet this requirement should be kept as low as possible.
2. The design of front structure to be such that replacement costs (component and fitting costs) of parts damaged in frontal collisions up to say the equivalent of a 20 mile/h barrier impact should be kept as low as possible.
3. No significant intrusion into the passenger compartment for full head-on impacts equivalent to barrier impacts of between 40 and 50 mile/h. The passenger compartment deceleration should not exceed say 30g.

Project 4

Car door and adjacent structure designed to protect occupants at waist level in side impacts.

Initially to design and construct doors which have a strong outer skin linking the hinges to the anti-burst locks, but with a deep padded energy absorbing interior structure to mould to the shape of the human body when one is impacted into the other. Adjacent structures such as seats and lower A and B posts might be modified to meet or assist in meeting these requirements, particularly for 45^{o} side impacts.

Project 5

Design of A and B posts, side and frontal headers and windscreen edge to attenuate impacts by occupants' heads.

The A and B posts and headers are to be redesigned to withstand normal design loadings, impact loadings when the car overturns (as specified by whatever is latest requirement) and also to attenuate impacts by occupants' heads during impacts to the car.

Project 6

Build front seats into car structure.

This proposal is to see whether intrusion due to side impacts and the resistance of structural collapse due to overturning can both be improved by this means. It permits the optimum placing of belt anchorages, windscreens and windscreen pillars, but it requires steering columns and foot and hand controls to be adjustable in position.

Project 7

Fascia/parcel shelf development to reduce knee/hip injuries.

This is required to demonstrate a type of design meeting the knee/hip tolerance level requirements. The layout should accommodate a full range of sizes of human lower limb, and should be arranged to reduce the chances of limbs angulating around the lower edge of the fascia.

Project 8

Controlled yielding steering assembly.

Lightweight higher angle steering assemblies such as fitted to some of the smaller cars have generally satisfactory yielding characteristics in bending when impacted by drivers during accidents. Further work is required to see whether the wheel, spoke and hub can be developed to further improve this situation.

Project 9

Self-levelling body or headlight adjustment system to accommodate variations in car loading.

Some further development is required for these systems to ensure that headlight alignment is always satisfactory for range of loading and operating conditions.

Project 10

Alternative passive restraint systems.

In principle, devices are required which fit closely around the occupants and in particular, development is needed for effective restraints against side impacts.

Project 11

Crash deployed occupant protection.

Would include airbag and study of limiting parameters when supplied to small cars.

Project 12

Study of impact properties of engineering plastics.

Not limited to components but to consider fundamental properties.

Project 13

Head-up display.

To include aid for assessing distance of vehicles ahead as well as for speedometer reading, warning signal, and other information used frequently.

Project 14

Tire deflation and wear warning.

Tire deflation warning should be given to the driver within a few seconds of a drop of pressure of more than, say, 8 psi below recommended. It may not be necessary to use a radio link if some audible warning can be used. The wear warning could be a conspicuous marking exposed on the tire tread.

Project 15

Warning and command signals transmitted from ground installations.

Car radios modified to receive messages from signals generated in ground loops can be used to warn drivers of approaching hazards or delays. Alternatively, ground signals can be used to provide command instructions fed straight into a vehicle control system either to guide the path of a vehicle or to control its speed. Various developments are at the stage of requiring the attention of car manufacturer design teams.

State Of The Art Projects

The following projects are not strictly development projects but just engineering re-assessments of the existing "state of the art." They are needed to form the basis of stricter requirements for several vehicle systems.

Project 16

Brake system review.

The aim is to specify a satisfactory system with a life of 100,000 miles or ten years, but failing this a period of half the life of a car, i.e., 50,000 miles or five years. Another aspect of the brake system is the introduction of non-locking brakes on all wheels.

Project 17

Review of car handling.

Handling characteristics are built into cars to satisfy the preferences of the general public and hopefully to make the car safe and easy to drive. A review of the situation and investigation into the relationship between handling parameters and accident involvement is required.

Project 18

Review of ergonomic control and instrument layout and operation for the driver.

This project would investigate and develop optimum pedal force and response conditions for all hand and foot operated controls as well as to review essential and informatory information to be presented to the driver.

Project 19

Review of visibility requirements.

Would include consideration of desirable front and rearward visibility as well as reconsideration of vehicle lights to see and to be seen.

With the above outline programme in mind the United Kingdom representatives welcome the opportunity at this second international ESV Conference to make a progress report on their own contribution to the Car Safety Programme. We would like to emphasise once again that in our view road safety measures should be applied over a wide front and that the cost effectiveness of the various measures should be taken into consideration when determining priorities and regulations. As far as we are concerned in the United Kingdom road safety requires continuous development in a number of fields including the road system, the vehicle (including its driver) and the environment, and will continue to do so in the foreseeable future.

As far as the vehicle is concerned we in the UK, Industry and Government together are developing car safety features in practical engineering forms and assessing these features independently and at different levels of performance. Nevertheless, we have in mind to combine the best of these features and others, which may become available from the interchange of information under the Experimental Safety Vehicle Programme, into a complete safety vehicle. In this way we should have a full knowledge of the contribution afforded by the individual design features and be sure that we are getting good value from the expenditure on the total package.

Since the first international conference we have placed a number of contracts. Very briefly these are as follows:

- Project 1 – *Passive Seat Belts*: This work is progressing very well and some acceptable designs are being developed.
- Project 11 – *Crash Deployed Restraint Systems*: This is not limited to the airbag and a number of other proposals together with a number of combinations will be investigated and developed.
- Project 13 – *Head-up Display and Station-keeping*: This work is more appropriately related to accident avoidance as it gives the driver much more information to help him avoid the accident situation.

Other projects for which contracts have been or are about to be placed cover:

- *Project 3* – The design of the front structure of small cars to collapse in a pre-determined controlled manner.
- *Project 4* – Car door and side development to obtain the optimum balance between the degree of intrusion and interior padding to provide maximum occupant protection.
- *Project 5* – Interior structural design to attenuate impact by occupants' heads on header rails, A and B posts, and windscreen pillars and frames.
- *Project 7* – Development of fascia and parcel tray area within the tolerance limits of the lower limb and chest areas of human occupants.
- *Project 8* – Improvements to steering wheel assemblies and hub mountings to control the collapse of the steering wheel as well as the column.

In addition, contracts have been placed with Research Associations in order to provide basic data in a number of fields as follows:

a. impact properties of plastics
b. human impact test devices
c. impact properties of front bumpers
d. impact properties of car bonnets
e. yielding characteristics of steering assemblies

Further contracts are under active discussion covering a wide range of projects and our programme is gathering momentum.

Project 15 – A great deal of emphasis is attached to braking performance and two important investigations are being undertaken. The first of these is a field trial of the anti-lock brake system. We know that anti-lock brake systems are available which in control tests are capable of providing effective and stable braking. A field trial is however necessary to investigate their performance in use in the hands of the general motoring public so that a realistic estimate can be made of the benefits likely to arise if they were adopted universally as standard equipment.

The second is to investigate the possibility of the development of a completely reliable braking system which would last the life of the vehicle, neither requiring maintenance nor adjustment and to have a repeatable and predictable response. One possible solution lies in a completely sealed system and sophisticated means of energy absorption.

Later in this Conference technical presentations will be made by UK representatives on the desirable handling characteristics of cars in relation to reduction of accidents, test methods of roll-over studies, passive seat belts, injury criteria, dummy test devices and recent anti-skid studies on braking and cornering.

Finally, I would like to say a few words on behalf of the Chairman of the European Experimental Vehicles Committee which has been organised to cooperate and coordinate the programmes of the European governments participating in the ESV study. The Chairman observes that the existence of that committee demonstrates the determination of the European countries to support the American initiative for greater vehicle safety and improved environmental conditions.

ITALY

DR. ING. VINCENZO MARCHIONNE
General Management for Motorization
Ministry of Transportation

A. The activities aimed at the realization of an ESV Program in Italy are directly pursued or supervised by the Ministry of Transportation within the framework of the memorandum of understanding signed with the Government of the United States and on the basis of the collaborations established in Europe under the auspices of the Governmental Technical Committee.

The Committee entrusted the Italian government and industry with certain topics of study which include mainly the following:

1. Handling of the vehicle on the road
2. Handling of vehicle in a collision or rollover
3. Driving in fog
4. Braking
5. Lighting and signalling devices
6. Passenger restraint systems
7. Fire protection

B. The organizations participating in the research and experimental program are:

- Ministry of Transport, General Office of Civil Motorization
- Alfa Romeo
- Fiat
- National Electrotechnical Institute, "Galileo Ferraris" of Turin
- Institute of Experimental Autos and Motors (ISAM) of Anagni

Some body manufacturers and equipment manufacturers have also offered their help in specific areas, either at their own expense or on the basis of the grant of subsidies or reduced rate financing on the part of the Government.

C. The topics of study numbered in Part A were divided among the participating organizations thusly:

A.1 Ministry of Transport and ISAM
A.2 Alfa Romeo and Fiat
A.3 Ministry of Transport and National Electrotechnical Institute
A.4 Ministry of Transport, Fiat and ISAM
A.5 Ministry of Transport and National Electrotechnical Institute
A.6 Ministry of Transport, Alfa Romeo and Fiat
A.7 Fiat

A detailed program, indicating the direction of the research and the desired goals in each area being considered, was established at the same time.

D. *Handling of Vehicle on the Road.* The Ministry of Transport will conduct, with the help of ISAM, research on the possibility of using non-conventional systems for control of the trajectory of the vehicle and on the performance that the trajectory can provoke outside the limits permitted in the normal coupling of the tire and the pavement. We are thinking, for example, of using controlled air jets or other similar devices.

ISAM initiated a program of considerable activity in this area. ISAM includes, besides, the adjustment of systems apt to set up and register the rolling, pitching and drift of the vehicle when moving and its responses to accidental exterior disturbances (transversal winds, aerodynamic interaction between vehicles of different sizes when passing or crossing). ISAM plans also to proceed to the evaluation of the vehicle response to instinctive and sudden actions of the driver, as in an emergency. The Institute will develop research and tests on the environment inside the vehicle in traffic, mainly from the point of view of irritating vibrations of the structure that cause fatigue, vibrations that may be noticeable or unnoticeable.

Behavior of the Vehicle in Collision or Rollover. Alfa Romeo, for its research in this area, will use cars having a regular construction (motor in front and rear wheel drive). The studies will be developed by considering all kinds of crashes including low speed collisions for which they will examine either the bumpers (not completely tied to the type of car and therefore applicable to very different cars) or the structure to which the bumper is attached. The relative tests will be conducted on cars now being built and they will include the use of new solutions (for example, use of unconventional materials such as "sandwiches" and plastic materials). The studies will also be concerned with the hitting of pedestrians and the case of fuel spillage in a crash.

Fiat will concentrate its studies on small and medium size cars with front and rear engines. It will use cars now in production or including structural modifications through specialized production.

The relative tests will be either dynamic or static by equipping the cars with appropriate instruments and anthropometric dummies, to determine the survival space and to mark on some diagrams assumptions of energy and acceleration of forces relative to the collision points and the occupants. Fiat will study also the new bodies which provide for the use of mechanical units of standard production and incorporating all the improvements and safety developments derived from acquired experiences.

Driving in Fog. This problem will be studied by the Ministry of Transportation, in collaboration with the National Electrotechnical Institute, on all sides: lighting signals, acoustics, by radio and electronics, visibility and possibility of eliminating local fog, driving attitudes, etc. Some tests involving electronic devices are now being planned.

Braking. For braking, the Ministry of Transportation will concentrate, with the assistance of ISAM, on researching the possibilities of developing and using aerodynamic brakes, effective at reduced speeds. Fiat, for its part, will study the general improvement of present braking devices and more specifically the development of antiskid devices.

Lighting and Signalling Devices. The National Electrotechnical Institute will take on the related studies under the supervision of the Ministry of Transportation. The studies involve, among others, the improvment of crossbeams, including the use of polarized light, and the limits of intensity of road lighting. Furthermore, they will study new systems of stop lights to avoid confusion with other lights and to eventually signal the intensity of a deceleration. The improvement of lighting devices thus reflects that the orientation of head lights in different uses will also be the subject of research on the part of the Institute.

Passenger Restraint Systems. The Ministry of Transportation will undertake the study of a seat attached to the driving compartment by means of elastic or flexible materials, in order to prevent the occupant from being subjected to much movement inside the car that is not associated with movement of the seat. They will watch to see if the driver can, in each instance, keep complete control of the vehicle and have at his complete disposal all the means of information and control. Some other research will also study the possibility that the interior part of the passenger compartment may be separated from the exterior part, with energy absorption through elastic systems where the two parts meet. Finally, the Ministry will study the possibilities offered by other new conceptions. Alfa Romeo, for its part, will conduct studies either on restraint systems involving the intervention of the occupant (active) or on those that function automatically in case of a crash. Fiat will concentrate on the interior set up of the vehicle and on eventual modifications of structural elements of the car as a consequence of the introduction of restraint systems, by studying thoroughly the devices themselves and in particular the air bag, automatic seat belts and padded interiors.

Fire Protection. Fiat, which is heading the research in this area, plans to study the set up and the constructive characteristics of the gas tank and of the related tubes (or hoses), by conducting crash tests on different types of cars and different types of gas tanks.

Studies of a Different Nature. In the framework of the Italian program, we also plan to develop certain research activities on particular aspects of improving safety, such as air conditioning (air climatization) inside the car, automatic regulating devices, devices to clean headlights, improved windshield wipers, etc. Alfa Romeo is particularly interested in leading the studies.

This entire program will be financed mainly by the Government, either as direct expenditures or as a partial reimbursement of the cost of industry research. The first allocation of funds has occurred and the program has just started.

Meetings are held regularly between the Ministry of Transportation and other organizations and firms interested in the program to discuss development and coordinate the different activities.

A Ministry Commission with an industry representative was set up to supervise the program by order of the Minister of Transportation.

FRANCE

MONSIEUR MICHEL FRYBOURG

Directeur de l' Institut de Recherches des Transport

I will join right away with my colleagues in giving the thanks of the French delegation to our hosts: the Federal Republic of Germany and the Daimler-Benz Society for the excellence in the organization of this conference and to the initiator of this project: the government of the United States.

Like any industrial product, the automobile should unswervingly progress toward an ever-increasing satisfaction of the needs of the community. These needs can be expressed not only in terms of mobility, but also in terms of safety and improvement of the style of life.

Certain experts, and I am thinking most of all about Colonel Stapp, have, since the 1940's, directed attention upon the large numbers of possibilities offered by the improvement of the structure of automobiles and by the restraint devices for limiting the consequences of the second collision, that of the passenger against the walls of the vehicle.

In France, since the 1960's, the National Body for Highway Safety: the O.N.S.E.R., has been directing attention upon the possible progress for the protection of the passengers.

The French delegation, therefore, considers this meeting as one step further in a continuing work, from which it is not seeking to draw either price or prestige, whether this be for its government or its builders. Our engineers, if they believe in science and technology, are not shaped by the methods of publicity. They are not trying to bring about a "dream car" nor are they trying to sate their curiosity. They keep strictly to research and experiments which we wish to see give rise to solutions which are effective and compatible with the role that the automobile should take in our modern civilization.

It is in this frame of mind that France has resolutely set out into a program called S.E.E.S.[1] in French (and E.S.S.S. in English)[2]. It is a question of utilizing all the progress that technological perspectives allow us to get a hold of in order to test some "sub-systems" on vehicles of a series, all the while making studies of cost-efficiency on each of the devices liable to be incorporated into the vehicle. We think that this method is realistic and effective in order to ultimately set up an entirely new

[1] Sous Ensembles Experimentaux de Securite
[2] Experimental Safety Sub-System

book of expenses, of such a nature as to permit a break-through (that which you have called a "break-through," Mr. Volpe) a rather promising area.

To establish evaluation criteria for the devices tested, we feel that we should take into account the income level of the population and the nature of the existing type of vehicle. The allotment, between the car that is doing the striking and the car that is being struck, of the means of diminishing the risks in the case of a collision could lead to very different results according to the make-up of the existing types of vehicles. You will hear two reports on these subjects which lead to believe that some answers to the problems could – and should without a doubt – call for some solutions to be adapted, if not in every country, at least in every large market.

The necessity of studying vehicles of 900 kilos and even of 750 kilos is now recognized by everybody.

It will be fitting to sift out methods which, all the while satisfying the demands of the large markets, guarantee that free international exchange will not be hampered.

We should likewise know that one can neither improvise nor form specialized researchers in an area which demands as much experience as that of automobile safety. For, we all want, I believe, our research to arrive at concrete results which can be progressively exploited with the new models which will be conceived in the future. Then, whenever we convoke engineers and mathematicians to ponder over these essential problems, we should ask ourselves about the possibility of overburdening their work – or drawing them away from it – by asking them at the same time to adapt upon existing vehicles disparate regulations, which had been elaborated, sometimes hurriedly, by each other.

This is a problem of conscience about which, I think, governments should concern themselves.

Other questions can also usefully be the object of an exchange of points of view between governments without the same solutions necessarily being adopted by all. I am thinking about a sharing of the research effort between on one side, big industry, specialized and compelled by the demands of administration, and on the other side, independent teams. I am also thinking of the role in the financing of the research that public power could or should play, in order to take into account the social character of these initiatives, the publicity which will be given to the results, and of the risk run by the solicited enterprises and the sizes of these risks.

I confirm that the French government is entirely open to the greatest possible cooperation through an exchange of information about means, results and costs.

This cooperation will be carried out within the framework of the bi-lateral agreements which each of the participating countries have passed with the United States. It will also be carried out within the multi-lateral framework offered by the group from London which is assembling the European nations.

We think that one could thereby avoid double work, poor utilization of means and excessive multiplication of destructive experiments. We believe that antitrust legislation should not have any influence in this endeavor, for it would confuse commercial confidence, linked to the strategic planning of the enterprise, with industrial confidence based on patents, the importance of which in these matters, in our opinion, has been highly overestimated.

Having taken into account the levels attained in our country for that which is of the most important safety, the common elements of our objectives consist essentially in bettering the safeguarding of the occupants by researching the structure of the vehicles and the restraining devices.

The methods and the means for attaining them can differ, but it is necessary to know that any unduly directive approach would be severely judged by the countries that would have to suffer the consequences of it.

It is in this frame of mind, which wishes to be simultaneously – but strictly – scientific and pragmatic, that the French government carries out its action, and that the French delegation participates in this conference, and that you will hear the technical reports of the specialists of our country.

THE NETHERLANDS

MR. J. G. KUIPERBAK

Deputy Director Road Transport, Ministry of Transport Service

Mr. Chairman, Gentlemen,

Due to the fact that the Netherlands is not officially and effectively participating in the project of the Experimental Safety Vehicle, my comments may be very brief. My country is, although not engaged in the project, very much interested in the work that is being done in this field. Also all our research organizations and institutes and last but not least our industries, i.e., automobile industry and components industry have a very high interest. This is the reason why most of these organisations are represented here in the Netherlands delegation. Our research organizations and institutes are not only interested but are doing detailed research in many fields concerning automobile and road safety. If they can be of any assistance to any one of the participating countries, I am convinced that they are willing to assist as much as is in their ability. I hope that this conference will lead to a large step forward to reach the ultimate goal of this ESV project, that is to be able to build a really safe automobile that is also economically feasible and through this, lower the death toll on our roads and highways.

SWEDEN

MR. GUSTAV EKBERG

Head, Vehicle Department, Swedish Road Traffic Safety Office

First of all I wish to express my gratitude to the U.S. Department of Transportation and to the Federal Republic of Germany for having invited Sweden to take part in this very interesting and important conference.

Sweden is certainly outside the NATO organization but we are facing the same problem as the member countries – that of the very high number of victims of road traffic accidents. We believe that road traffic safety can be increased by more rigorous requirements concerning the design of vehicles. We are therefore anxious to take part in the international work on safer vehicles.

Sweden has not signed an agreement with the Department of Transportation concerning the development of experimental safety vehicles or subsystems. My position at this conference will therefore be as an observer. Sweden has however agreed with the Department of Transportation on mutual exchange of information concerning the creation of safer vehicles for our roads and thus on cooperation in the work for increased road safety.

Having studied the program for the conference I am convinced that it will turn out to be an important step towards safer vehicles. May I also express the hope that Sweden in the future will be able to publish results from research work and investigations that will contribute to the development of ESV.

BELGIUM

MR. PAUL NICOLAS

Director of Administration of Transports, and Ministry of Communications

Gentlemen,

Traffic Safety has always been a matter of great concern to the Belgian Government.

Belgium's highest authority, His Majesty King Baudouin, openly demonstrated his interest in traffic safety by attending the formal opening ceremony of the XIIIth FISITA[1] Congress, which took place in Brussels in June 1970. It included the European part of the International Conference on Vehicle Safety, co-sponsored by the SAE of New York.

On several occasions, the present Minister of Communications, Mr. A. Bertrand, confirmed his personal feelings and engagement in this field and took far reaching legislative action which, though sometimes unpopular at the time of the release, proved beneficial later on.

Supported by such highly valued patronage, the Belgian Administration actively studies the three determining factors for traffic safety: the vehicle, the road and the driver. Appropriate action is taken as soon as positive results warrant to do so. Restricting ourselves to the vehicle aspect only, we can proudly state that Belgium is one of the few European countries and even the first one where, for years now, vehicle type approval and periodic vehicle inspection by approved independent technical control stations, have been in full operation. They are often referred to by other governments when contemplating the implementation of similar administrative and technical procedures.

Belgium also maintains a well staffed Safety Research Foundation (Fonds d'Etudes et de Recherches pour la Securite Routiere), which is available to the Administration for conducting any studies on problems involving traffic safety. Amongst the more recent assignments, we can single out investigations on the use of passing beams in built-up areas, on traffic noise from road vehicles, on crash helmets for motorcyclists, on the photometry of vehicle lights in service. This Foundation also publishes a periodical on traffic safety problems and awards every two years a substantial money prize for the most outstanding contribution to traffic safety.

Even if economical factors have considerably curtailed Belgium's activity in the vehicle manufacturing field, we nevertheless have a most flourishing automotive assembly industry and practically any product manufactured around the world can be found operating on our roads. This provides a unique condition for comparing notes and for discovering the advantages and disadvantages of world technical trends and developments. With the experience thus collected, our engineers actively participate to the work of international bodies contributing to technological automotive progress. Belgian delegates are currently present in various WP29[2], ISO[3], BPICA[4], CIE[5], CISPR[6], GTB[7] meetings and their unbiased opinion often helps to develop a satisfactory compromise between originally diverging national positions.

We, in Belgium, the Administration as well as the Industry, have welcomed with enthusiasm the United States' initiative to develop and evaluate an Experimental Safety Vehicle (ESV). It is also most encouraging and to be quoted as an example, that the US Administration and the US Industry are prepared to share with their European counterparts the knowledge and experience accumulated during such study.

Right in the early stages of this project, it became of course evident that the characteristics of this 4000 lbs American ESV would not necessarily apply to a 2000 lbs vehicle, which is about the weight of an average European car. The US suggestion that a 2000 lbs European ESV be developed was of course favorably received as to the principle, even if, to some of us, a different means of achieving the same end result may appear more attractive and better in line with current European practice. We share the opinion of those who feel that progress will be faster to evolve and produce tangible benefits if the work is split and various groups deal with different basic vehicle components. If Belgium has little to offer when considering the development of a complete ESV, we have on the contrary a well established and world known safety glass industry that has been at the origin of what can probably be named the number one safety item. Current laminated and tem-

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1. FISITA: Federation Internationale des Societes d'Ingenieurs des Techniques de L'Automobile
2. WP29: Group of Experts on the Construction of Vehicles (UNO), Geneva
3. ISO: International Organization for Standardization
4. BPICA: Bureau Permanent International des Constructeurs d'Automobiles
5. International Lighting Commission
6. CISPR: International Special Committee on Radio Interference
7. GTB: 1952 Brussels Working Party on Automobile Lighting

pered safety glass of superior quality and high reliability achieved by strict manufacturing control, is being shipped all over the world. But our laboratories are not sitting idle and new types of laminated safety glass have recently been offered to the attention of the automobile technicians. They may quite well initiate a new concept in the "containerization" of vehicle passengers.

Several of the world leading tire manufacturers have manufacturing units in Belgium and maintain research facilities feeding the results of their work into the general technical group activities. If less spectacular, our contribution to tire safety certainly is worth being singled out. And is there anybody who will question the paramount importance of the tire on the overall safe performance of the vehicle?

Having thus pointed out in which particular fields Belgium is prepared to cooperate in the studies towards a 2000 lbs European ESV, we would still like to offer another suggestion, in line with information already given previously.

The purpose of designing an ESV is to give the technicians a unique opportunity to start from scratch and develop ideas and techniques that need not be hampered by economical or market limitations. We thus must hope and expect that radically new concepts will evolve. Are we sure that our present evaluation concepts or methods will then still apply? Without expressly saying NO, we nevertheless do feel that the matter deserves consideration and that we should try and restate the final purpose of the respective safety systems. In a number of instances, i.e., safety glass, the available standards and test methods have simply confirmed existing practices. It is about time that we reset our sights and that we define what we actually expect from safety glass as a contributory means for restraining the occupant in the vehicle. Once we have listed these various basic requirements and know how to check and/or evaluate them, we will be in a position to consider the new solutions being presented to us and equate them all on the same basis. We would suggest therefore that via the proper national channels we all urge the appropriate international bodies to get hold of the problem and come up as quickly as possible with purposeful standards and/or testing procedures. We, in Belgium, have already launched a similar move via our Belgian Standardization Institute, with respect to a safety glass standard to be developed by ISO/TC22/SC11. We will likewise cooperate with any other international body bent on preparing safety standards along similar lines.

Thank you for your kind attention.

SECTION 2

TECHNICAL PRESENTATIONS

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- Fairchild Industries
- AMF Incorporated
- The General Motors Corporation
- The Ford Motor Company

Part 2 – Germany
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- The Daimler-Benz A.G.
- The Adam Opel A.G.
- The Bayerische Motorenwerk A.G. (BMW)

Part 3 – United Kingdom
- Passive Seat Belt Systems
- Factors Affecting the Choice of Standards for Accident Avoidance
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Part 6 – France
- Distribution and Gravity of Collisions as a Function of the Damaged Part of the Vehicle and the Obstacle Hit – *O.N.S.E.R.*
- Why Citroen Chose 1500 lb. Vehicle for Its Studies and Experiments
- Citroen's Program of Thematic Action for Secondary Safety over a Period of Two Years
- Peugeot/Renault Association Program on Vehicle Behavior in Front End Collisions
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- Reasons for the Line Taken by the Peugeot/Renault Association in Studies Regarding Safety

SECTION 2

PART 1

THE UNITED STATES TECHNICAL PRESENTATION ON ESV DEVELOPMENT

FAIRCHILD INDUSTRIES

Dr. N. Grossman
Vice President

Good afternoon ladies and gentlemen. The presentation which you will be given is basically in two parts. We will have Mr. Sol Davis, who is our Chief of Systems Engineering, discuss the progress we've made to date on Crash Injury Reduction. He will be followed by Mr. William Wait, who is Chief of Systems Test, on Accident Avoidance. The material was all developed since the summer of 1970 when this contract was awarded to us. Now our primary area of competence is in the field of the design, development, test and production of military aircraft. We used much of the technology from that field in the design concepts introduced into the safety vehicle. However we were very fortunate in having the technical assistance and support of two of our subcontractors in areas where we lacked this competence. And so I would like to take this occasion to acknowledge with thanks the support of the Chrysler Corporation who were technical consultants to us and provided some of the hardware, and to the Digitek Corporation of Los Angeles, Calif. who provided the test facilities. So without further delay I would like to introduce the first speaker, Mr. Sol Davis.

Mr. S. Davis

Thank you Dr. Grossman, good afternoon ladies and gentlemen. It is my pleasure to present the Fairchild Experimental Safety Vehicle.

Slide 1

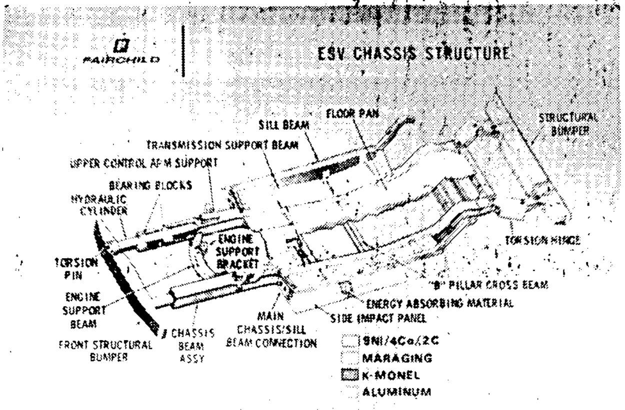
This three quarter view illustrates the program management decision that this Family Sedan should have the appearance and design of a real world automobile. The vehicle has a curb length of 220", it has a width of 80", and a height of 58" excluding the periscope. The chassis is mounted on a 121" wheelbase. The size of the car was dictated by the need to accommodate five 95th percentile occupants, and the padding required by the passive occupant restraint systems.

For the structural design approach we had several options based on our aerospace technology experience. We could have proceeded with a steel tubular truss structure covered with a non-structural material such as fabric – the way simple aircraft was built in the past. This technique would have offered a design easy to analyze and test, and cheap to manufacture. On the other extreme, we could have used sophisticated aerospace materials such as beryllium and titanium, which have very attractive strength-to-weight ratios. We chose the middle route: a structural design that would look and smell and feel like a real world car, within the manufacturing restrictions of a prototype vehicle. Our goal has been an integrated system design that would aid in the setting of future automotive safety standards.

I would like to go into the details of the structural configuration and then we will go into some performance characteristics.

This slide is color-coded to indicate some of the materials that we are using in the chassis structure. The dark blue is a 9-4-20 high strength steel, the yellow is a high strength maraging steel, the small red circles you see are torsion pins made of K-monel metal, and we have used some aluminum as indicated by the light blue.

Slide 2



Starting on the left of the figure we have the front bumper and the hydraulic cylinders. I would point out that the stroke of the hydraulic cylinders is 18" when the bumper is in the retracted position; in the extended position at speeds above 30 miles an hour we have a hydraulic stroke of 30". Continuing toward the right we have the front chassis beam assembly followed by the main chassis beams underneath the passenger compartment; in the rear you see our torsion hinge assembly in yellow. The arms of the torsion hinge assembly are designed not to yield. That is why they are made of the special maraging steel. I would point out that the particular design concept was dictated by the short time schedule of our program. In actual production we feel that an S frame could be designed by a repeated design/test/redesign program to give us the same results. Finally we see the rear bumper.

Slide 3

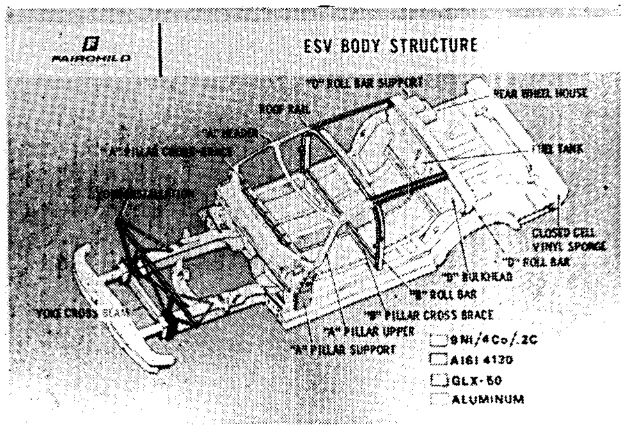
FAIRCHILD — STRUCTURAL MATERIAL PROPERTIES

TYPE OF STEEL	F_{TU}/F_{TY} (KSI)	% ELONG	CHARPY V NOTCH (FT-LBS)
9NI/4Co/.20C	190/180	14	45
18 Cr/15Mn STAINLESS	112/ 68	45	100
MARAGING STEEL	280/275	6	15
K - MONEL	140/100	25	80
GLX - 50	65/ 50	22	15
TYPICAL AUTOMOTIVE (1008)	**50/35**	**30-48**	**15-50**

In order to understand the choice of materials, we've made up a table showing some of the structural materials and their properties *(Slide 3)*. The first column shows the type of material, for example 9% nickel, 4% cobalt, .20% carbon steel. The next column shows the ultimate strength and the yield strength; for the 9-4-20 steel, it is 190,000 ksi for the ultimate strength and 180,000 ksi for yield. Also important in yielding structures is the percent elongation which is 14% for that particular steel. Also of use in evaluating materials for crashworthiness is the Charpy V notch value in foot-pounds.

We are using some stainless steels where we need very long elongations. As you note stainless steel has a 45% elongation. The maraging steel has an ultimate of 280,000 and a yield of 275,000 pounds per square inch, and the K-monel metal is somewhere between the strength of the stainless steel and the 9-4-20. The GLX-50 is a commercial grade of steel with a somewhat higher yield strength than the typical 1008 automotive steel which has only a 50,000/35,000 ratio of ultimate to yield. In order to get increased strength with minimum weight, our approach has been to go to higher strength steels rather than increase gauges.

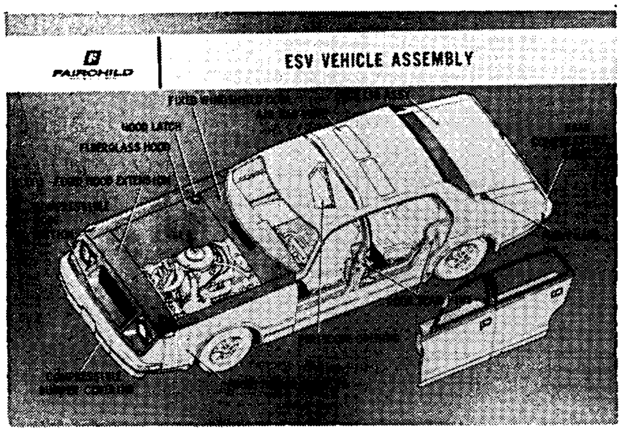
Slide 4



The next slide shows additional elements of the body structure *(Slide 4)*. You'll notice on the left side, in orange, is an AISI 4130 steel we use for our unique radiator bulkhead. This structure serves primarily for rollover protection; if you draw a line between the B pillar and the radiator bulkhead, that line limits the deformation at the A pillar to about 3 inches. We also see more of the 9-4-20 steel being used in the B pillar to improve rollover protection.

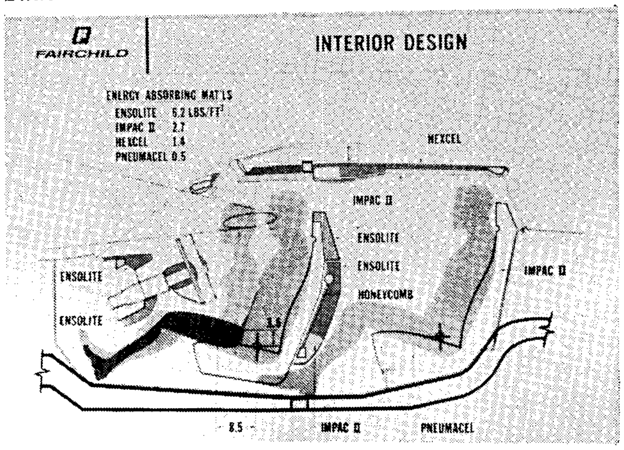
Here is the exterior view of the vehicle assembly which shows that we are primarily using conventional sheet metal on the outside of the car. Inside the doors you will find, not shown here, stainless steel side support beams which will be described later. They are stainless steel because we need very large elongation. This figure also shows the compressible nose section, just in front of the head lights. This will deform during a 10 mph frontal impact, and return elastically to its original position. Also shown in this figure on the roof is the position for

Slide 5



the periscope and for the airbag vent ports which we will discuss a little later.

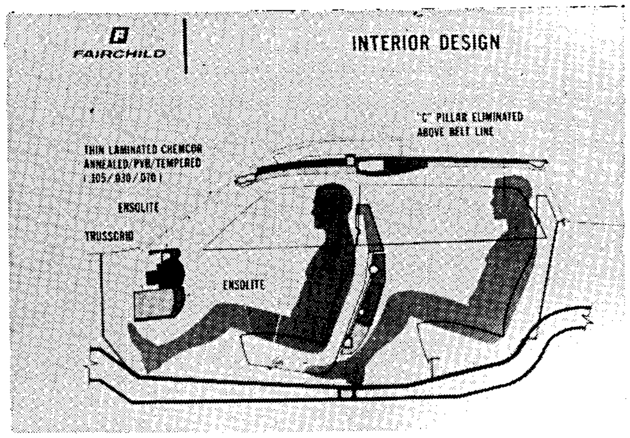
Slide 6



This is an interior view; let us look at the driver position first. The driver's seat range is 8½ inches fore and aft, 3½ inches up and down, in order to accommodate from the 5th percentile female through the 95th percentile male. The steering column is a conventional collapsible column with a forward and aft adjustment of the assembly to accommodate the range of drivers. Also shown in the driver's position is the blue impact area which is Ensolite. Let us look at the table at the top of the chart. This indicates some of the interior padding materials which we are using in our safety sedan. Ensolite, which weighs 6.2 lbs. per cubic foot, is a comparatively heavy material but it has much greater energy absorption per unit volume than any of the others. We are also using Impac II which weighs only 2.7 lbs. per cubic foot in less critical, secondary impact areas. We are using a Hexcel honeycomb which crushes at a prescribed pressure level, and it has a very attractive density of 1.4 lbs. per cubic foot. We are using Pneumacel in the actual seat cushions for comfort, and that has a density of 0.5 lbs. per cubic foot.

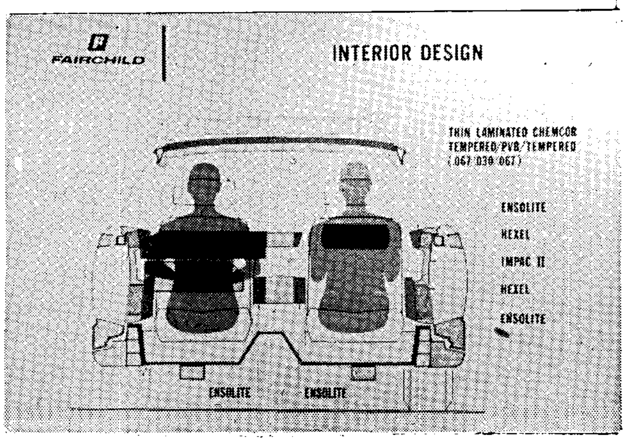
Getting back to the driver, the knee restraint for the driver is a one inch thickness of Ensolite backed up by a crushable panel. There is an airbag inside the deep dish steering wheel, and that bag would be activated at speeds above 15 mph. In this view you can also see the rear passenger. His airbag is mounted in the roof, and his knee restraint is basically Ensolite, backed up by that aluminum honeycomb panel. You can see the Impac II and the Hexcel honeycomb in the roof. It would be desirable to put in Ensolite there, but as it is considered a secondary impact area (it is very difficult to predict what will happen) we have chosen to save some weight there and go to somewhat less efficient Impac II material. Also shown here is the periscope subsystem made by Donnelly Mirrors.

Slide 7



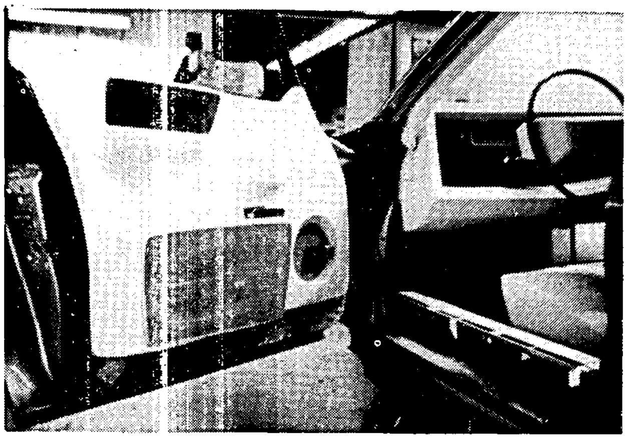
This view shows the front passenger position with the airbag mounted in the dash panel. The knee restraint is made of Ensolite, backed up with Trussgrid, a crushable honeycomb material. The windshield is a thin laminated Chemcor, such as we started to develop on our New York State Safety Car Program.

Slide 8



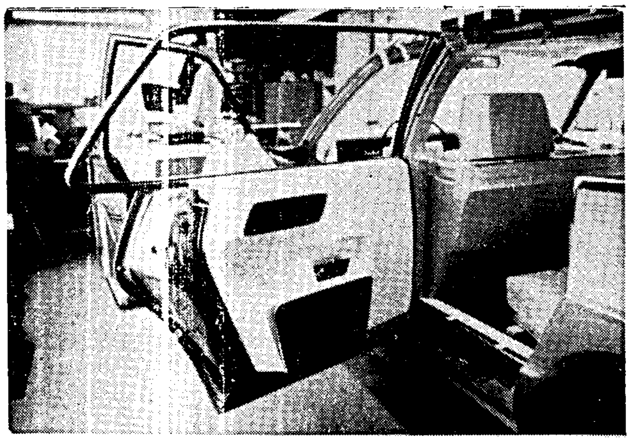
Here is a view that shows some of the side protection safety materials. We have a shoulder restraint. We have a hip restraint. These have been sized to consider the proportion of the weight in the body that has to load up these two areas. We're using a combination of Ensolite and Hexcel honeycomb. The Ensolite has the important characteristic of returnability, so that if you push on it lightly it will return to its original position. In a severe crash the Hexcel, if loaded up to its crushing level, will permanently deform and would have to be replaced. We also have a side support in the center, between the front passenger and the driver, which will serve to restrain them sideways if the crash is on the other side of the car.

Slide 9



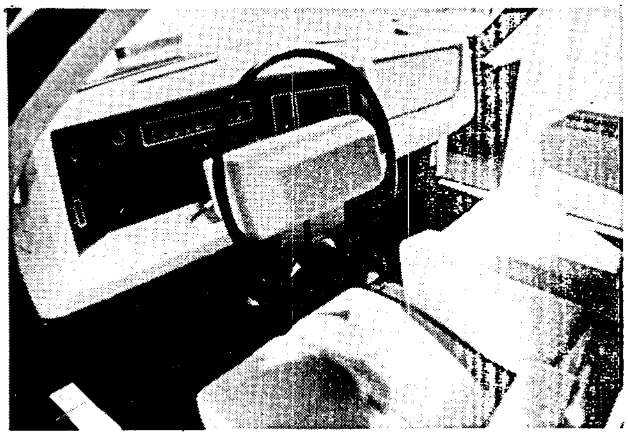
Here is a mockup, made by Loewy/Snaith, showing the front door with the shoulder restraint and the hip restraint and also showing access into the vehicle. We also see the recessed door knob and the window regulator.

Slide 10



Here is another view, showing the rear door. Notice the cutout on the door, which aids in getting in and out of the car at the rear seat. You'll also notice the very large rear door window that was done for two purposes: one was to increase visibility, and two, to try and get the head side impact area to be glass rather than a steel support post.

Slide 11



This is an interior mockup of the driver's position showing the location of the airbag and a partial view of the instrument panel.

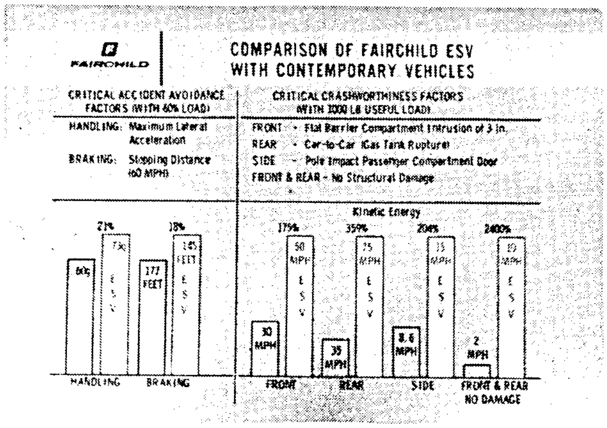
Slide 12

This mockup shows the unique rear system. The rear can accommodate three 95th percentile persons. The hip and arm supports that you see there move up when you want a person to occupy the center seat. It is a passive restraint in that it will normally be in the down position unless you physically push it up.

Now I'd like to discuss some of the performance characteristics and the details of the front impact subsystem which we consider to have the highest priority.

This slide indicates some of the performance that we have in the ESV in comparison to contemporary vehicles. On the left side we have typical accident

Slide 13



avoidance factors, for example, handling. The first two comparisons show that a typical car can sustain about .60 g's as the maximum lateral acceleration, and our ESV can get about .73 g's. Under braking, a typical stopping distance is 177 ft. for contemporary vehicles; our ESV is expected to stop from 60 mph in 145 ft.

But of greatest importance is the crashworthiness area, and we can see from the comparison for front impacts that contemporary vehicles have a capability of 30 mph for no more than 3 inches of intrusion whereby our ESV is expected to have a 50 mph capability. For rear impact, for example, if we use the rupture of the gasoline tank as the criteria, typical current vehicles can sustain about a 35 mph rear impact speed; our ESV should be able to take 75 mph by another ESV without gas tank rupture. For side impact, current vehicles have a capability of about 8.6 mph, our car will have a capability of 15 mph into a rigid pole. But the most dramatic improvement is in the front and rear no damage performance. Current vehicles, and by that I mean at the time the program was started, had a capability of perhaps 2 mph; we are going to have 10 mph front and rear capability with no damage.

We think that this kind of safety improvement is going to be dramatic. However, you don't get anything for nothing, and we just want to point out some of the weight increases we have had to incorporate into the vehicle which we have had very little control over.

For example, in order to accommodate the requirement for passive restraint (and that means the airbags and padding as opposed to a belt system), we have had to put in about 208 lbs. of weight. In order to improve the braking performance, using a Bendix-Chrysler type system there is a weight penalty of 72 lbs. We were forced to go to a periscope because the head restraints for the rear occupants effectively block out the backlight. The Donnelly Mirror Co. periscope system has

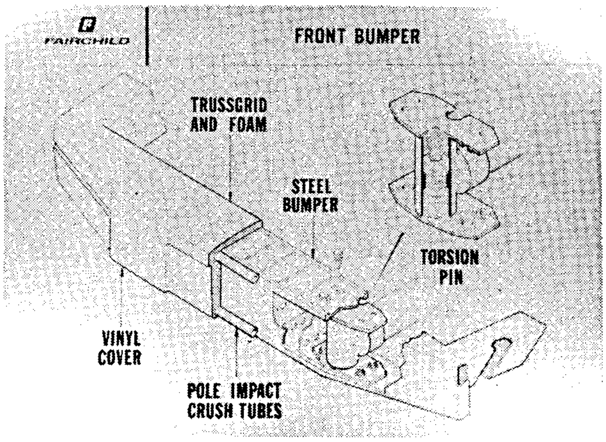
Slide 14

FAIRCHILD | MANDATORY WEIGHT INCREASES

ITEMS	WT/LBS
PASSIVE RESTRAINT	208
ANTI-LOCK BRAKES	72
PERISCOPE	45
SEAT ADJUSTER	19
ANTI POLLUTION (73 vs 71)	25
TOTAL	+369 LBS

added about 45 lbs. Seat adjusters to accommodate the range of the driver and be able to stay in place during the 50 mph crash conditions has added 10 lbs. Anti-pollution requirements to raise the engine capability from the 1971 emission requirements to the 1973 emission requirements have added 25 lbs. A total of 369 lbs. has been added in terms of things we had no control over in order to meet the requirements.

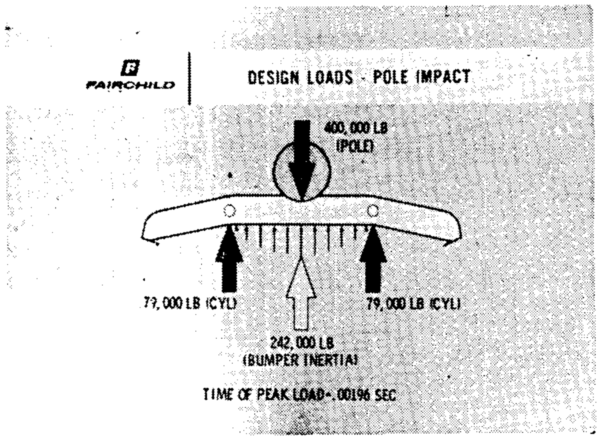
Slide 15



This is a close-up of the front bumper. The bumper itself is made of steel and is covered with Trussgrid and foam, and finally by a vinyl cover. You will see the two pole impact crush tubes which are made of stainless steel; these are there primarily to help absorb the kinetic energy of the bumper itself during a front pole impact at 50 mph. Also shown are the torsion pins that connect the hydraulic cylinders to the front bumper; these aid in getting us better performance in angular impacts which is of course, one of our requirements.

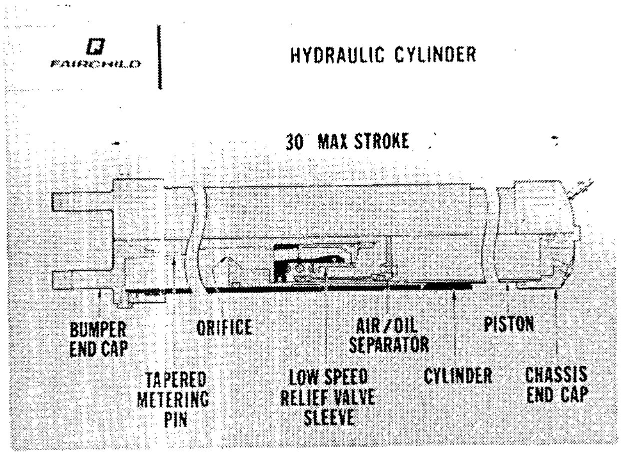
The most severe condition for that front bumper, which I indicated, is pole impact. This shows the

Slide 16



analytical prediction of the loads to which we designed our bumper: the hydraulic loads are only 79,000 lbs. per cylinder at the time you get the worst inertia loading on the bumper. The inertial loads due to the mass of the bumper are 242,000 lbs., for a total load of 400,000 lbs. We have designed the bumper to take that kind of load; we hope the pole can take it.

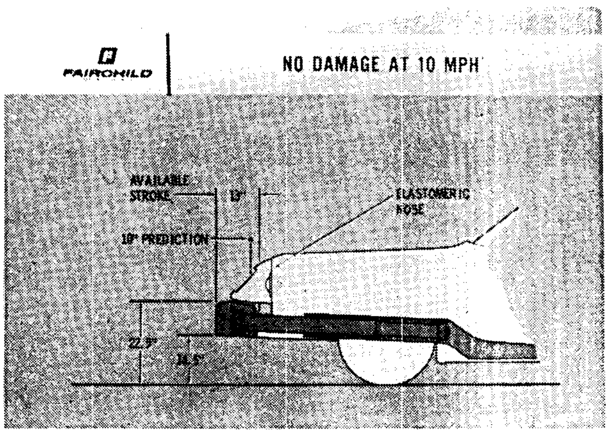
Slide 17



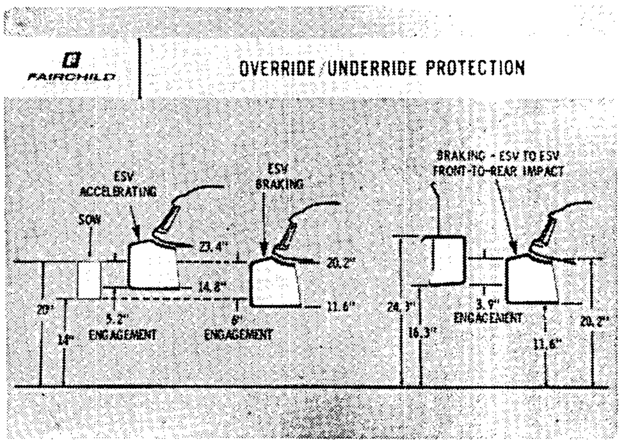
This is a view of the variable orifice hydraulic cylinder. Starting on the left, we have the front bumper end cap, then the gray is the tapered metering pin, the blue is the piston, and the space between the blue and the gray represents the orifice which is a function of stroke. Also shown is the low speed relief valve sleeve assembly which gives us the 10 mph no damage design with returnability.

This slide illustrates the front design where we expect no damage at 10 mph by the addition of the elastomeric nose which is colored green. The bumper stroke we predict on the complete ESV to be about 10", compared to an allowable stroke of 13" before we would get any damage.

Slide 18



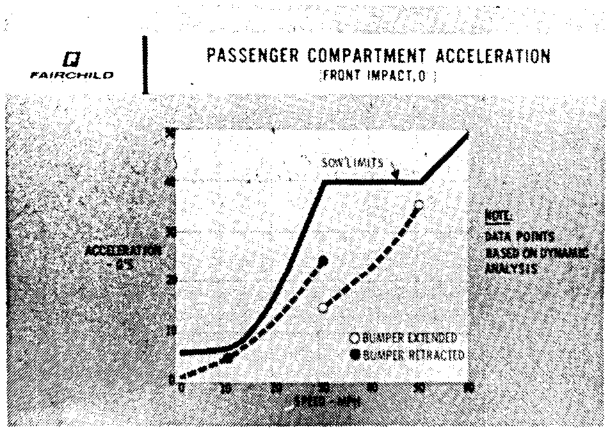
Slide 19



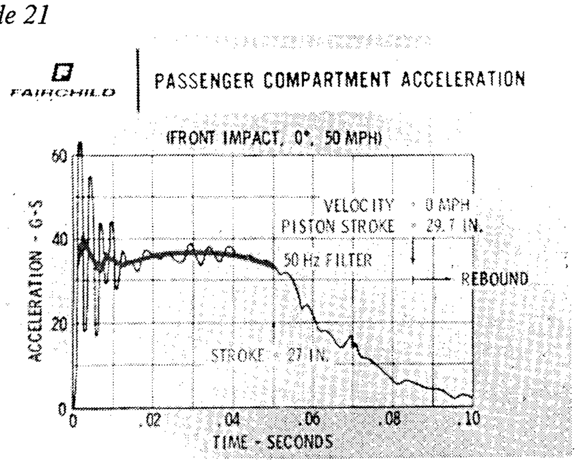
Override/underride protection is a significant criteria in our Statement of Work. If the ESV is accelerating, the first figure on the left shows that the bumper would have a 5.2" engagement with the Statement of Work (SOW) body block. If the ESV is braking, the second figure shows that we would have a 6" engagement with the body block. On the extreme right, we have the case of car-to-car impact with both vehicles braking. The front bumper of one vehicle goes down, the rear bumper of the other vehicle goes up and we have a 3.9" intersection. So we feel we have provided very adequate override/underride protection.

With regard to crashworthiness performance, this curve summarizes performance for zero degree front impact. The vertical scale shows acceleration in g's, the horizontal scale shows speed in mph. The heavy black line is the Statement of Work limits, and the dash lines show our expected performance based on dynamic analysis. The analyses are based on a nonlinear transient analysis computer program that we have used for this and other crash conditions such as angular impact and pole impact, and this is a typical result. The dashed curve on the left represents the retracted bumper position; the dashed curve connecting the open circles is the extended bumper position. As you can see we expect to be well within the specification.

Slide 20



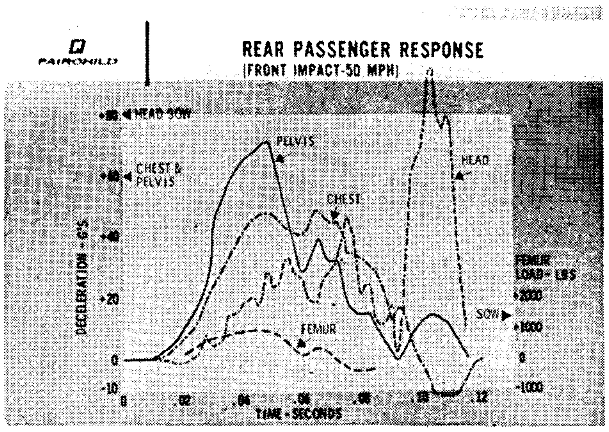
Slide 21



To give you an example of how we got the points on the previous curve, this figure shows how we got the 50 mph data point for front impact. This figure shows acceleration on the vertical scale, versus time on the horizontal scale. The black wiggly curve is the output from our digital computer program which includes all the vibration modes of the structure; the red line is an estimate of what the data would look like if it were filtered with a 50 Hertz filter. Clearly, we are coming in with very close to a square wave for the first 27 inches of stroke. The total stroke is 29.7 inches, and the curve also shows that after a certain time, .085 seconds, we start the rebound. From our experience in the test program we expect a rebound velocity in the order of 3-5 mph in a 50 mph crash.

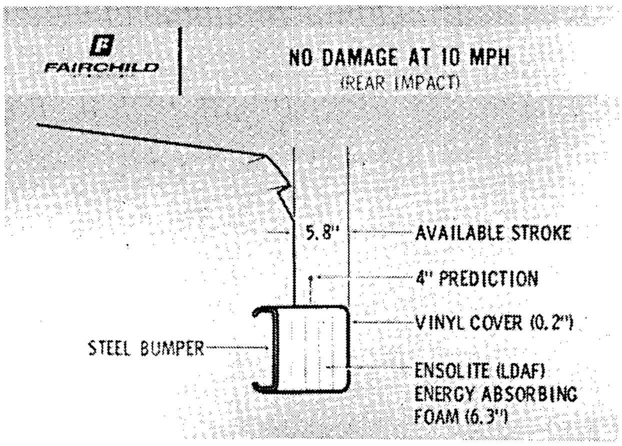
This is a typical passenger response analysis. The vertical scale is deceleration, the horizontal scale is time in seconds. On the right vertical scale we have femur

Slide 22



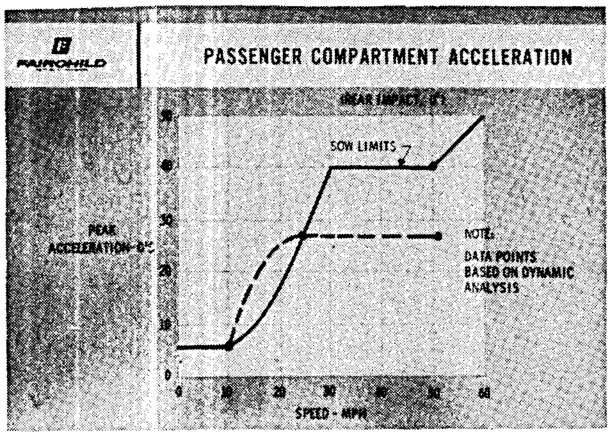
loads. These are the results of a dynamic analysis for the rear passenger which is the most complex position in the car because the airbag hits flexible structure, namely the front seat backs. We see the deceleration curve for the pelvis going up to about 70 g's which is somewhat higher than the SOW limits indicated by the arrows on the right scale: 60 g's for the chest and pelvis and 80 g's for the head. The chest level seems to be below the 60 g level. The head g's at the end of the time period suddenly take a sharp spike up. This is probably a problem with the dynamic model of the occupant we used because the head bottoms out on the chest. We don't expect that kind of head performance in the actual tests that are currently being conducted on a body buck at Wayne State University. The femur loads are well within the 1400 pound allowance. These analyses were used to estimate the effect of occupant loads on the structural design.

Slide 23



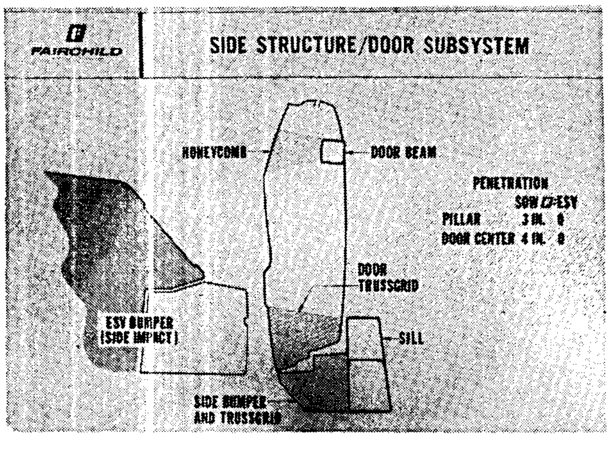
For the rear impact subsystem we have a "no damage at 10 mph" requirement. Our system in the rear is a 6.3" depth of Ensolite energy absorbing foam which will deflect about 4 inches during the 10 mph impact by the J972 moving barrier, and there will be no damage. The torsion hinge assembly will not yield because the loads are low.

Slide 24



Here is a curve showing acceleration on the vertical scale vs. speed on the horizontal scale for the rear impact subsystem. The heavy black line indicates the Statement of Work performance requirements; the dashed line is our predicted performance. You will notice that in the speed range of 30-50 mph our system design is much better than the SOW requirements; however, in the lower speed 10-20 mph region we may slightly exceed the allowable limits. We feel that the trade-off in getting the lower g's at the high speeds more than outweighs the slight deviation at the lower speeds.

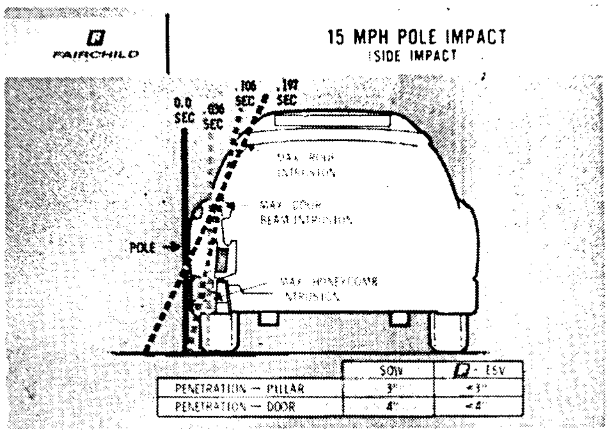
Slide 25



Looking at the side structure, we have a cross section of the door. At the bottom of the door we see the main sill. In front of it is Trussgrid which is like an aluminum honeycomb but is less sensitive to impact direction. For a car-to-car crash we have shown the front bumper level of the striking ESV. We expect that we can take a 30 mph impact when the bumper is retracted and at least a 35 mph impact if the bumper of our car is extended. Essentially, we will have no penetration under these conditions in a car-to-car impact.

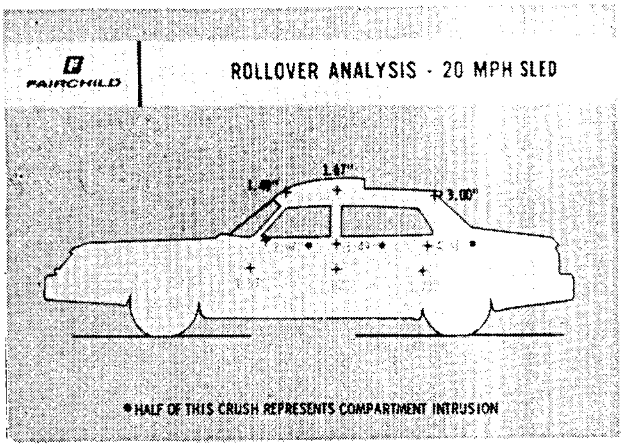
Also shown in the door is the upper door beam which has honeycomb in front of it. This is not specifically required for car-to-car impact but is required for pole impact, which is described on the next slide.

Slide 26



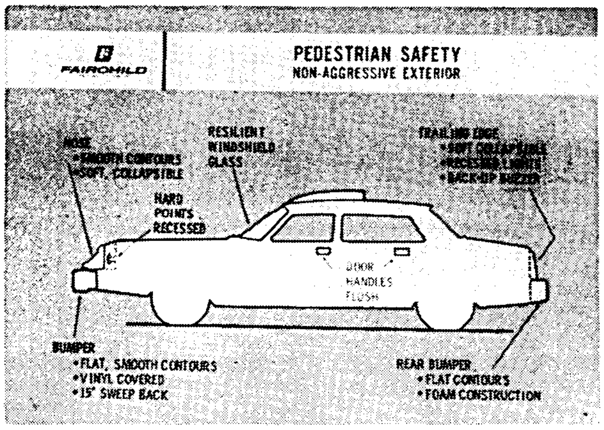
When the car hits the pole, it is the car that is going to roll. For convenience we have shown the relative position by rotating the pole. What happens is that in a 15 mph side pole impact the car will initially strike the pole at the lower sill. This induces a rolling motion and if we didn't have that door beam in the upper part of the door you would get large penetration at that particular level. This figure shows the successive penetration of the car into the pole, and the red line (.197 sec.) shows the maximum penetration at the roof line. Based on these analyses we expect that penetration will be limited to 3 inches at the pillar and 4 inches at the door.

Slide 27



For rollover we conducted analyses for a 20 mph sled test. That sled test is the Mercedes type of test, where the vehicle is mounted at 23° and run down a sled and caused to roll. We feel this 20 mph speed will be sufficient to roll the car twice. Based on the dynamic analyses we have shown some of the deformations that we expect on the side of the car, the maximum deformation being 4.33 inches. However, only half of that number is actual penetration; the rest is crush of the outside of the car.

Slide 28



Primary consideration, of course, has been given to occupant injury reduction as per our Statement of Work; however, we have given consideration to the pedestrian problem. You'll note that the collapsible nose section on the front is soft and is not a pedestrian hazard. We have also swept the front bumper rearward 15° on the outboard ends which helps to deflect the pedestrian out of the path of the car. The bumper is fairly smooth and we think it is the best design we could get within the other restrictions on the vehicle.

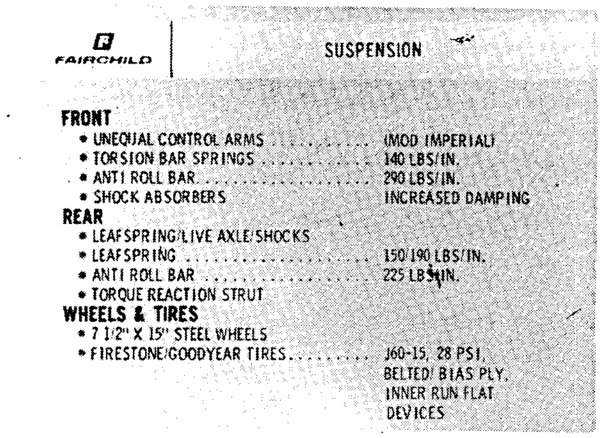
On the rear of the car we have, of course, a flat contour and our Ensolite foam material has a very soft impact surface, so we think we don't have any problems there. We also have added a warning buzzer to warn pedestrians. On the side we have a smooth shape and even the door handles are recessed.

That is the end of the crashworthiness part of the session; Mr. Wait will now continue with the Accident Avoidance characteristics.

Mr. W. Wait:

Thank you Sol. Before engaging in any discussion on the Accident Avoidance criteria of the car, I think it's proper to discuss a little bit of the priorities of the program. The primary thrust of the program as Mr. Davis has stated, was directed towards the improvement of crashworthiness. As such, the vehicle configuration and the performance of the other subsystems of the car, were to be traded, if there were to be any trades, in the terms of improving the crashworthiness. As such the configuration of the car was dictated in this fashion. Further, the handling requirements of the vehicle do not represent any breakthrough or state-of-the-art developments. They represent a good present automobile, and this is what we feel we've done with this car – developed an automobile that will have good handling and be fun to drive. How did we get there? First of all we utilized two chassis mules; one was a 1970 Plymouth which was modified by installation of ballast, suspension components, and wheels and tires. The second was a Chrysler Imperial equipped with anti-lock brake system, and ESV wheels and tires and ballasted to the ESV weight and distribution.

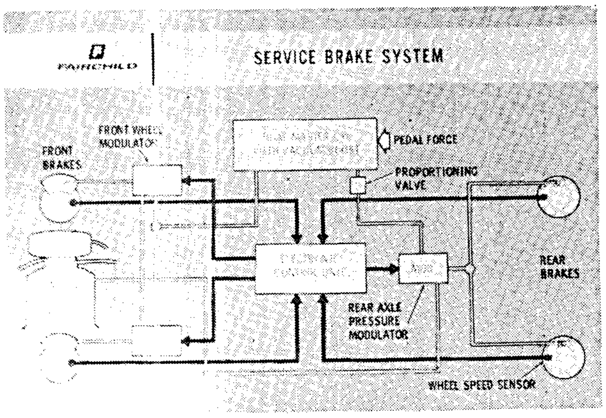
Slide 29



Now, if we may, let's consider first the chassis structure. What does this consist of? In order to fit the front energy management system in, a torsion bar front suspension system was the most logical arrangement; therefore we did use the torsion bar with unequal control arms, which were modified Imperial components, a front anti-roll bar and shock absorbers with increased damping. The rear suspension was quite conventional, leaf spring, Hotchkiss live axle, shock absorbers, but again with the addition of an anti-roll bar and a torque reaction strut. Wheels and tire are tire-wise either Firestone or Goodyear; J size, 60 aspect ratio, and 15 inch rim diameter. They're belted bias construction, equipped with inner run flat devices, which precludes the requirement for carrying a spare in the car. They are operated at 28 psi in the normal tire chamber and approximately 15 psi higher than that in the inner tire chamber. Wheels are 15 inch diameter rim, with a 7½ inch rim width.

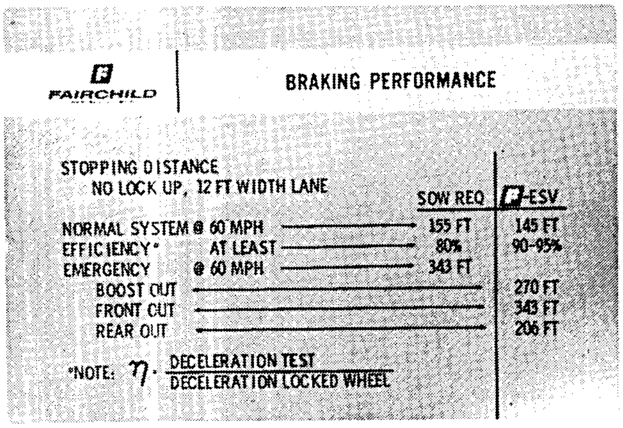
The braking system, again in avoiding the trap which is so easy to fall into, "to reinvent the wheel," we utilized normal components wherever possible, and

Slide 30



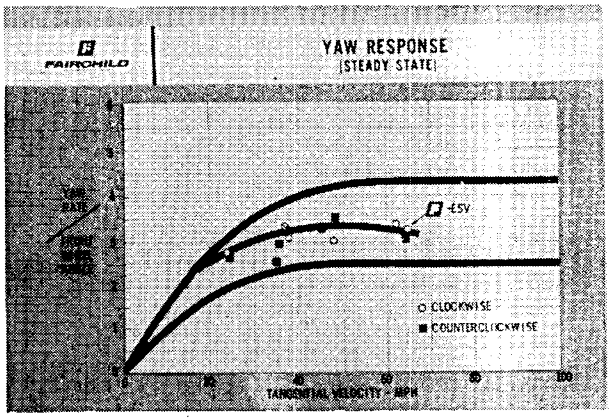
modified when necessary. The brake system is composed of the Imperial foundation brake system, of disc brakes in front, drum brakes in the rear, a dual master cylinder with a front to rear split, a proportioning valve, and a vacuum boost system. This system is modified further by the addition of the Bendix-Chrysler "Sure Brake" system composed of wheel speed generators at each wheel, electronic logic control unit, modulators for each of the two front wheels, and a single modulator which functions to dump pressure to both rear wheels when either rear wheel indicates a skid signal.

Slide 31



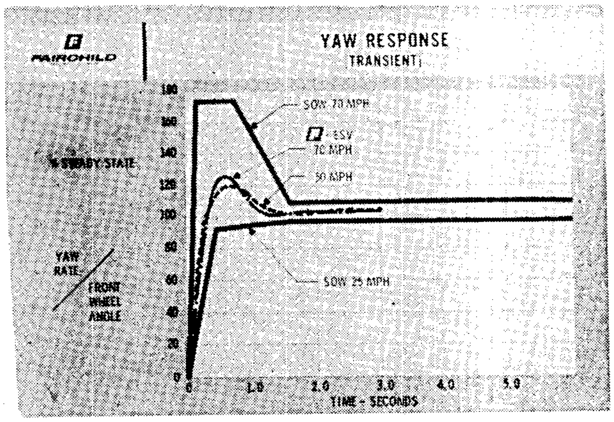
We have obtained the following performance with this system, well within the requirements of the Statement of Work. Stopping distance with normal system operation on dry pavement has averaged in the order of 145 feet against the 155 feet requirement. The best stopping distances achieved have been in the order of 136 feet. The efficiency we have achieved has been approximately 90-95% against 80% requirement defined in terms of the test deceleration noted vs. a locked wheel deceleration. Emergency stopping distances, again from 60 mph, against a requirement of 343 feet have achieved a distance of 270 feet with the boost out, 343 feet with the front brake system inoperative, and 206 feet with the rear brake systems inoperative.

Slide 32



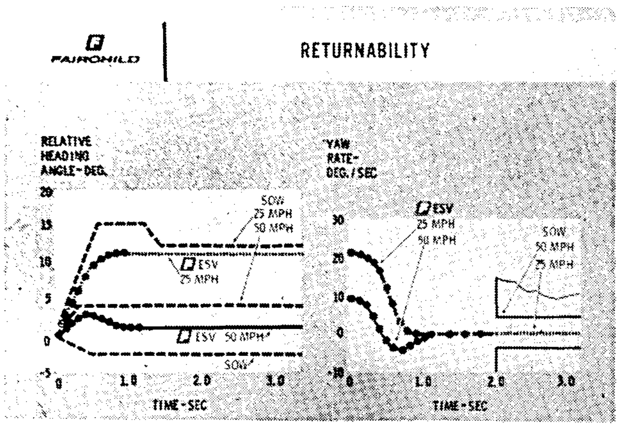
Next area of interest to us will be the steady state yaw response. This chart presents the standardized format of yaw rate, that is, yaw rate divided by front wheel angle, vs. vehicle velocity. The red lines define the allowable envelope and the blue line defines the test data which we obtain. It will be noted that the curve is concave down as required by the Statement of Work. Also to be noted it is well within the allowable envelope.

Slide 33



The transient yaw response is shown in the form of a time history. Again standardized yaw rate, yaw rate divided by front wheel angle, however, in this case it is presented in terms of a percentage of a steady state value. That steady state value being the standardized yaw rate required to generate a lateral acceleration of .4 g's. The green lines indicate the allowable envelope, the upper representing the 70 mph limit and the lower speed limit. The two curves shown, 50 and 70 mph, will be noted to lie within the allowable envelope.

Slide 34



The returnability is determined by establishing a lateral acceleration at various speeds of .4 g's and releasing the wheel. This also is shown in the form of a time history, however in this case it is shown as a relative heading of the vehicle response and the yaw rate of the vehicle response. The upper dotted line represents the maximum allowable deviation in the heading when released from 20 mph, the lower or middle dotted line represents the higher speed or 50 mph limit. Two curves with the data points illustrate the vehicle response. Again well within the allowable envelope.

The curve on the right presents the same data in terms of vehicle yaw rate. The upper and lower envelope representing boundaries which cannot be exceeded, and the dotted line through the middle representing a total damping at 25 mph.

Slide 35

FAIRCHILD | LATERAL ACCELERATION

100 FT RADIUS, MANUAL CONTROL,
DRY SURFACE, DESIGN TIRE PRESS.

SOW .65 g
ESV .73 g

The maximum lateral acceleration as defined in our Statement of Work called for several configurations of tire pressure and surface condition. However, we utilized this parameter as a tool to develop our overall cornering power, and devoted our energies almost entirely to the dry, design pressure area. We felt that if we obtained sufficient margin in this area we would have no difficulty in meeting the off design and low friction coefficient requirements. As you can see, we were able to generate a lateral acceleration well in excess of the requirements and this has given us the confidence that there will be no problem in meeting any of the off design conditions.

Slide 36

FAIRCHILD | HANDLING

CONTROL AT BREAKAWAY
REGAIN PATH IN LESS THAN 4 SEC

RADIUS	TIME	
	SOW	ESV
100 FT	4 SEC	2.35 SEC
225 FT	4 SEC	-
417 FT	-	2.45 SEC

Control at breakaway test is conducted by driving on various radii at maximum attainable lateral acceleration, then increasing the speed until the radius is increased by 10 feet, at which time the throttle is closed and the vehicle returned to the original path. Statement of Work requirement allows 4 seconds to return to the original path. We have been able to achieve this in under 2½ seconds on both the 100 foot radius and a 417 foot radius circle. No problem is anticipated in this area either.

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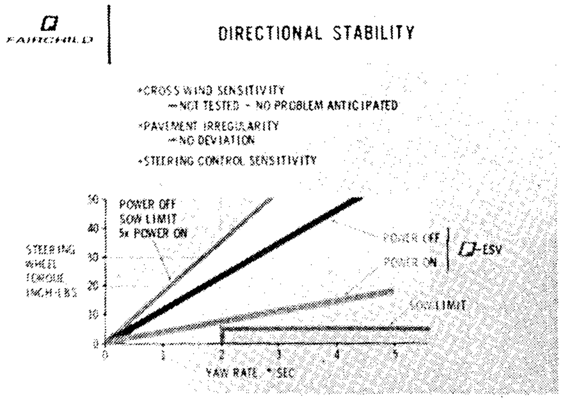

Directional stability is broken into three basic components. First the vehicle sensitivity to cross winds. This was not investigated with the chassis mule as we did not feel it was a true aerodynamic representation of our final car. Further, most modern American automobiles do not suffer from this to any great degree, therefore this was not investigated.

The pavement irregularity on the other hand, was anticipated to be somewhat of a problem; the very low aspect ratio tires used were anticipated to have a pull or nibble tendency when crossing pavement irregularity such as trolley tracks or any of the pavement separators at various angles. However, much to everyone's surprise the vehicle was completely unresponsive to any of these disturbances.

The final area involves that of steering control sensitivity, and a Statement of Work requirement that for a 2° per second yaw rate, a wheel force of no less than 5 inch-pounds of torque is required. The blue line represents the vehicle performance in the chassis mule, resulting in 7 inch-pound torque requirement, somewhat in excess of 5 inch-pound requirement. The "power off" requirement, when the steering boost is inoperative, is that the force shall not be more than 5 times the "power on." This provided us with an allowable torque "power off" at 2° per second yaw rate of 35 inch-pounds. The black line represents the vehicle performance in this area, again well within the allowable performance.

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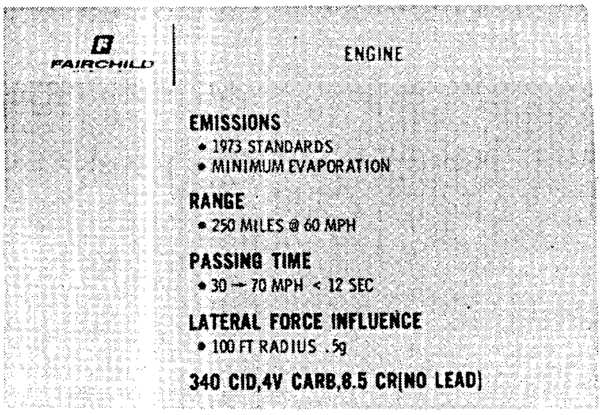

The engine must meet the 1973 emission standards and have a minimum fuel evaporation from the fuel system. The engines which we will utilize have been run and successfully demonstrated to meet these emission standards and the fuel system is equipped with the various check valves, filters and ingestion systems to eliminate all practical fuel fume evaporation. The range requirement of 250 miles at 60 mph is believed attainable although not tested at this point in time, but the fuel capacity, rear axle ratio, automatic transmission which we are utilizing should result in satisfying this requirement. Passing time requirement 30-70 mph in less than 12 seconds is also believed attainable with the drive line components and engine performance which we are utilizing. Lateral force influence, that the vehicle will not suffer a power fluctuation when subjected to a half g laterally has been demonstrated satisfactorily. The engine is a Chrysler 340 cubic inch displacement V-8, equipped with a four barrel carburetor, 8½ to 1 compression ratio, operable on low lead or no lead fuels.

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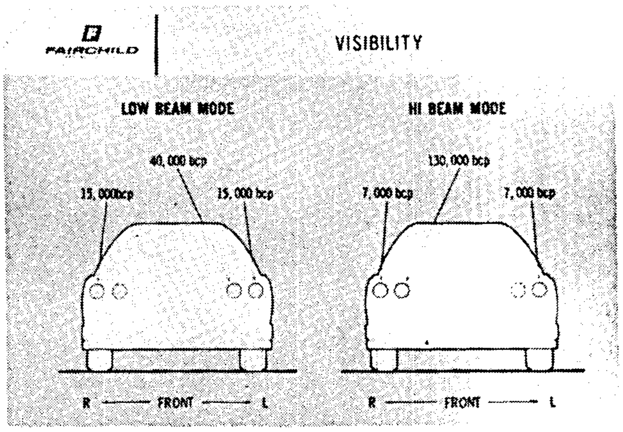

The visibility area will be discussed next. The head lighting utilizes a GE 3 light, sealed beam system. In low beam mode of operation, the two outer lights are operated at 15,000 beam candle power, while the left hand inboard light is operated at 40,000 beam candle power. In high beam mode, the two outboard lights are reduced to 7,000 beam candle power, and the right hand inboard light is illuminated at 130,000 beam candle power.

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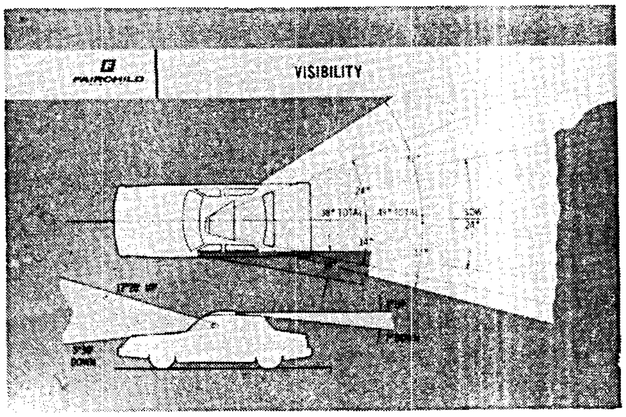
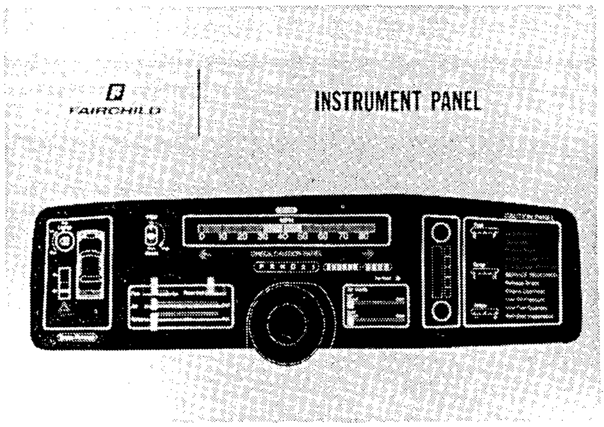


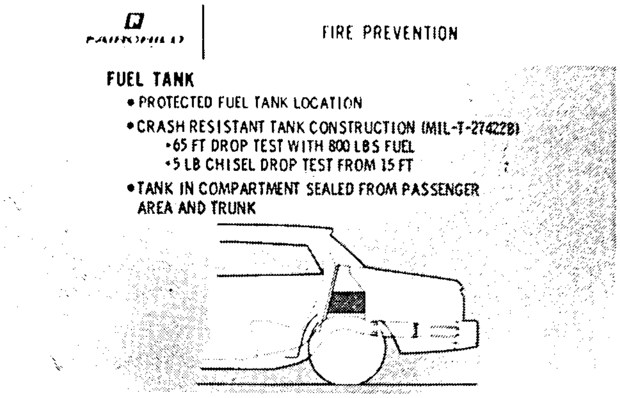
The driver's visibility will be discussed next. The Statement of Work requirements called out a 24° included angle of visibility to the rear; utilizing the periscope we are able to achieve a 49° included angle to the rear, 32° to the right, 17° to the left. Utilizing the same rearview mirror, which is adjustable by the driver to look directly out of the rear window and not through the periscope, the yellow area of visibility is realized here as a 38° included angle. The question of if we could get this visibility with just the rear view mirror why bother with the periscope. The prime reason for this was to achieve the down angle visibility which is effectively blocked off when utilizing the normal rearview mirror through the rear view window by the seat head rests. The forward visibility upward angle has been achieved quite handily, however we have not met the downward angle at the driver's position in spite of the very large envelope of driver seat movement. We have chosen to take exception to this limitation in view of our yoke rollover protection and in view of the priorities of the program in terms of crash injury reduction we felt that rollover protection should take precedent over the visibility requirement.

Slide 41



The instrument panel represents some unconventional or aerospace techniques and some normal automotive methods. The center of the panel represents normal driver information system, utilizing a speedometer, odometer, heater control, fresh air controls, turn signals and passing beam, warning light and windshield wiper operation switches, all these are the normal conventional system. On the left side we have the lighting panel. In addition to the normal push/pull switch to activate the headlights and parking lights on and off, the twist to control the intensity of illumination of the instrument panel, a plan view of the car is provided with indications of the status of each of the lights on the car provided by fiber optics; when a light is illuminated it will appear as an illuminated light on the plan view car. The emergency warning flasher operation is next to the plan view car. If we move to the right hand side the radio is quite conventional and the normal driver advisory instruments in terms of fuel remaining, coolant temperature and generator status for the electrical system. However, the extreme right portion of the car is where we utilized what is referred to in fighter aircraft as a "peek and panic" or a master caution panel. Directly under the speedometer you will note the words, "Check Caution Panel." These are illuminated, your attention is directed to the extreme right hand side where one of the legends of several items underneath the caution panel will be illuminated. The red ones are those which require stopping the car, and immediate attention, such as a door is open, a brake system malfunction. The yellow items represent service items, which require service at the earliest convenience, like low oil pressure, high coolant temperature; things of this sort.

Slide 42



In terms of fire protection, we have looked at several areas. The primary area is the fuel tank, being the largest source of fire within the car. It is located in a position where we believe it is well protected from impact, being well in from the rear of the extremity of the automobile, and between the two rear wheels. The tank is made in accordance with a Department of Defense Specification required for combat helicopter fuel tanks. When these tanks are used for helicopters, utilizing this fabrication technique, they must be capable of being dropped without rupturing from 65 feet containing 800 pounds of fuel. They must also be capable of withstanding the impact of a 5 pound chisel when dropped from 15 feet. In addition the tank compartment is sealed from the front passenger compartment and from the rear trunk compartment of the car.

The other areas of fire protection which we have addressed have been the satisfaction of the Motor Vehicle Safety Standard 302. We have a check valve in the fuel system to protect any spillage of fuel in the event of overturn of the car, the fuel feed line is all metal and equipped with breakaway fittings, which seal when broken, at the chassis engine interface and an automatic battery disconnect has been provided.

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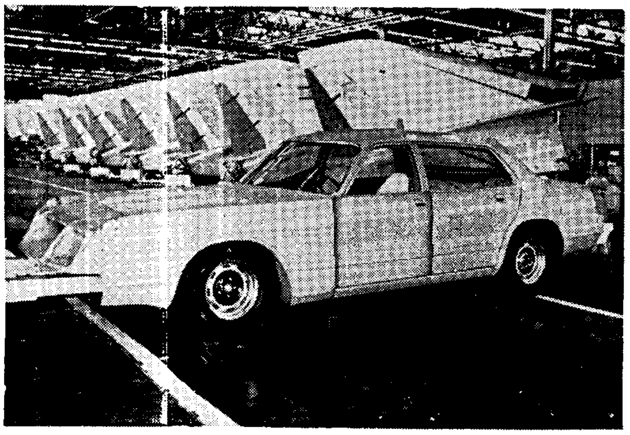
Slide 44



Next question that might be asked is where do we stand now? This is the car, as we took it off our final assembly fixtures, just before we came over here. At this point in time it is about to be shipped for final chassis tuning tests, and it will be delivered to Secretary Volpe on December 25. Thank you.

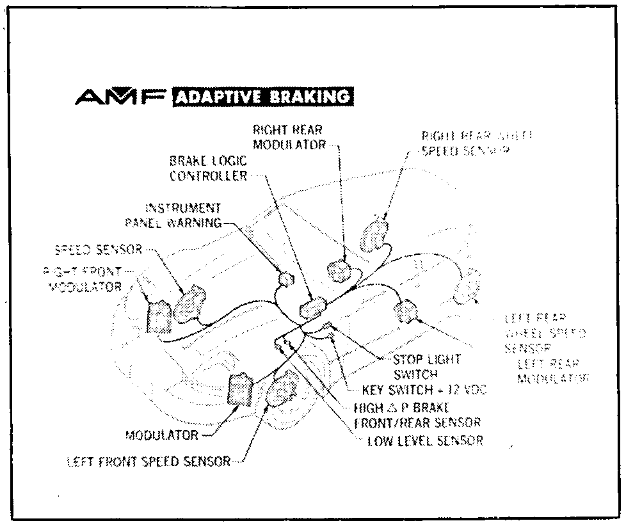
AMF INCORPORATED

Mr. Alan H. Roth
Director

Members of the conference, AMF will provide to you a brief description of the general features of the automobile in the form of a short slide and motion picture presentation. I will then conclude my part of the presentation with a status report as to the construction of our vehicle. Then I will turn the microphone over to Mr. Wingenbach who will discuss the crashworthiness features of the vehicle, and show your our most recent test results, in the various energy management and structural systems.

AMF, as you may know, is a leading producer of leisure time and industrial products. We are known for our AMF pinspotter bowling equipment, our Head skis and Tyrolian bindings, Voit basketballs, undersea equipment, Harley-Davidson motorcycles, Ben Hogan golf clubs; and also, our very special machines which form and tie the pretzels which go so well with the beer over here. The Advanced Systems Laboratory in Santa Barbara has been involved with many of the U.S. aerospace programs. While we don't build automobile vehicles, we have developed special one- or two-of-a-kind vehicles for the space program. Things such as the Saturn Missile Transporter, large rocket stage transporters, and many of the mechanisms and systems in the Crawler for the Apollo program. We've been a contractor to DOT for the past four and a half years.

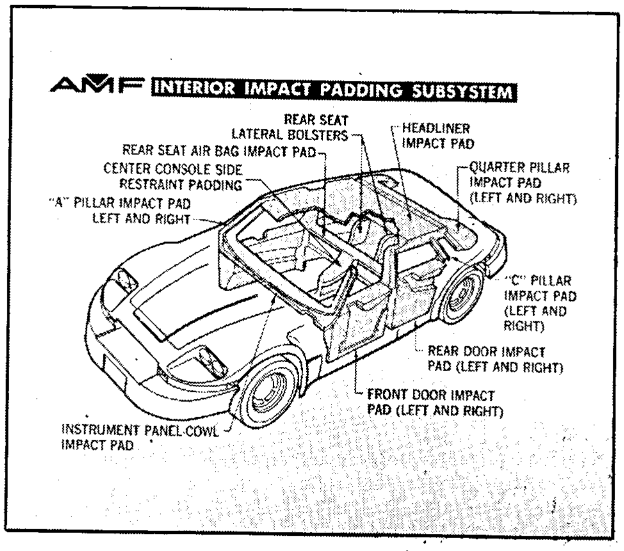
Slide 1



The first slide shows the vehicle's adaptive braking system. Bendix Research Labs is supporting AMF in this area and providing the adaptive braking system. This particular slide shows the location of the modulators and speed sensors for the adaptive system. A sensor on each wheel sends a signal to an electrical control unit in the trunk which controls the actuation of three modulators, one each for the front wheels and one for the two back wheels together. The control unit causes the modulators to release the brake pressure to the wheel that is about to lock up. In the adaptive brake system, hydraulic pressure is controlled so that the wheels never do lock up; and therefore, steering control is never lost during braking actions. The system is inactive under 10 miles per hour.

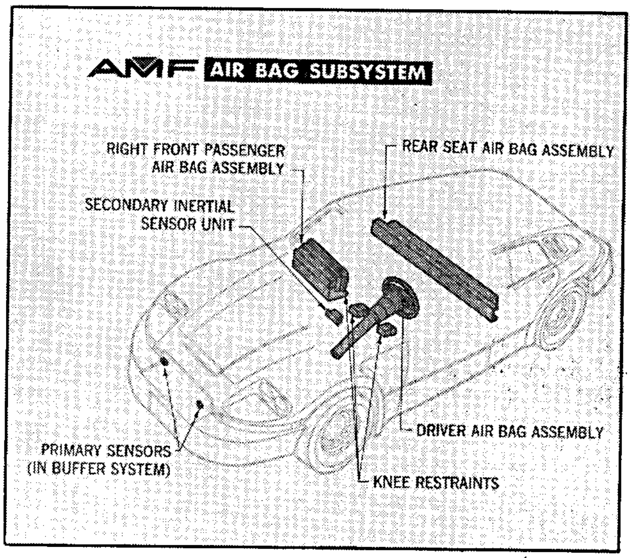
The interior impact padding subsystems are shown on the next slide. The padding itself is made of a polyure-

Slide 2



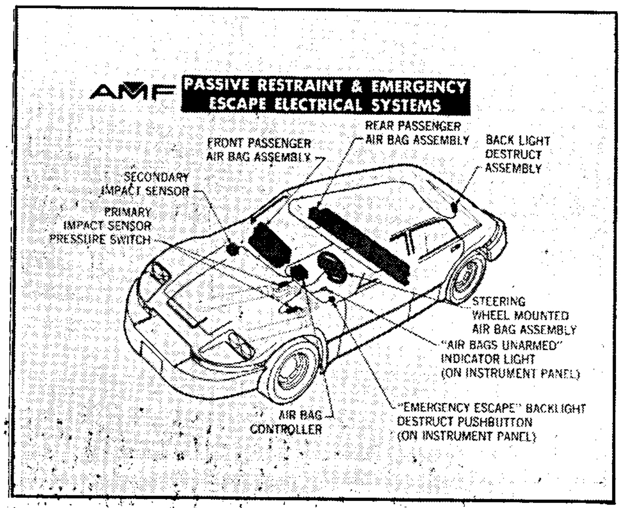
thane foam, which is sculpted and glued in place in the passenger compartment. The interior is fire-retardant and fire-resistant. The foam padding protects the unrestrained occupant in collisions up to 20 mph.

Slide 3



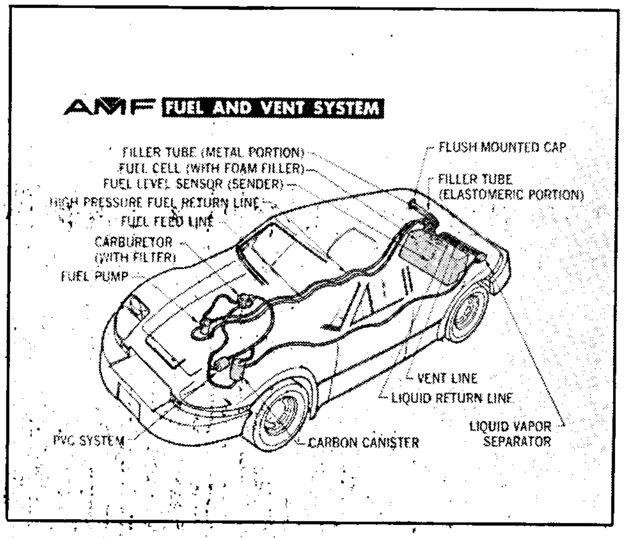
The next slide shows the location of the airbag subsystems. The rear airbag compartment contains the three individual airbags for the rear passengers, and is located approximately chest-high in the rear of the front seat. There are two separate systems in the front: a right front occupant and a steering wheel system. The airbags are being provided by the Eaton Corporation Safety Systems Division in Troy, Michigan. The airbag systems are actuated using squibs and a high-energy cooled gas generator system.

Slide 4



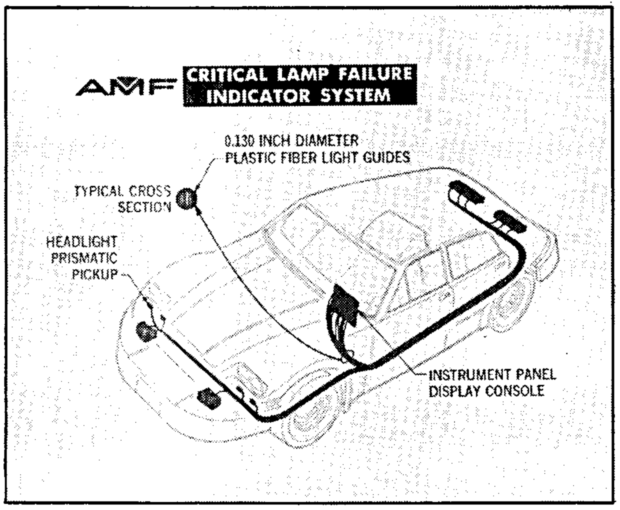
The next slide shows the passive restraint electrical system, showing the location of the pressure sensors for the airbag systems, located in the front energy management system buffers, and the location of the back-up inertial sensor, which is called the secondary impact sensor. Only 4 milliseconds are required for response time by the pressure transducers mounted in the front buffers. Total actuation time is 30 milliseconds.

Slide 5



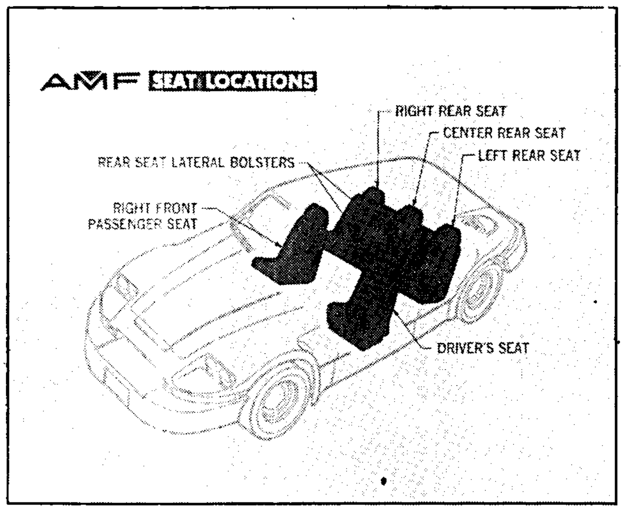
The fuel system depicted on the next slide utilizes a flame-proof fuel tank or fuel cell which is provided by Don Allen. G-sensitive electrical system disconnects add to the fire preventative characteristics of the vehicle. For impacts above 14 g's, the electrical system is disconnected from the battery and grounded.

Slide 6



The lighting systems include flashing turn indicator lights, both front and side markers. In the rear, there are three individual lamps on each side mounted at bumper height; stop lights, rear taillights and turn lamps and the backup lamps. Glazing for the front windshield is laminated safety glass as it is in the rear doors. Front doors utilize tempered glass. The rear backlight is tempered glass which shatters when the airbag actuates, to relieve pressure in the passenger compartment.

Slide 7



The next slide shows the passenger seats, two in front, three in rear. There is a console, separating the front passenger from the driver for restraint purposes. The seat structure is made of special high-strength steel frames with foam padding over rubber strip supports. The seats can withstand over 40 g's.

The bumpers provide the "no vehicle damage" protection for low-speed collisions at 10 mph or under. The front bumper will stroke 9 inches at 10 mph and slowly return to its normal position after impact. The normal bumper stroke is 30 inches in the front and 15 inches in the rear. The system is a velocity-sensitive one utilizing a variable orifice principle. The hydraulic cylinders are 4 inches in diameter and are made of high-strength alloy steel. The bumpers themselves weigh about 100 pounds each and are made from high-strength aluminum alloy forgings. There is a torsional linkage from the bumper to the cylinders to allow for oblique impacts and the differential stroking which results. The system has a hydraulic crossover feature which allows for both cylinders to share the load. Bumper wing tips. fastened by splines are made to yield or deform under certain loads, thereby absorbing some of the load.

In the following film, the exterior styling model shows the original concept of the vehicle. It has a wheel base of 121 inches and overall length of 220 inches. In the final version, the front and rear bumpers are less massive, and all exterior panels are made out of fiberglass. The interior buck shown here was a design tool used to try out and to improve the interior seating arrangements; also the placing of the critical items, such as the tilt and telescope steering wheel; the driver's seat, the airbags and a rearview periscope system. The driver's name is Lynne, if anyone is interested, and she lives in Santa Barbara. This interior buck was also used for other studies of visibility for the driver, and for the location of the instrument dials and driver controls; the placement of the padding and other protection for the occupants. An extensive program was conducted by AMF to develop the required riding, handling and braking characteristics. A special vehicle was constructed having the same front end shape as the prototype, with provisions for changing weights and moments to simulate various loading conditions. The ESV suspension system selected was a torsion bar front and leaf-spring semi-floating axle rear. Aluminum wheels and J60-15 tires of advanced design were selected. During a five-month program, we tested various types of tires. We recorded and analyzed vehicle performance under steady state transient yaw conditions; demonstrated immunity to overturning; and made preliminary measures of braking performance. The slalom type of overturning immunity tests are very impressive, both as a spectator and as a driver. All the requirements tested for were either met or exceeded. For example, the pylon course was run at velocities well in excess of the 45 mph specified, 50-55 mph in several instances. The instrumentation which you are looking at, used in measuring the handling performance, was developed, installed, and operated by AMF personnel. An additional structure of the inside of the passenger compartment was built for use in dynamic testing of the interior protective systems. This testing simulated three types of car impacts: frontal, lateral, and rear. It was done by Cornell Aeronautical Laboratory on a dynamic sled. Dummies of various sizes, covering the range of the 5th percentile female to the 95th percentile male were placed in various seating positions for the tests. The series you are seeing here was related to the requirement for providing protection for the unrestrained occupants, that is, without seatbelts, without harnesses, no airbags or other devices. The design goal was to limit occupant decelerations to 60 g's for frontal vehicle velocity and 20 g's for the same lateral velocity change. To accomplish this, we used polyurethane foam extensively on exterior surfaces, from 2-3 inches thick on the pillars, and 3-4 inches thick on the doors and other areas.

This is our full-scale mock-up, and is what our vehicle will look like when we deliver it to DOT. The vehicle is all fiberglass, the doors include aluminum honeycomb for impact protection and intrusion resistance. The doors include triple hinge, triple pin and clevis door hardware. The vehicle frame is made of T-1 high-strength steel which totally encloses the passenger compartment in a space frame configuration. The periscope system provides a wider and clearer field of view to the driver.

Photographs

This set of photographs was taken in Detroit, at the Pioneer Engineering & Manufacturing Company, where two prototypes are being assembled. The fiberglass skins have been assembled, the engine and drive line was in, the wheels were being put on, the doors had been installed and were check fitted, and the front windows roll up and down. The bumper system was in the process of being installed. This was fabricated in Santa Barbara, and is the second-generation bumper system, which is made out of aluminum, and as such, has reduced 300 pounds from the vehicle weight. Fiberglass was used, not

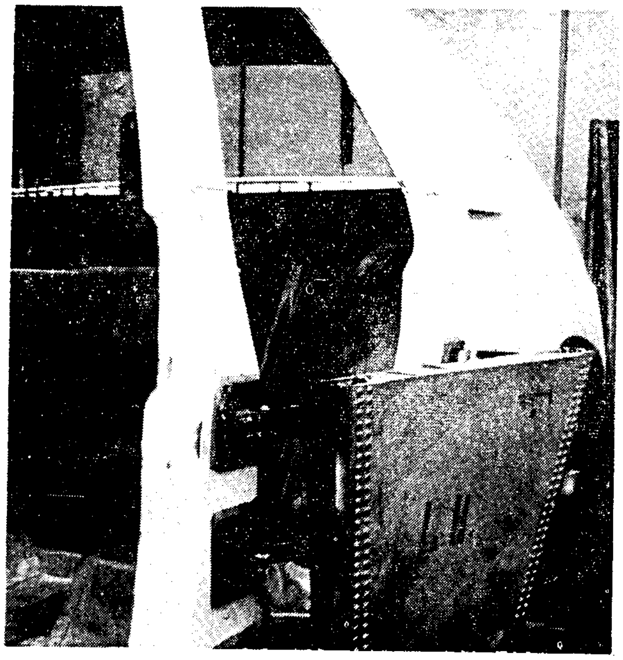


Figure 1

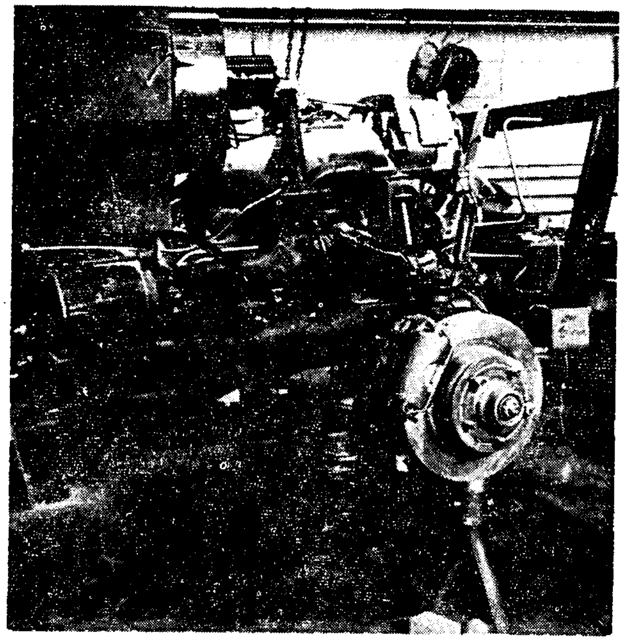


Figure 2

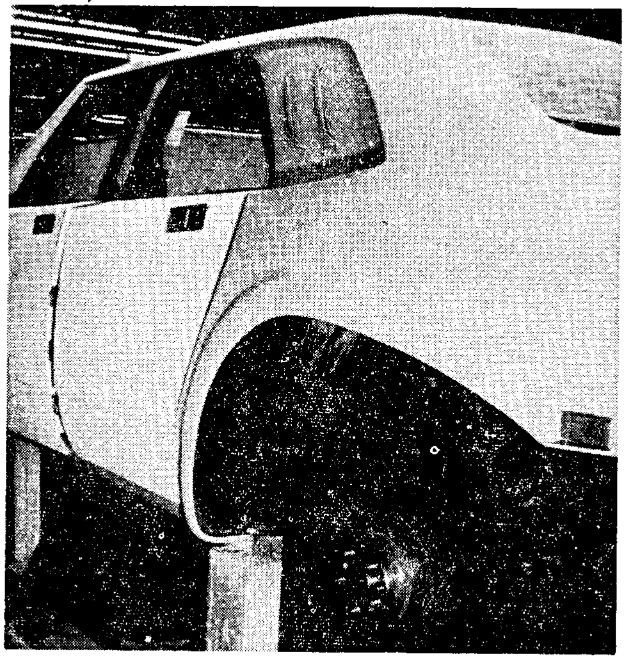


Figure 3

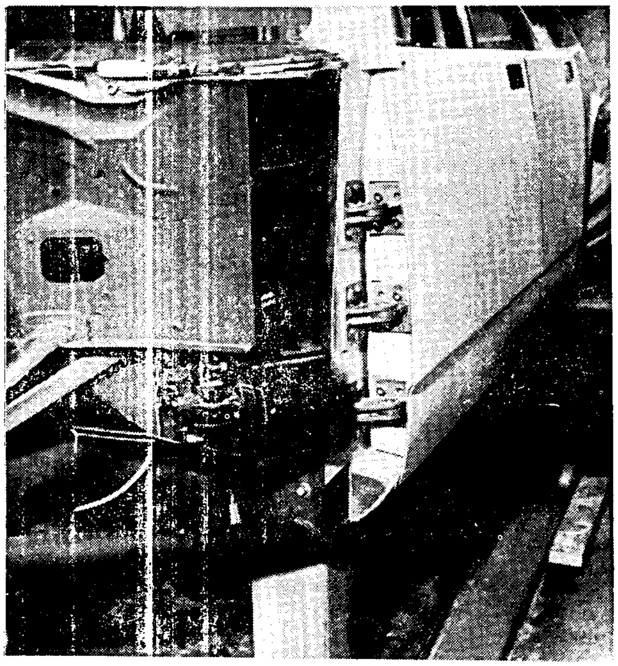


Figure 4

Figure 6

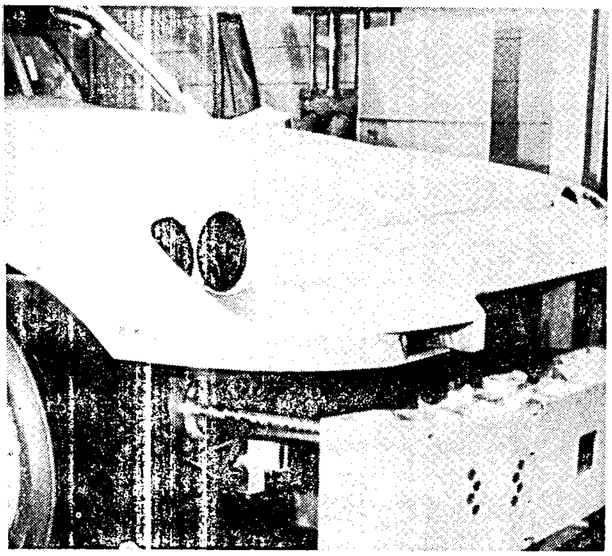


Figure 5

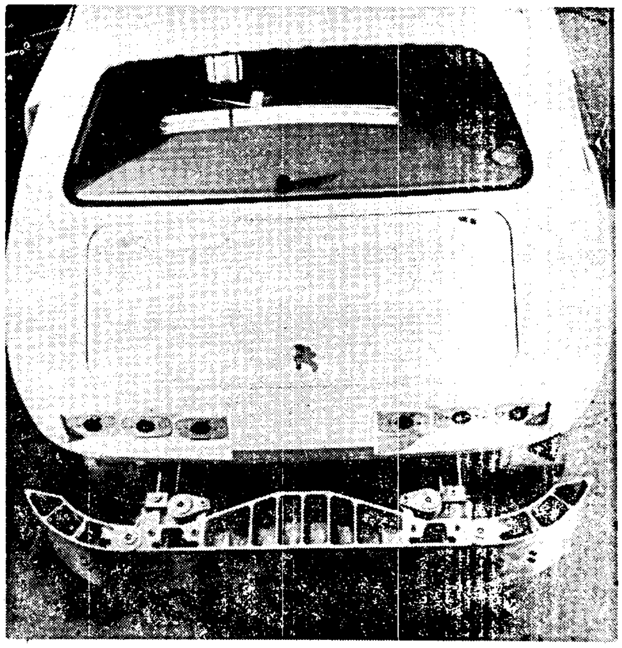


Figure 7

for weight saving advantage, but as an expedient, and also for minimization of cost in design and fabrication.

The vehicle is powered by a standard 350 cubic inch Chevrolet engine which will meet the emission requirements for 1973. The transmission is the Chevrolet Turbo Hydromatic type. We eliminated all our interferences in the engine compartment through the use of a front-end configuration buck, and wooden mock-up, which provided confidence for us that when we put all the pieces together, they would all fit. We expect that the vehicle will be delivered to Bendix for some final shake down testing in the ride handling area in December.

Now, I would like to turn the floor over to Mr. Bill Wingenbach, who will go into detail on the crashworthiness systems, and also show you the results of our development tests in those areas.

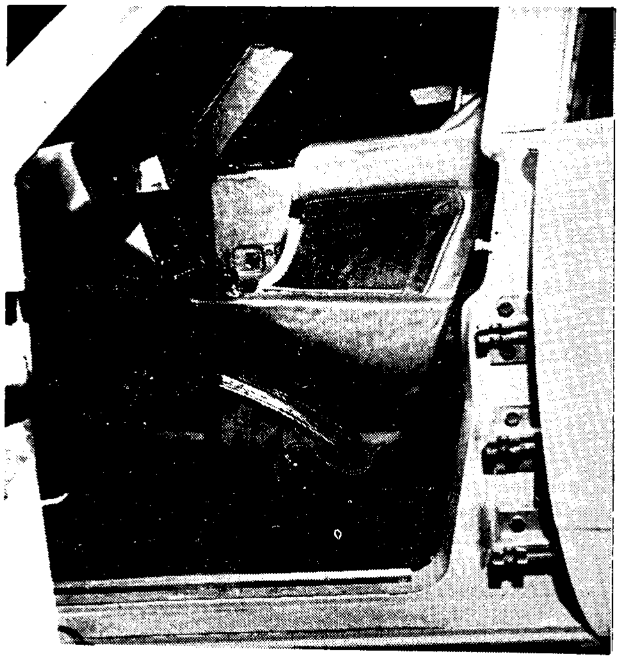


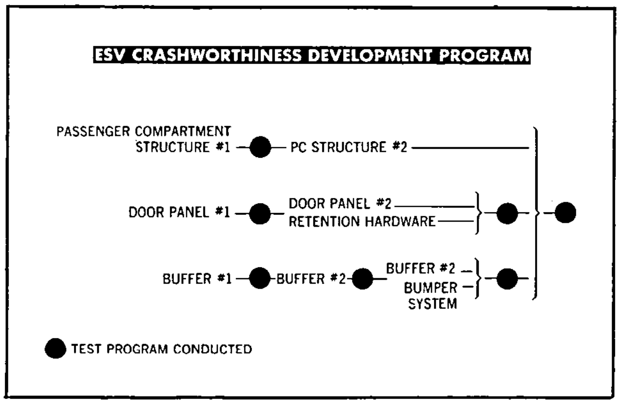
Figure 8

Figure 9

Mr. William J. Wingenbach

Ladies and gentlemen. First, I think I would like to define crashworthiness. My definition of crashworthiness is the ability of a vehicle to sustain the defined impact conditions while maintaining the survivable occupant's space. Survivability means control of both intrusion and acceleration.

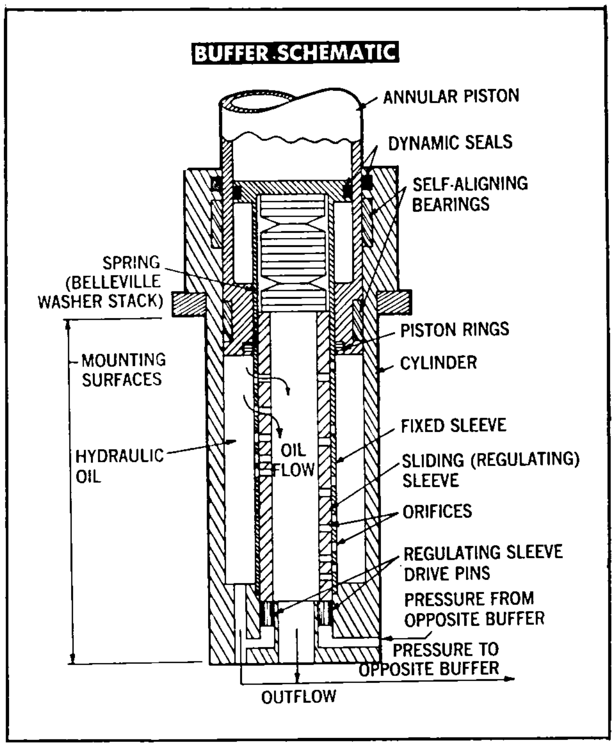
Slide 1



My first slide defines the logic which was used in the crashworthiness development program. We began by defining three principal components of the structural system. These were: the passenger compartment structure, that part of the structure which forms a space around the occupants; the door panel, which is a key element in absorbing the side impact energy; and the hydraulic buffers, which are the key elements in absorbing front and rear impact energy. We performed two complete engineering cycles on these three components. The engineering cycle consisted of synthesis, analysis, design, fabrication, test, and evaluation. During the second cycle for each component, we added auxiliary components to aid in their development and to expand the system so that its behavior would be similar to the behavior of the prototype ESV. I will go through and discuss these components, the problems and solutions. I might point out that we did prepare papers on both the intrusion resistant side structure and the front and rear energy management systems, and they will be available to you. I am assuming that you understand the requirements on all of these systems by this time, and I will not refer to them. If you do not know what the requirements are, they are given in the papers.

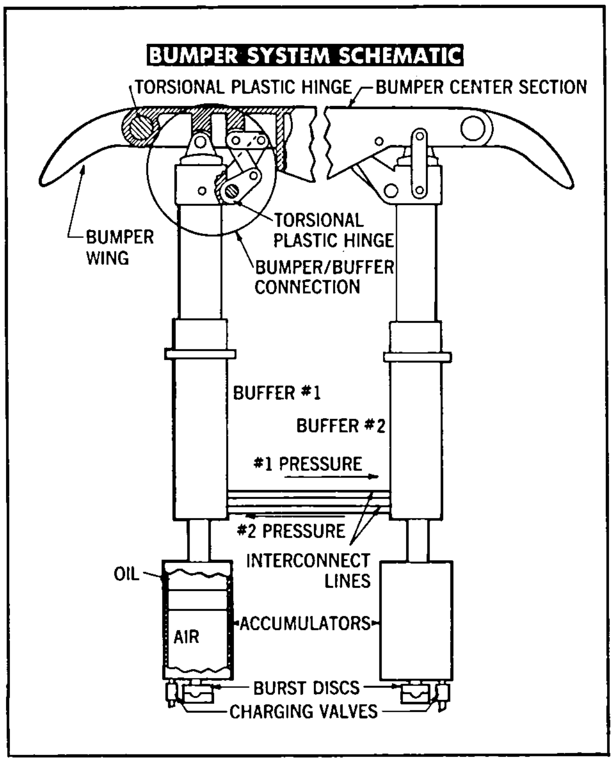
This slide is a schematic of the hydraulic buffing unit that we use. It is a complete hydraulic energy absorbing system. By that I mean, we absorb all of the energy front and rear with the hydraulic buffing units. There is a pair of hydraulic buffing units front and rear. The complete energy management systems front and rear are similar with the exception of the stroke of the buffing units. The front buffing unit strokes 30 inches, and the rear 14 inches, which reflects the difference in energy

Slide 2



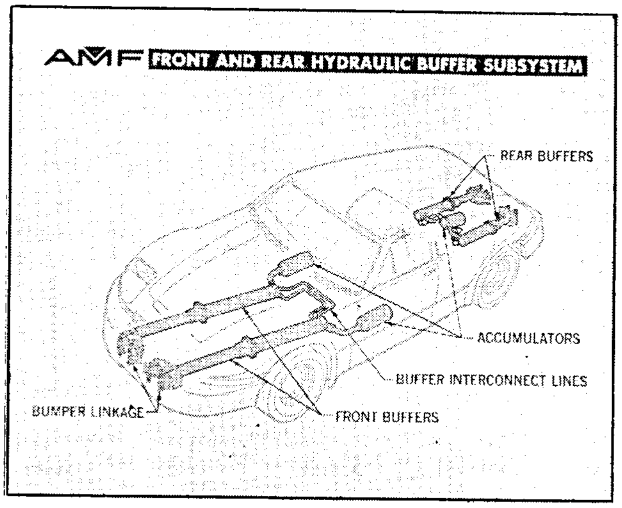
absorbing requirements on these two systems. The principal parts of the hydraulic buffer are the piston, the cylinder, a fixed sleeve, and a regulating sleeve. During impact, the piston strokes downward, forcing oil out of this chamber and through the orifice holes and on out the system. You can see as the piston strokes downward, it progressively covers up these holes, so that the orifice area decreases with stroke. The sizing and spacing of the holes are such as to give something close to a rectangular deceleration pulse. To this point, we have a more or less conventional variable orifice buffing unit which produces a force and consequently an acceleration which is constant with stroke, and a length of stroke which is a fixed dimension. The force varies to the square of impact velocity. This system will not, of course, meet ESV requirements, but it is the basic starting point. Beyond that, we have the regulating sleeve. Oil pressure from the chamber behind the piston is forced down through this passage, in behind the regulating sleeve, and through a series of pins which are around the circumference of the regulating sleeve, driving it upward a distance which is dependent on the hydraulic pressure, and which is also dependent upon impact velocity. The regulating sleeve at certain positions uncovers a new set of orifices and at the same time, covers up this set of orifices so that we now have again a variable orifice system, but of a different pattern. There are, in fact, three separate and distinct patterns in the front, and two in the rear at which the regulating sleeve may line up. The effect is to convert from the constant stroke velocity squared system to a system which is linear both in force and stroke with impact velocity. This is a system which does meet the specified ESV requirements. I might point out a design detail of the pins which actuate by the pressure within this buffer and the other half are regulated by pressure in the opposing buffer.

Slide 3



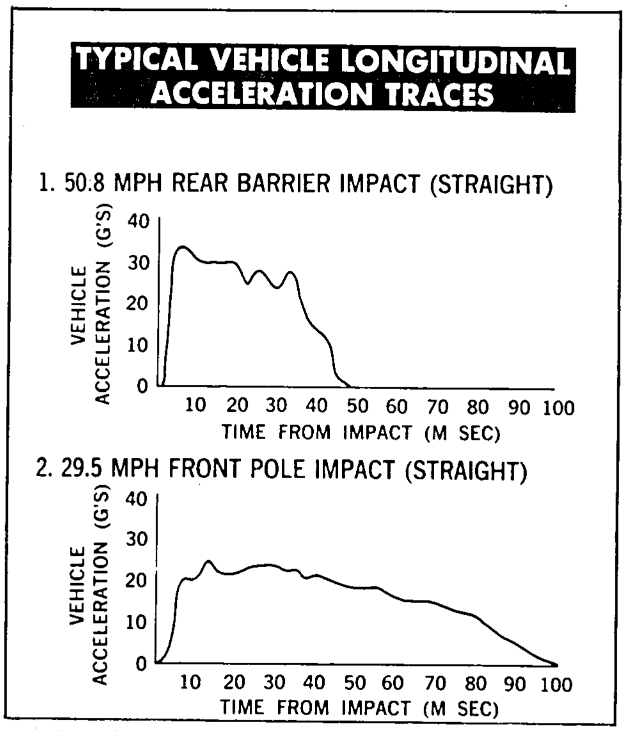
This slide is a schematic of the entire buffer system consisting of the bumper, the various connections, the pair of buffing units, and the hydraulic connections. The effect of various kinds of impact is a varying behavior of this system. I'll discuss the most critical, which is the case of the pole impact directly over one of the buffing units. One way to solve the problem is to make completely rigid joints, between the bumper and the buffing units. This would make the system independent of the point of application of the impact, but would result in very high moments at these joints. These very high moments would result in an extremely heavy bumper and piston, both of which are moving parts which would give the system very high inertia. The problem is essentially unsolvable with the rigid joint. An alternative is to make a loose or pin joint. This would allow the system to have differential motion between the pistons, but the misalignment between the pistons would be quite severe, and would introduce high transverse loads between the pistons due to differential stroking of the buffing units. They would bind up and not work reliably, so the problem is essentially unsolvable by a completely free joint at the connection of the bumpers and the pistons. Our solution is to use a controlled moment between the piston and bumpers. That is, a system that has a constant moment at the joint as one piston strokes with respect to the other, so we do allow a differential stroking, but in a very controlled manner. Part of the control is exerted at this point. This is a torsion link which, as the buffing units stroke relative to each other, applies a constant moment to both the pistons and the bumper. Another control of moment is at this point. If the point of impact of the barrier or of the pole with the bumper is outboard of the piston, it will contact the wing. If the moment is too high, this particular link yields, allowing the point of impact to move back inward until it is at a level which the system can sustain. There are a number of problems which develop by using a system such as this. One is the control of moment; another is the control of the side forces which develop between the two pistons as a result of the change in length of the bumper with respect to the fixed transverse distance between the two. We solve these problems with an additional linkage which is not shown in this slide, but it is shown clearly in the paper. This linkage allows the hypotenuse of the bumper to grow with stroke resulting in a fixed transverse distance between the two points of attachment, and eliminates any transverse force which might develop through differential stroking. One of the more difficult problems is control of the longitudinal force developed by the buffers under various impact conditions. We can see that if impact is at the center of the bumper, both pistons stroke at the same velocity and both have the same force. This will produce a given acceleration of the vehicle. If, however, the impact point is directly over one buffer, it will have essentially the same velocity as before, but now it would be desirable to produce twice the force as before in order to maintain the same acceleration and energy absorption. We accomplish that goal through these lines which are oil passages, interconnecting the two buffers. The signal going to the regulating sleeve is an average force or pressure between the two buffing units. In other words, if a point of impact is directly at a buffer, it will generate twice the buffing force that it would if the point of impact was at the center of the system. The piston which is opposite the point of impact will essentially generate no force under such an impact condition. The total system using this arrangement has approximately the same energy absorbing capacity independent of the point of application of the impact.

Slide 4



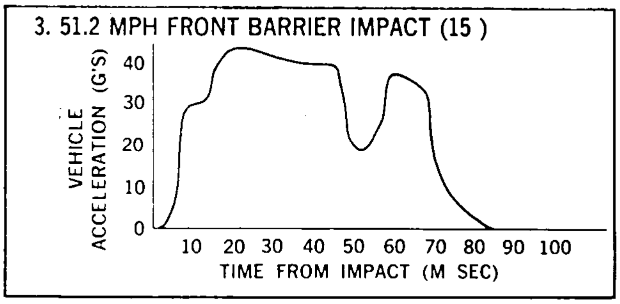
This slide shows the complete front and rear energy absorbing systems installed in the vehicle. These are the accumulators, which keep a preload on the buffing units during their no-use condition and restore them back to their original position after the impact. The rear system has only one accumulator, but both have the feature of return to normal position after impact.

Slide 5



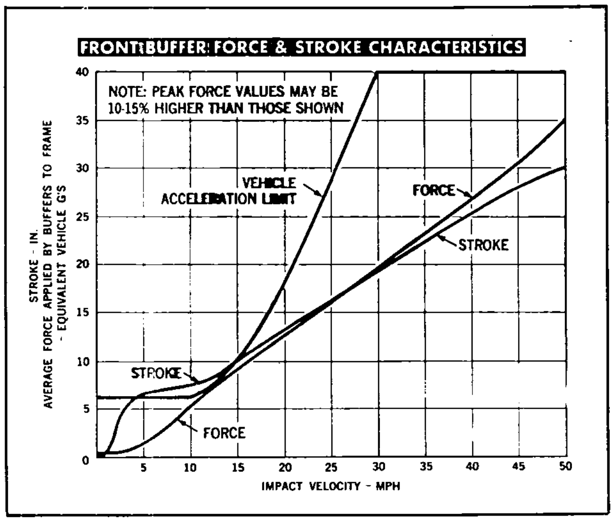
This slide shows typical performance of the unit during test. These are observed acceleration forces as a function of time during test at varying velocities. These are development tests, and do not show performance of

Slide 5 Continued



the final delivered system. We expect prototype performance to be better, although these results are generally considered to be acceptable. They are close to rectangular pulses, and are within the specifications in all cases, except this particular one: There was a component failure, and we got a peak acceleration of slightly in excess of 40 g's. This was at the most adverse impact condition. In fact, it was at a velocity of 52 mph rather than 50, and at the 15° oblique type condition. But behavior was still generally acceptable.

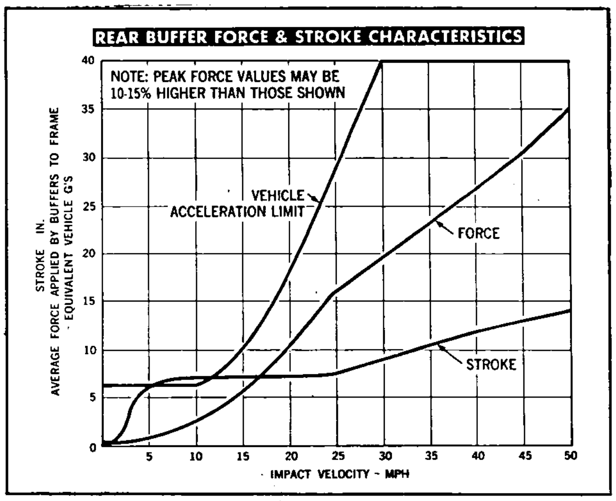
Slide 6



These graphs show behavior of the front and rear systems in terms of acceleration as a function of impact velocity. You can observe that both systems are well below the requirements for a straight-on impact. This is to assure ourselves that we stay below the specified acceleration under all oblique loading conditions.

These two curves show the stroke of the buffing unit as a function of impact velocity. I might point out that in our design, a stroke of 9 inches front or rear is permitted without damage. You can see from this that we would be able to sustain an impact in the front system of approximately 15 mph without incurring damage; and in the rear system, we could sustain an impact of 25 mph without sustaining damage.

Slide 7



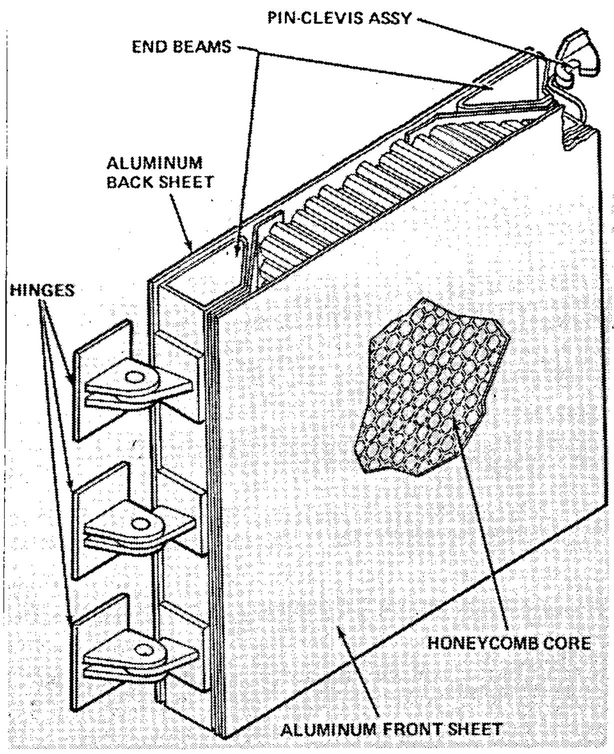
I would now like to show you films of some of these developmental tests in front and rear bumper systems.

The first test is a rear system impacting at 50 mph. The next test is at 20 mph and 45°. See the wings and some of the connections that we used in the development system. You can see the differential stroking of the buffing units. There are a few minor component failures that you may observe as we go along here, but these will not reoccur in prototype testing. This is a 30 mph, 45° test, which is the most severe impact condition for the rear system. Here is a 30 mph pole impact of the front system. You can see the longer stroke of this system. The front system has a maximum of 30 inch stroke versus a maximum of 14 inches for the rear system. The bumpers that are shown here are heavy weight systems that were used during the development testing program and are not the prototype bumpers. We have not yet tested the prototype bumper systems. This shows a 40 mph, 15° impact on the front system. Notice the differential stroking. This is the linkage which allows the differential stroking without binding the pistons. Next is the most critical design condition for the front buffing unit, the 50 mph, 15° condition. This is both front and rear systems impacting at 75 mph.

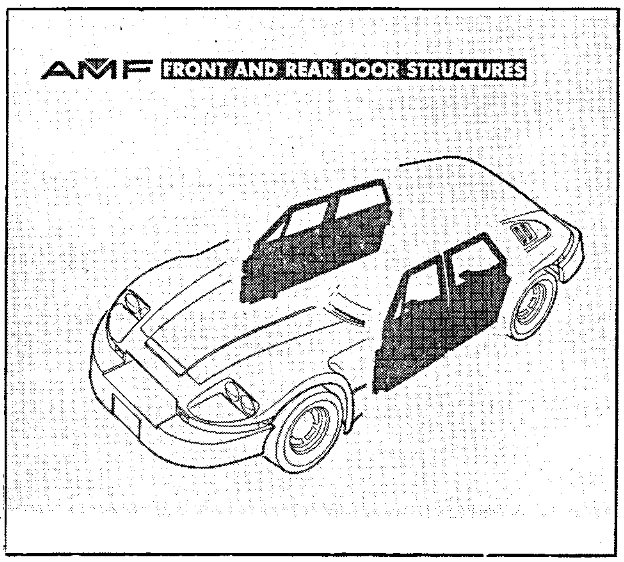
Now I will discuss the next component, the door panel. This panel is fabricated of aluminum honeycomb, with aluminum front and rear sheets, aluminum vertical beams, fore and aft, and high-strength steel hinges and pin clevis assemblies. The operating principle of this system is that the panel acts like a beam under initial contact. It behaves elastically for a while, and then starts to go into plastic beam action; following a period of plastic beam action, the honeycomb starts to crush, allowing stroke of the outside sheet without further stretching of the rear sheet. Finally, the honeycomb is completely crushed, and both the outer and inner sheets stretch as a membrane. In order to make this happen, both the hinges and pin clevis assemblies have to hold their position longitudinally, that is, they cannot stroke inward towards the panel as it is being deflected transversely. The energy absorption occurs both in crush of the honeycomb, and principally, in stretching of the face sheets.

Slide 8

DOOR PANEL AND HINGES

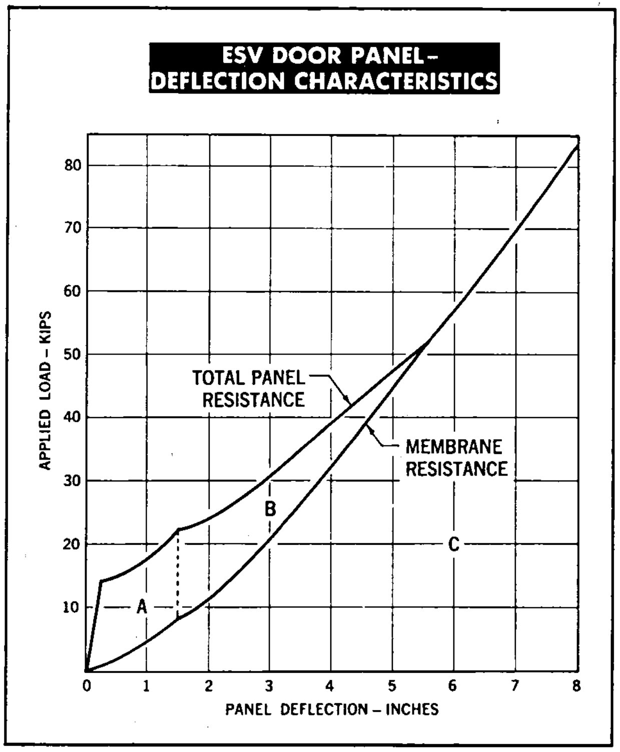


Slide 9



This slide shows the complete door configuration as it is installed in the vehicle. The front and rear doors are similar in principle, although slightly different shape. The front door also has a movable window, while the rear door system has a fixed one. The system uses a conventional latch to resist load from the inside out. It is an American Motors type of latch.

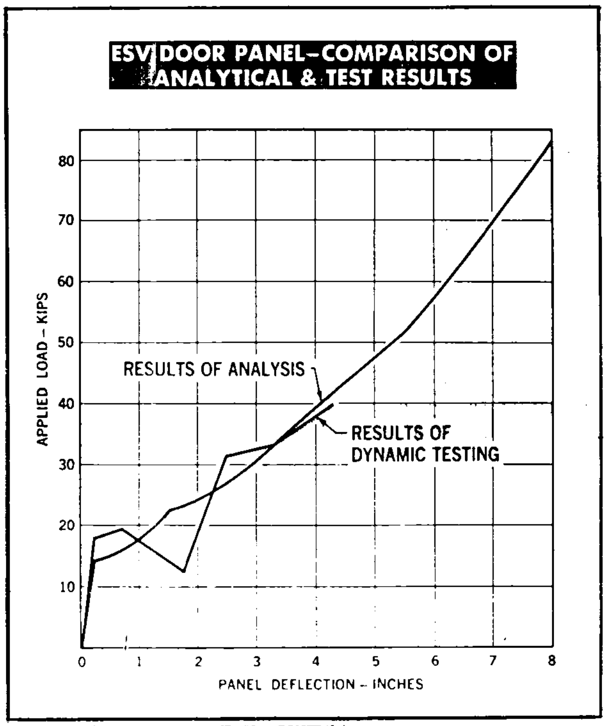
Slide 10



This slide shows the analytically predicted behavior of the door panel. The top curve shows the complete load deflection characteristic of the panel, while the lower curve shows only the membrane action of the front and rear sheets. The region of the area under that curve marked "A" indicates the amount of energy which is absorbed by beam action of the panel. The region marked "B" represents the energy absorption of the honeycomb during crush, while the region marked "C" represents the energy absorbed by membrane stretching of front and rear sheets.

This slide shows the comparison of analytical and experimental behavior of the door panel. The experimental behavior is superimposed over the analytical data. Test loading was not as high as we had hoped since we experienced a failure of a weld in the hinge at this point. We considered this to be a manufacturing defi-

Slide 11



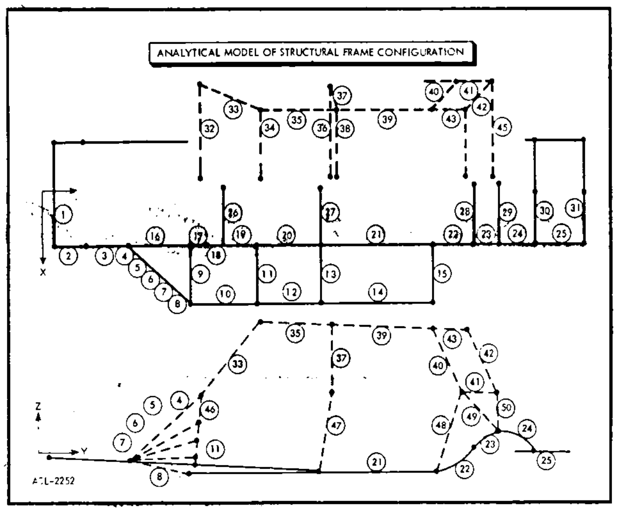
ciency which would not be repeated; and therefore, we considered this behavior as essentially satisfactory. We then installed a similar panel on a structural vehicle and subjected it to a dynamic test.

I would now like to show you a film of this test. This is a dynamic test, although it is not at 15 mph. During the stroke, you can observe the different behavioral modes as they progress. We did not get complete crushing of the core due to the hinge releasing the panel prematurely, but crushing was at about the stage it was supposed to be for the applied load.

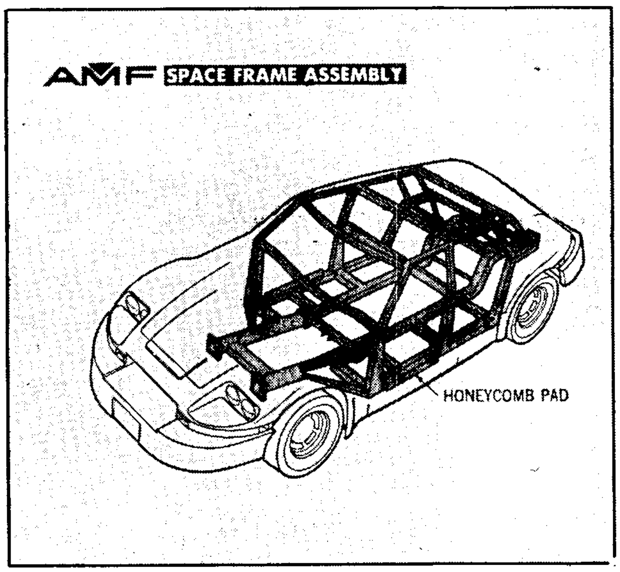
The next component that I would like to discuss is the passenger compartment structural frame. The frame serves as a mount for the front and rear energy systems and the side structures as well as providing occupant protection during rollover. It consists of main frame elements which run the length of the vehicle, perimeter frame elements which are most active during side impacts, substantial A, B, and C posts, and A, B, and C pillars, roof rails and cross members, frame cross members and some longitudinal load-carrying members which pick up the load from the hinges and transmit it back to the frame. I might mention something about the magnitudes of those loads. During the worst condition, which is pole impact condition at 15 mph, the total transverse load that we experience is something in excess of 100,000 lbs. The longitudinal load which is developed as a result of the membrane action is around 130,000 lbs. This is distributed to these three hinges. We need these longitudinal members to transmit some of that load back to the frame in order for the "A" post to survive.

Slide 12

This slide is a schematic of the math model of that particular frame.



Slide 13



This is a slide showing a complete structural vehicle containing both the structure which we just discussed with the honeycomb door panels installed. Material in the structure is all T-1 steel, which has about 100,000 psi yield strength. It is an all welded structure. You can see a protrusion below the front door. This is another honeycomb sandwich pad which is installed into the frame at the front door to help in the pole impact. It is intended to absorb a significant amount of energy during that particular impact condition, and is relatively much stiffer than the honeycomb core used in the door panels.

I would now like to show you a film of a test of this particular vehicle. The first test will be the 30 mph impact by an ESV front bumper system. Since there are a number of views of this test, we can get a good look at the behavior of the various structural elements. The maximum dynamic intrusion measured on this test was something slightly under 2 inches as compared to the allowable 3 inches. There is little damage to the vehicle as a consequence of this particular test. The estimated load for this impact condition is approximately 150,000 pounds between the bumper and the side structure. Behavior was a little stiff, and we softened the system since that test. This is the pole impact test into the center of the front door, at 15 mph. Again, there are a number of different camera views, so that you can get a good look at the complete structural behavior. The peak stroke of the vehicle relative to the pole was something slightly over 7 inches which resulted in an intrusion of the interior hardpoint into the passenger compartment of about 3¼ inches as compared to the allowable 4 inches of intrusion. Peak acceleration at the vehicle center of gravity was measured at 20 g. Observe the behavior of both the panel honeycomb sandwich and the frame honeycomb sandwich. Both are completely crushed, and have done the job assigned to them. Total load generated under this impact at the pole was about 105,000 pounds peak load. Final test on this structural vehicle, as we will see, is a 2-foot drop test on to the A post. Dynamic intrusion into the compartment was measured at 1¼ inches.

GENERAL MOTORS CORPORATION

Mr. William Larson
Mr. John Rosenkrands

Introduction

The Experimental Safety Vehicle that has been conceived by General Motors is shown in Figure 1. This is a totally new running car. We wish to describe its design. The goal was to operate within the restraints of contract specifications to provide a vehicle with a familiar configuration, that is aesthetically appropriate to the seventies and with the road feel of a medium size American car. Practicability and feasibility were not our concern.

The challenge was dummy survival, in terms of our contract, under the extreme conditions of a 50 mph barrier impact test. Here we are dealing with nearly a half million pound-feet of energy and it is difficult to conceive of survival under such conditions. However, in terms of our contract with the U.S. Department of Transportation, this is what we are progressing toward – as shown in one of the first 50 mph barrier tests of the ESV built by General Motors (Figure 2). This is equivalent to a 100 mph impact into another car. Of course, survival of dummies may be an entirely different matter than human survival – and we don't have too many volunteers to check this out.

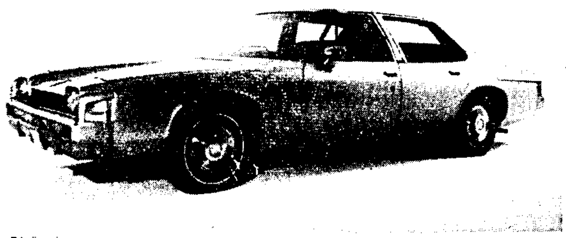


Figure 1

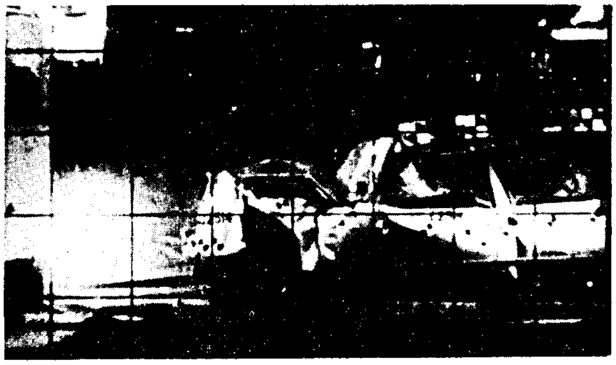


Figure 2

As we go through the design, there are a few factors that need to be remembered – factors that frankly temper the quality of our success. First, this ESV has been designed for the very specific crash test situations of our contract. We don't know the relationship of test performance to actual crashes in traffic. Second, our car has been tested by and built for a particular breed of anthropomorphic test devices which sit passively with perfect posture, calmly waiting for impact. This forces us to conclude that we are really not going to be able to determine from this particular program whether or not ESV specifications answer the question of human survival in real world accident situations.

Before getting into details of the design, we wish to outline the nature of our presentation. We will describe our approach to this assignment, introduce you to the overall configuration and provide some of our observations of the program based on our initial test results and progress (Figure 3).

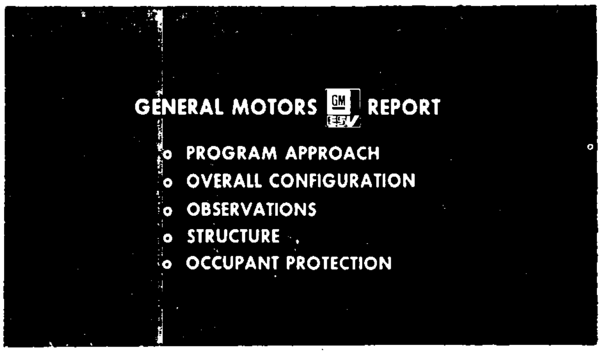


Figure 3

Within General Motors, the coordination of forward safety and emission control programs is the responsibility of the Environmental Activities Staff. For this reason, our Experimental Safety Vehicle Group is part of this larger activity (Figure 4).

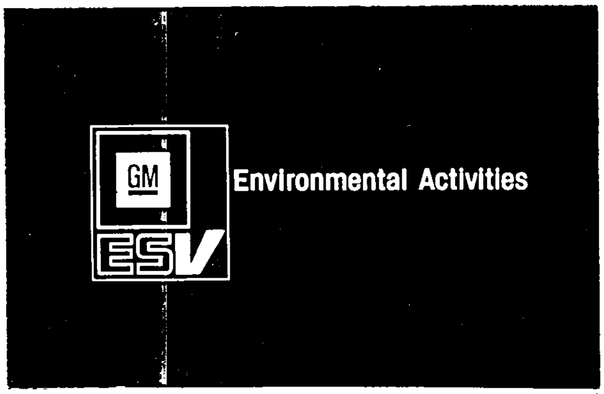


Figure 4

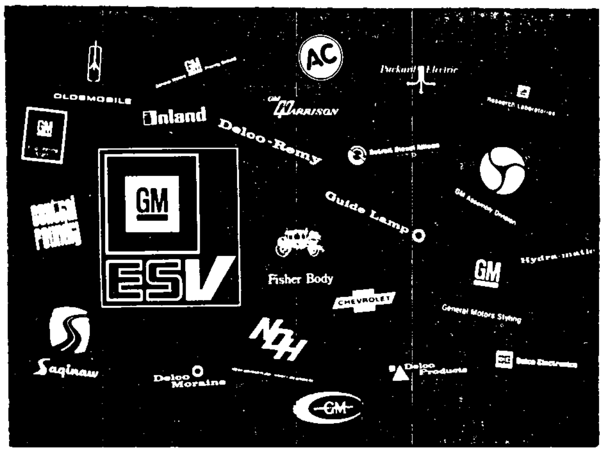


Figure 5

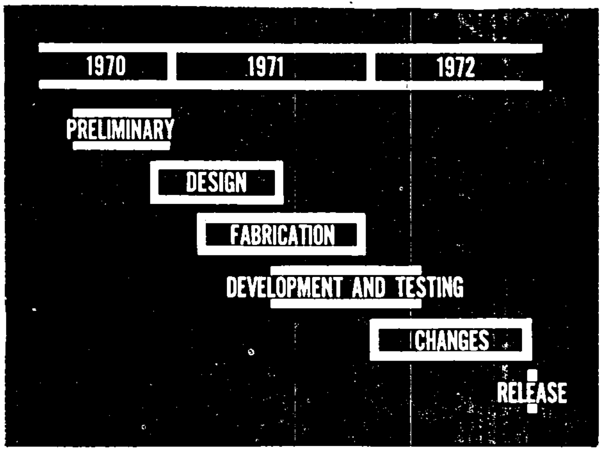


Figure 6

As one of the three original ESV contractors, General Motors organized its ESV program in July, 1970. Personnel from twelve different divisions and staffs were assembled within a flexible organization. We have had complete responsibility for design, testing, fabrication, quality assurance and styling. However, because these functions do not all operate in parallel, manpower has been adjusted to meet the needs of the moment. At the design peak last spring, we had about 150 men in the group. Significant contributions to this program have been made by 23 General Motors units serving as subcontractors and advisers on various facets of design, development, testing and fabrication (Figure 5).

Figure 6 illustrates the overall timetable and the various phases of the program. Following the preliminary design phase and completion of styling during the first six months, personnel were added for detailed design, tooling and fabrication. We are currently in the development and test phase which is basic to the GM program and the principal difference from others. This includes the development and durability testing which we consider is required of any new model, as well as evaluation of many crashworthiness requirements, using complete vehicles. This will enable us to make any necessary design changes prior to final release of the two prototypes to our government in 1972.

Configuration

The ESV built by GM is a 5-passenger, 4-door family sedan. It has a wheelbase of 124 inches, an overall length of 219 inches, a 64-inch tread, an overall width of 79.6 inches and height of 58 inches. The maximum dimensions allowed by our contract were needed to achieve the required performance. This preprototype weighs approximately 4,700 pounds – and keeping weight at this level has been one of our most significant challenges because our contract is for a 4,000-pound car (Figure 7).

The powertrain consists of a 362 cubic inch displacement V-8 engine, a 3-speed torque converter type automatic transmission, a drive shaft with two universal joints, and a live rear axle (Figure 8).

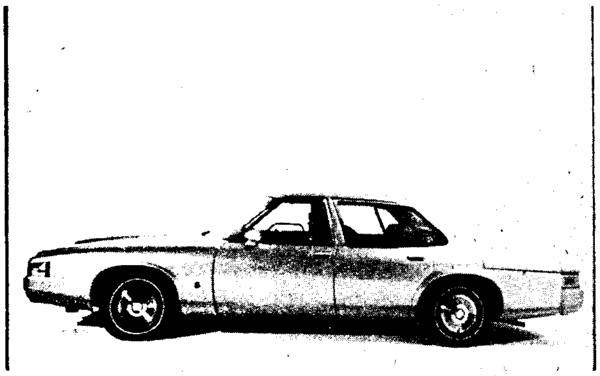


Figure 7

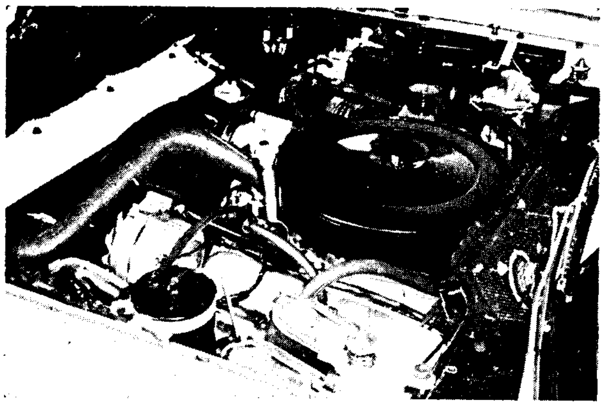


Figure 8

The engine is a modified production unit with an experimentally tooled aluminum cylinder block, heads and intake manifold. This saves about 180 pounds over conventional cast iron. With an 8.1 to 1 compression ratio, designed to run on nonleaded 91 octane fuel, the engine develops 185 net horsepower at 4000 rpm. Engine accessories are mounted on brackets designed to permit the lower profile hood required to meet the specified 8-degree down vision angle (Figure 9).

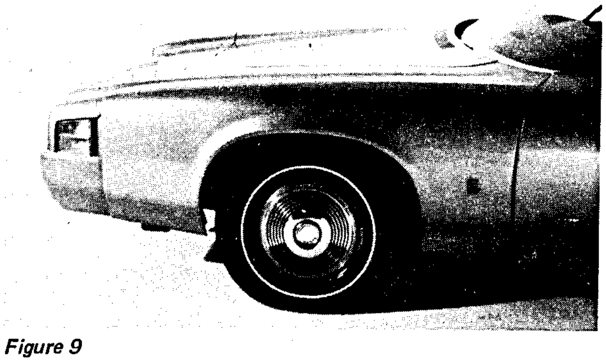


Figure 9

Emission controls are designed to meet 1973 U.S. Federal requirements for hydrocarbon, carbon monoxide and oxides of nitrogen control. They include a positive crankcase vent system and the General Motors Air Injection Reactor. A transmission controlled spark advance, an evaporation control canister and an exhaust gas recirculation system are also used. The sealed 23-gallon fuel tank is provided with special fuel line provisions to prevent spillage in any vehicle attitude (Figure 10).

FOR 1973 US FEDERAL REQUIREMENTS
HC, CO, and NOx

POSITIVE CRANKCASE VENT
AIR INJECTION REACTOR
TRANSMISSION CONTROLLED SPARK
EVAPORATION CONTROL CANISTER
EXHAUST GAS RECIRCULATION
SEALED FUEL TANK

Figure 10

Both brake and steering systems feature hydraulic power assist to reduce driver effort (Figure 11). An

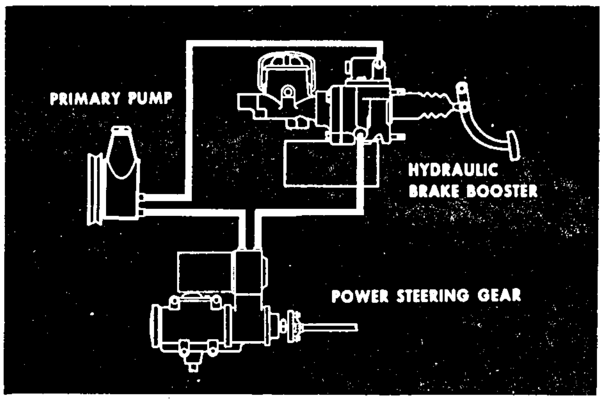


Figure 11

engine-driven pump supplies high pressure oil for this purpose. However, both the power steering gear and the brake booster have built-in back-up pumps which are electrically operated to maintain hydraulic pressure in the event of a failure in the engine-driven pump or connecting hoses (Figure 12).

The brake system employs dual piston brakes at each wheel (Figure 13). Two separate, dual master cylinders are used, one for the front and one for the rear brake circuits (Figure 14). The two pistons at each wheel are connected to different master cylinders, eliminating the effect of a single line failure (Figure 15). Should such a failure occur, original system effectiveness is retained with only a slight increase in pedal effort. Both load proportioning and wheel-lock control devices at each wheel are incorporated in the system.

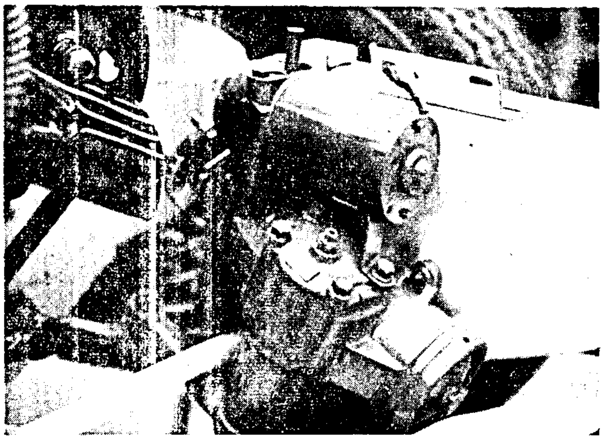


Figure 12

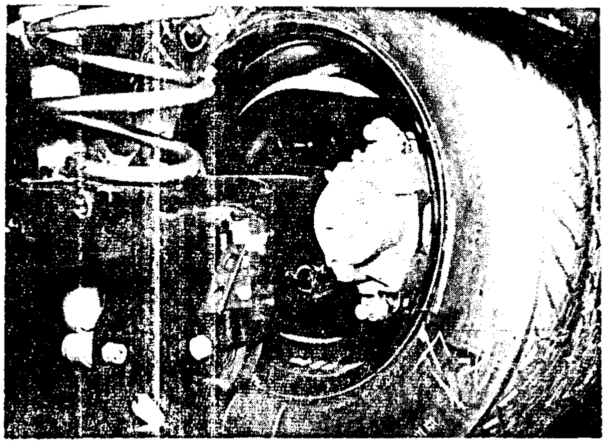


Figure 13

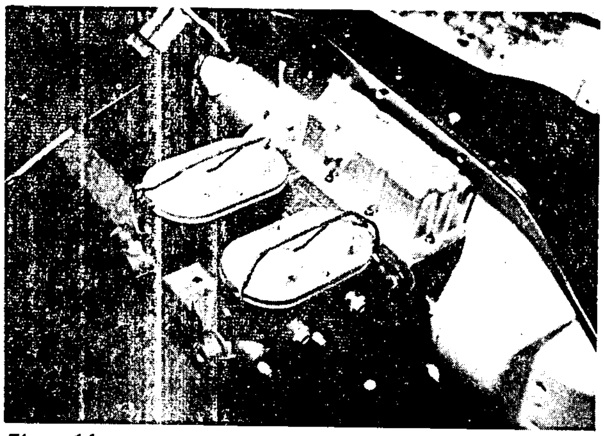


Figure 14

The front and rear suspension systems of the car are basically standard U.S. production configurations, but the geometry of each has been revised to meet the handling and steering requirements. A stabilizer is used in front (Figure 16). At the rear, coil and pneumatic

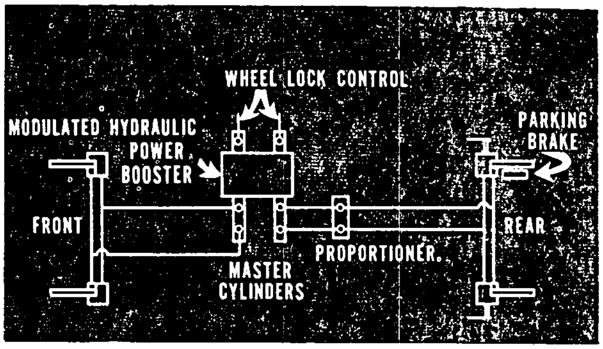


Figure 15

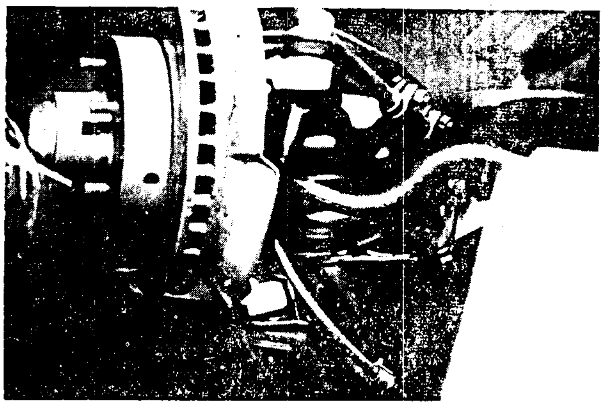


Figure 16

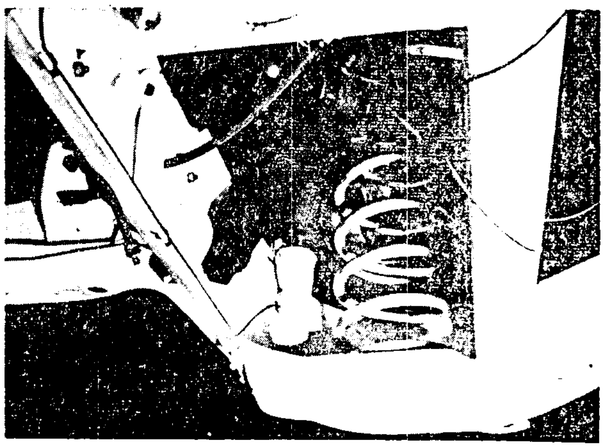


Figure 17

springs operate in parallel (Figure 17). The pneumatic springs also serve as part of an automatic leveling system to maintain rear height. To meet other handling requirements, a variable ratio steering gear with ratios from 16.0 to 12.4 has been selected (Figure 18). The tires are specially fabricated HR70-15s (Figure 19).

Because driver eye position is such an important factor to visibility, a single pivot seat design has been

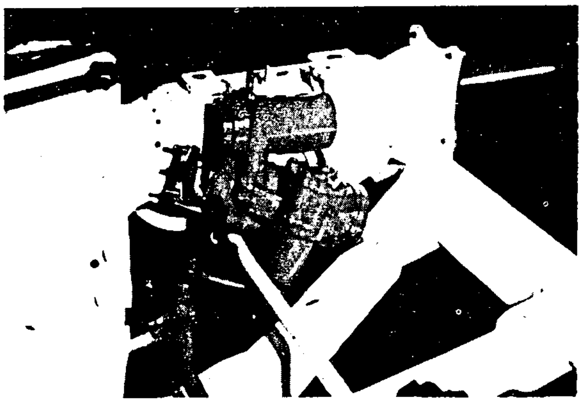


Figure 18

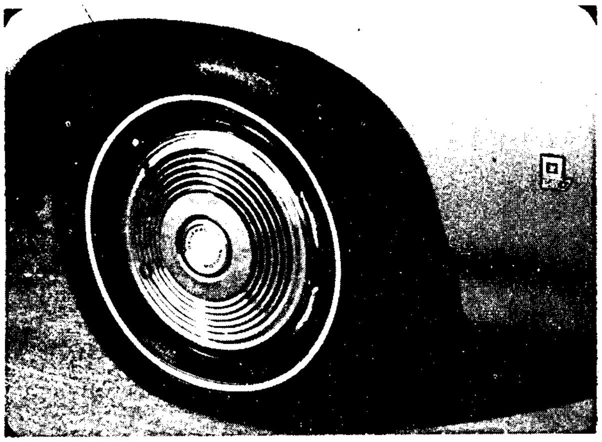


Figure 19

selected. This eliminates fore and aft seat adjustment. Movable pedals are, therefore, required to make up for the difference between 5th and 95th percentile drivers. The result of this arrangement is a smaller eye ellipse and appropriate vision arcs without having to resort to unfamiliar architecture in the upper portion of the vehicle body (Figure 20).

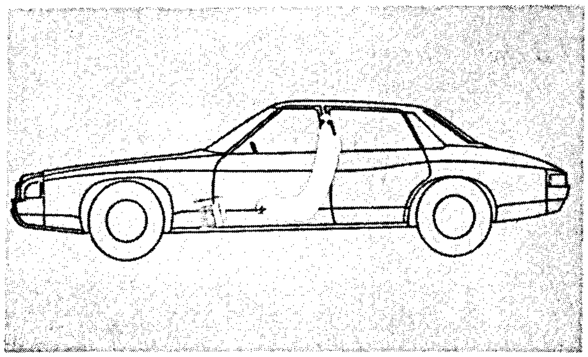


Figure 20

The car has about 10 percent more glass than a typical current production sedan. The forward portion of the roof is cantilevered from the center pillars, eliminating the need for pillars at either side of the windshield. The results are improved driver visibility and less likelihood of unrestrained occupants hitting a structural pillar (Figure 21).

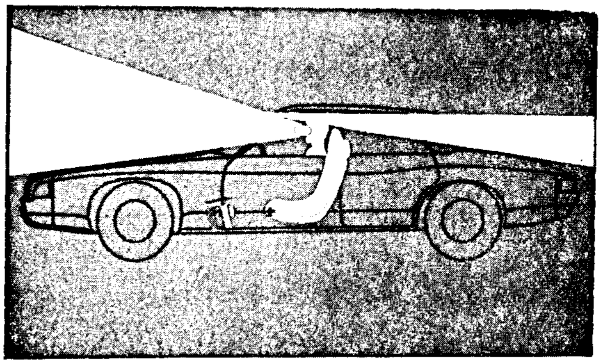


Figure 21

In the rear seat area, we have a full width, 3-passenger bench seat, except that the center section moves forward when not in use to provide a lateral restraint surface for outboard passengers (Figure 22). By simply pushing the spring-loaded center seat back to normal (Figure 23), the cushion is latched in place and seat dividers are automatically extended to provide lateral restraint for the third occupant (Figure 24). This is an extremely tight squeeze, however, for three above average size occupants.

Figure 22

Four sealed beam headlamps have shock resistant mounts (Figure 25). Amber front parking and turn signal lamps are mounted below the headlamps in the bumper. Corner lamps, as well as combination turn signals and side marker lights, are mounted on the wrap-around portion of the front bumper (Figure 26).

We have a distinctive rear signal system. The tail lamp arrangement includes high level mounted auxiliary stop and turn signals. These incorporate a dual intensity feature. In daylight the brightness of the upper lamps is high so that the intended signal may be clearly seen. This


Figure 23


Figure 24

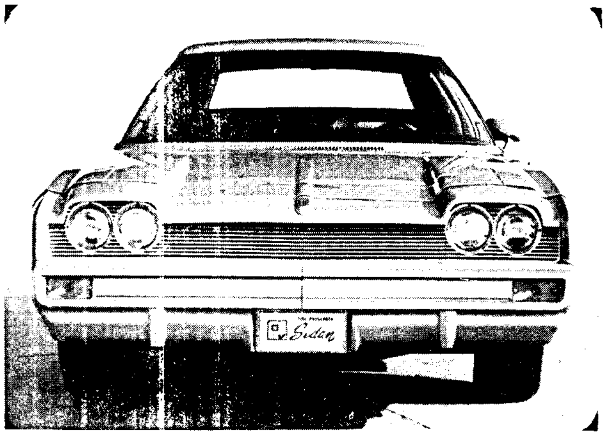


Figure 25

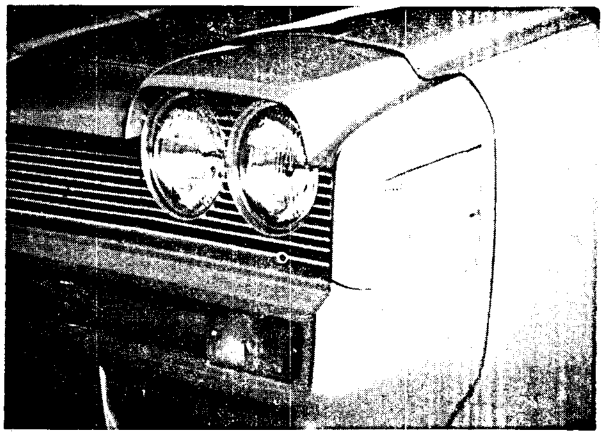


Figure 26

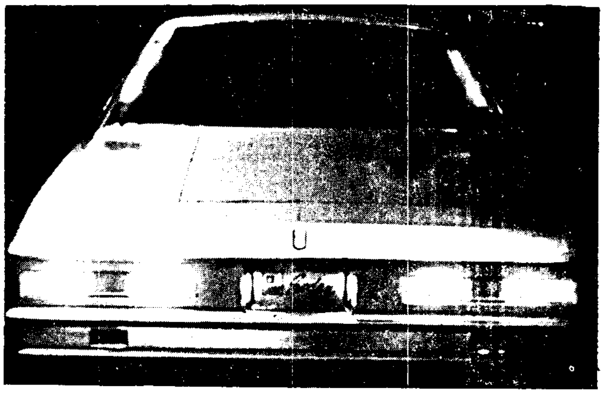


Figure 27

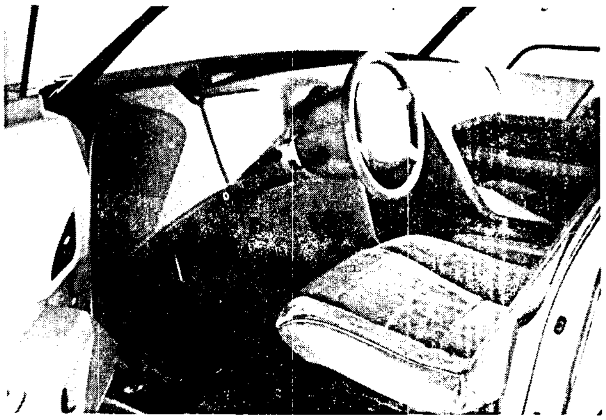


Figure 28

level is too bright for night driving and therefore the intensity is reduced whenever the headlamps are turned on. This effectively reduces glare (Figure 27).

Driver controls are in conventional locations (Figure 28). A high mounting position for the enlarged rear view mirror is provided along with a triple sun visor arrangement. This meets the specifications for rear vision as well as unobstructed upward viewing through 17 degrees (Figure 29). Instrumentation is unique. A message center concept is employed in which the driver views only critical, need-to-know information in a "primary" message center located in his forward viewing area above the steering wheel rim (Figure 30). Other more detailed information regarding vehicle conditions or malfunctions

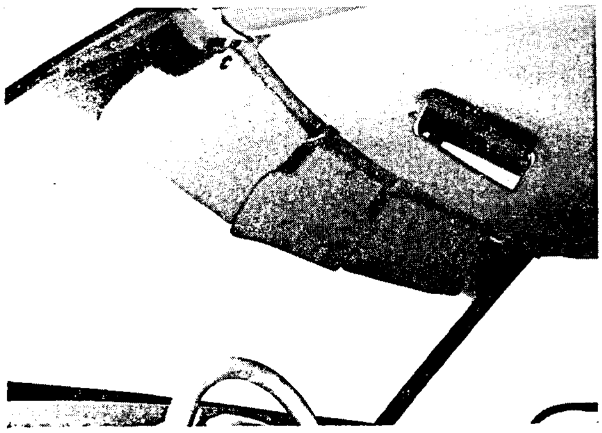


Figure 29

Figure 30

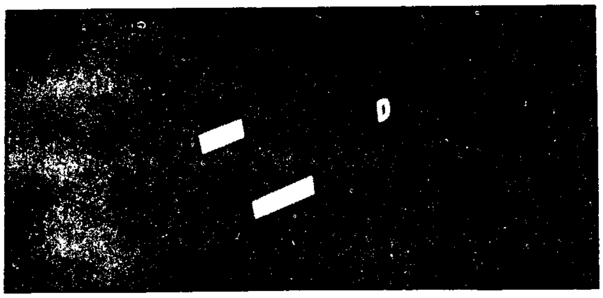


Figure 31

appears in a "secondary" cluster located in the center console where it is visible at a glance but not in his primary field of view (Figure 31).

Turning now to the important areas of crash-worthiness and occupant protection, our performance requirements have been derived essentially from 17 crash conditions representing our interpretation of the ESV specifications. These may be divided into low and high speed impacts, because the performance levels measured on the anthropomorphic test devices are specified in this manner.

The 10 mph rear (Figure 32) and front tests (Figure 33) are to produce no damage to the vehicle and deceleration is not to exceed 6 g's. The 20 mph test is to be conducted without deployment of any form of

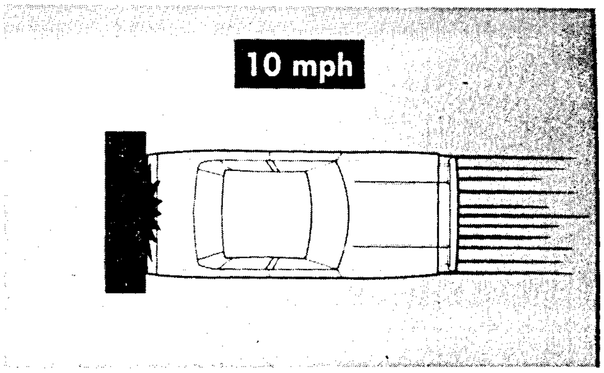


Figure 32

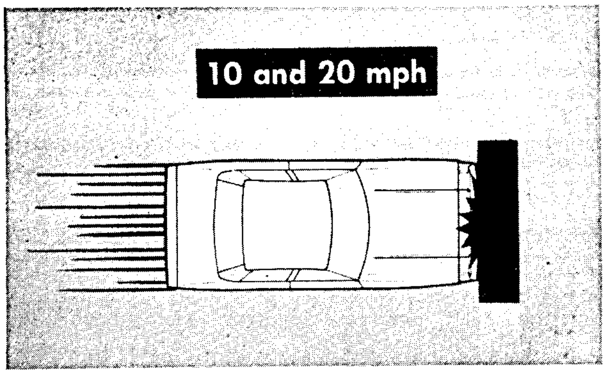


Figure 33

restraint system. In these tests, head, chest and pelvic g's on any of the five test dummies are not to exceed 60 except that pulses up to 100 are allowed for less than 3 milliseconds. Femur loads are not to exceed 1400 pounds. We do not intend to editorialize on the validity of these figures in terms of saving lives – except to say that the subject is still open to question.

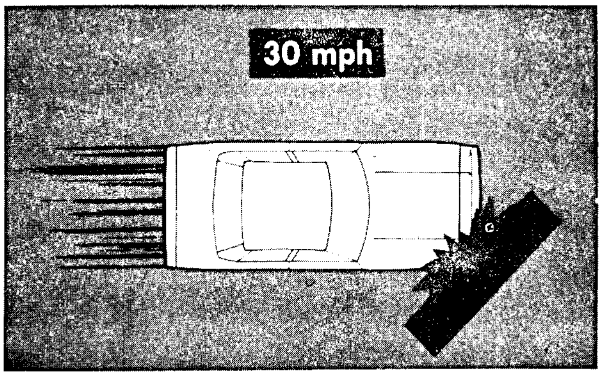


Figure 34

Higher speed tests include 30 mph front and rear corner impacts (Figure 34) and a 15 mph side impact into a pole (Figure 35). At 50 mph a succession of barrier and pole impacts are included. In these, dummy performance

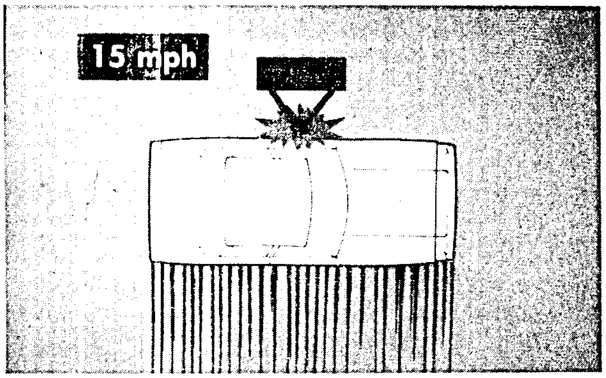


Figure 35

is the same as for the first tests, except that the head is permitted 80 g's for up to 3 milliseconds with no limit on peak deceleration (Figure 36). Another category of tests includes 75 mph car-to-car crashes – front and rear (Figure 37); a 2-foot inverted drop (Figure 38); and some form of double roll-over (Figure 39).

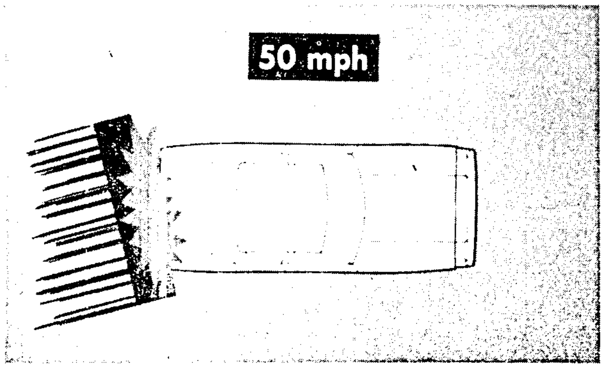


Figure 36

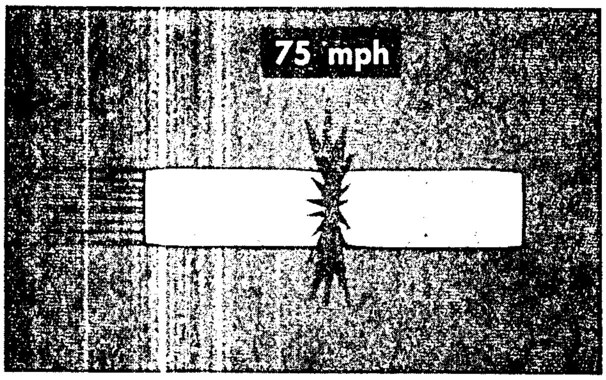


Figure 37

These requirements have led to a very substantial frame and body structure for the ESV. Aluminum panels were chosen for much of the body to achieve high

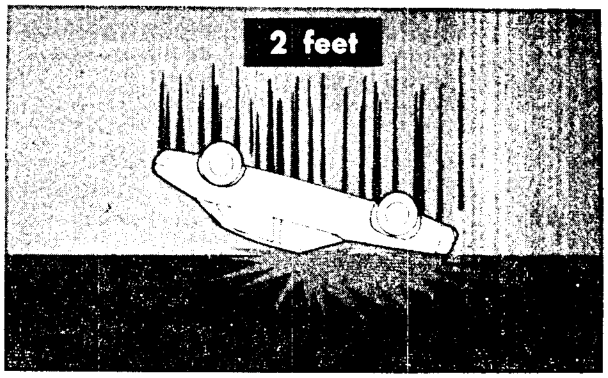


Figure 38

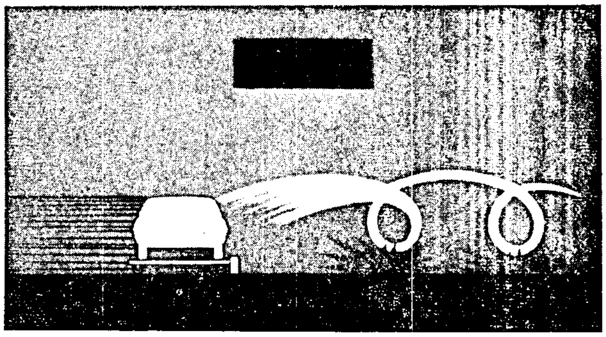


Figure 39

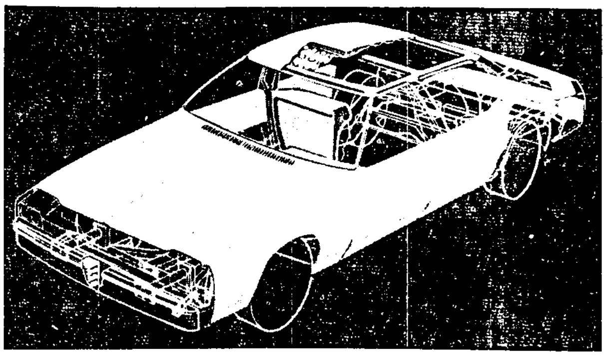


Figure 40

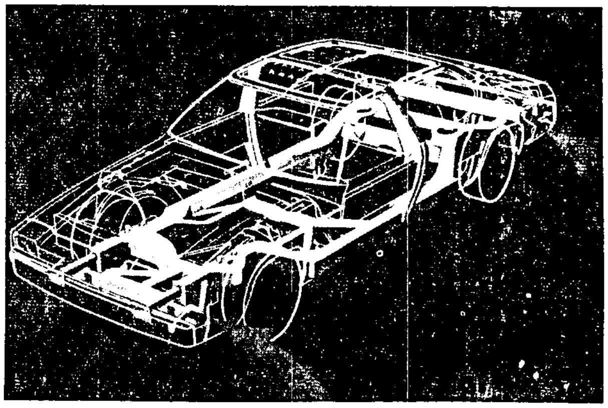


Figure 41

strength and maintain reasonable weight (Figure 40). In addition, aluminum is used in the bumper and door beams. Also to save weight, higher strength vanadium alloy steel is employed in the frame and body side pillars (Figure 41).

The frame has a full box section with both cross and diagonal bracing to accommodate corner impacts. The ends of the frame side rails house 3-inch diameter hydraulic cylinders with metered orifices. Three-inch diameter torque tubes are housed within the frame cross members, front and rear. These torque tubes connect to the hydraulic cylinders through a dual lever linkage to coordinate the travel of the energy absorbing bumper system in angle impacts.

Bumpers have a 9-inch stroke in 10 mph barrier impacts required by the contract (Figure 42). The bumpers are covered by molded urethane with the front system telescoping inside the body sheet metal and the rear urethane hinged to the rear deck (Figure 43). The amount of space required for the bumper and its travel significantly reduces available trunk space. Access to the 12 cubic foot trunk is from the sides through two hinged deck lid panels. Spare tire removal is somewhat easier in this design (Figure 44).

The air conditioned ESV has fixed side glass to reduce the chance of ejection during roll-over. However, there are small power-operated access sections in the front glass. For roll-over protection, the ESV has high strength roof supports in the center pillars. Sloping the pillar forward reduces the amount of unsupported roof structure over the front seat area and moves this massive member away from the path of some of the rear occupants who might otherwise strike it in certain contract crash situations (Figure 45).

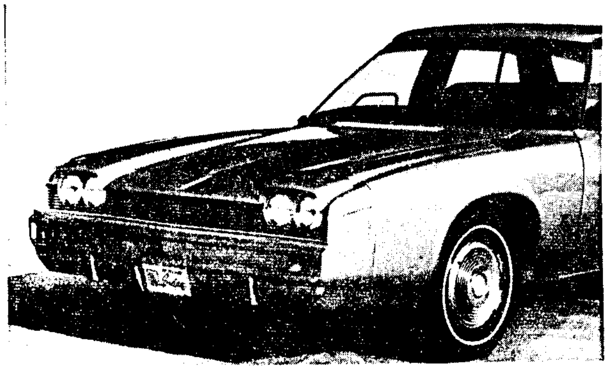


Figure 42

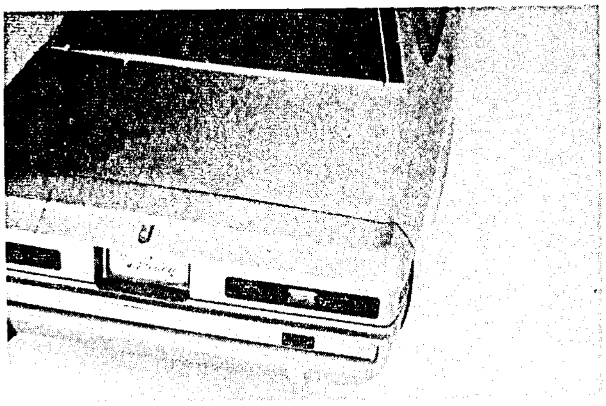


Figure 43

Figure 44

Figure 45

The interior of the ESV has what we refer to as a "30/50 occupant protection system." The interior is designed to provide protection in 30 mph barrier impacts for unbelted dummy occupants – without deploying special safety devices. To achieve our 30 mph barrier performance, considerable padding is required. In front of the rear seat passengers, there is a cross-car structure which we call the "credenza" (Figure 46). Once the occupants are in position, their free motion is effectively minimized. Getting into this position, however, is an art and a science that requires practice to achieve skill (Figure 47).

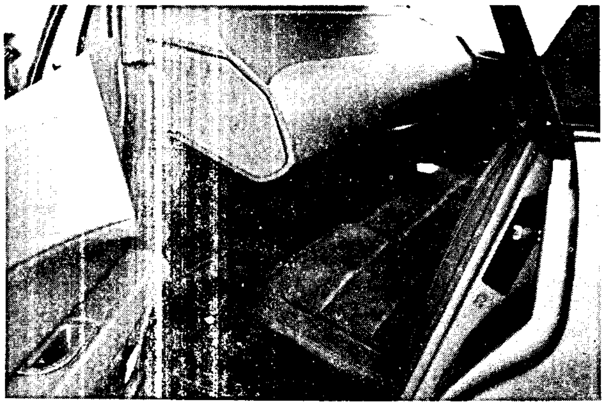


Figure 46

Figure 47

Protection (in contract terms) in 50 mph barrier impacts is accomplished by means of air cushions without belts or other devices that the occupant must actuate. The air cushions are deployed from the credenza in the rear, and from the steering wheel, driver knee area and the front passenger instrument panel (Figure 48). Movable knee panels are used to absorb upper leg impact energy (Figure 49). Air cushions in the system are actuated at barrier impact speeds over 30 mph by deceleration sensors mounted in the bumpers.

Following are some of the most significant differences between this car and contemporary models in the same size class. We should stress, however, that many of these features would have very significant costs.

- The braking system – a double brake circuit complete with automatic wheel lock controls and proportioning, as well as an emergency power source for the four-wheel disc brakes (Figure 50).
- Elimination of the windshield pillar – this has provided panoramic vision and a new approach to hardtop styling (Figure 51).
- The aluminum body results in significant weight savings without loss of structural integrity – without its use the car would be prohibitively heavy (Figure 52).

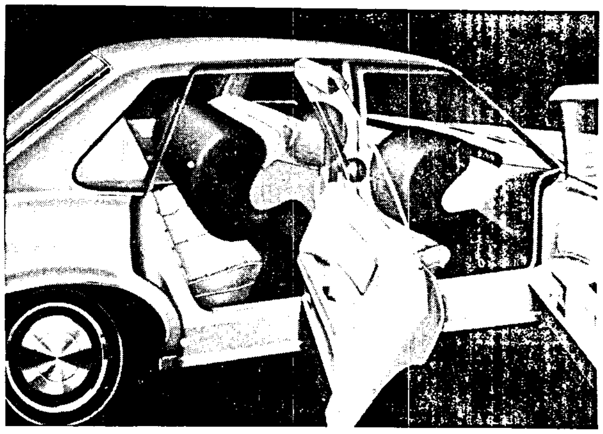


Figure 48

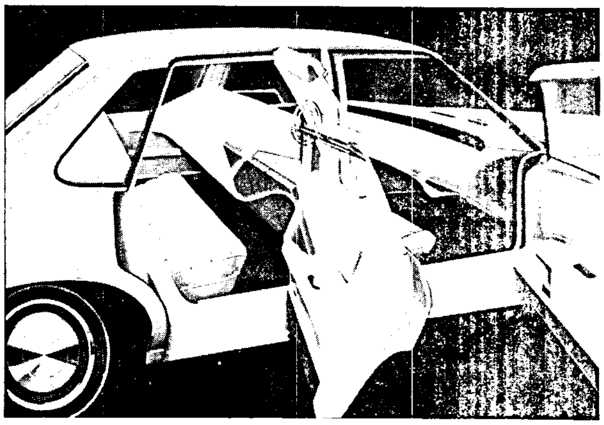


Figure 49

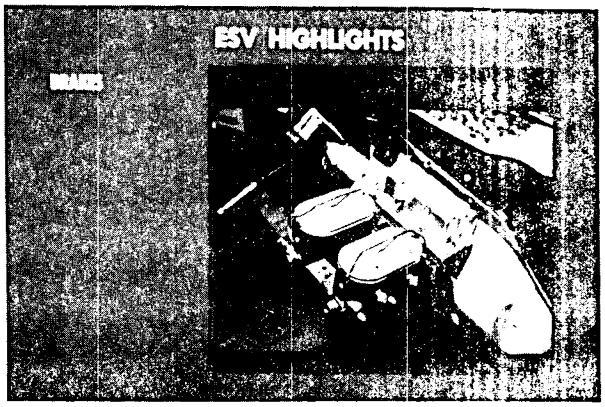


Figure 50

- Message center instrumentation provides detailed information and reduces driver distractions (Figure 53).
- 10 mph barrier impact bumper units, front and rear,

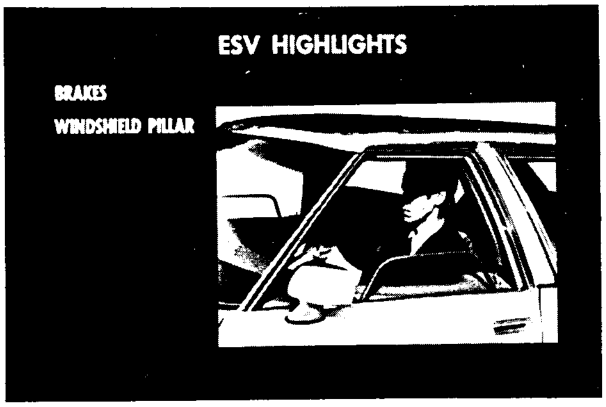


Figure 51

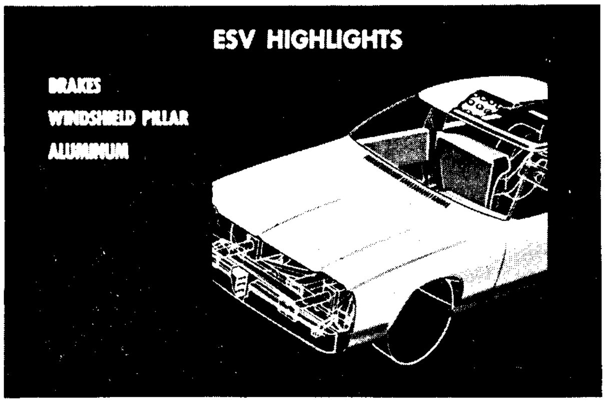


Figure 52

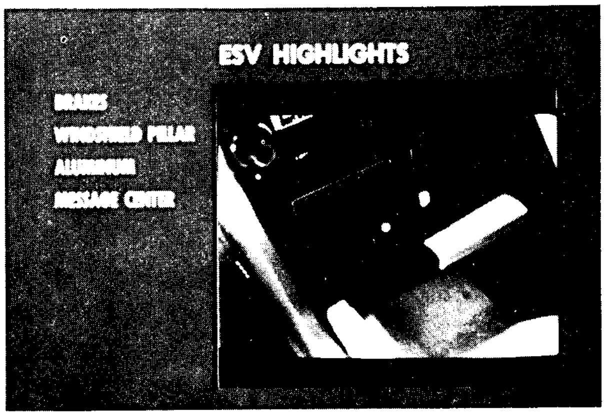


Figure 53

eliminate body damage in car-to-car crashes up to 20 mph (Figure 54).

- The side opening rear deck affords a new concept in curb-side loading (Figure 55).
- Fixed side glass is intended to keep occupants within the safer confines of the passenger compartment in a wide array of accidents (Figure 56).

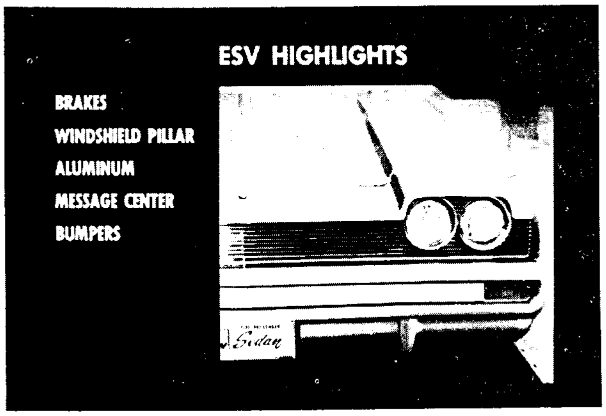


Figure 54

- High level rear signals – the dual levels of brightness provide for improved day optometrics and night visibility without glare (Figure 57).
- And last, the all-enveloping interior and occupant protection system (Figure 58).

We have considered design of the occupant protection system to be the most important and challenging portion of this assignment.

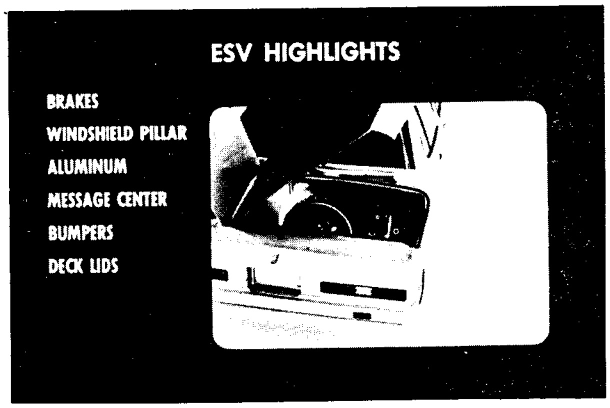


Figure 55

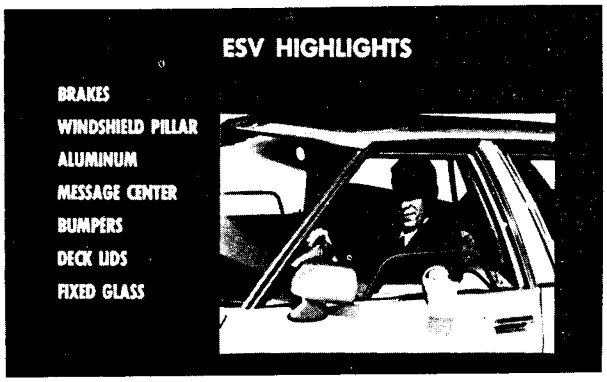


Figure 56

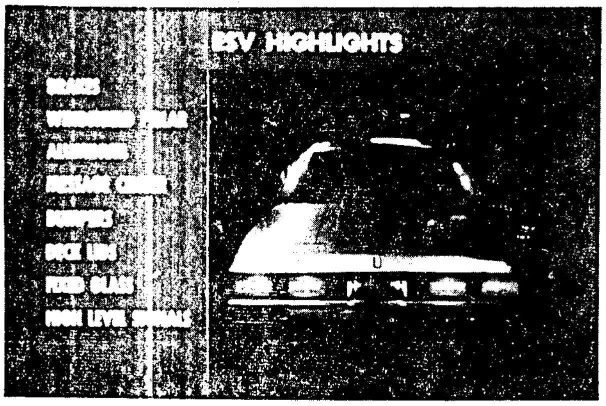


Figure 57

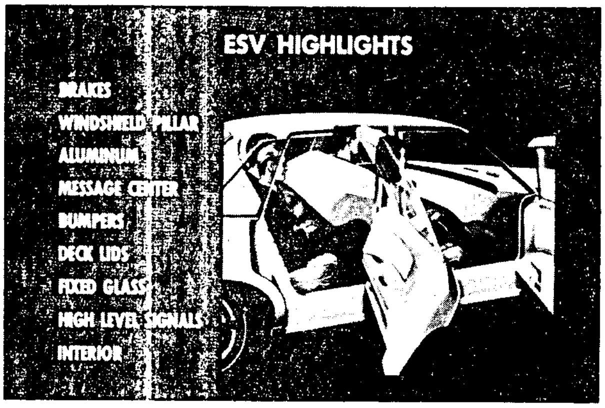


Figure 58

Structure And Occupant Systems

The engineering analysis involved defining vehicle structure and occupant kinematics parameters. In making this analysis we used all available simulation techniques. But first we had to make a number of assumptions and arbitrary decisions. Many different designs could be imagined, all possibly fulfilling the requirements of our ESV contract. We chose to make the configuration rather conventional. One reason was that some background experience was available. Furthermore, a more conventional approach could provide a basis for better comparisons.

To provide the maximum space for added structure, a seating arrangement equivalent to current intermediate size cars was used, combined with overall dimensions very close to full-size production sedans. This, incidentally, was also the exterior envelope defined in the contract.

While trade-offs between various requirements were acceptable, we decided that the specifications for a two-level occupant protection system provided the greatest challenge. The first level specified survivability in terms of the contract at a 20 mph barrier impact with no restraint other than the interior surfaces. We decided to try for 30 mph without restraint to make a more significant contribution to the state-of-the-art in occupant protection (Figure 59). The second level of protection involves a 50 mph barrier impact with a fully passive restraint system.

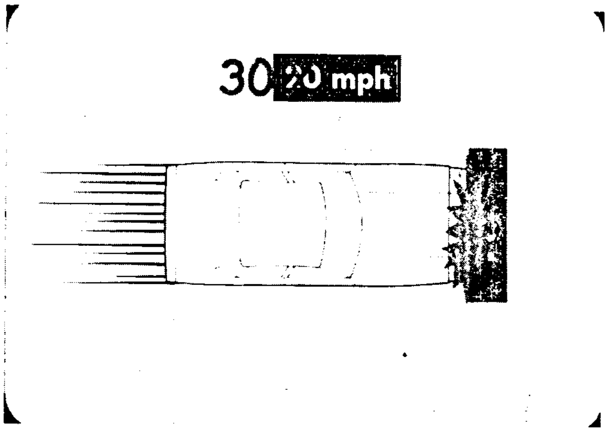


Figure 59

A lot of study went into the question of whether or not to design for changes in vehicle pitch during impact. It was apparent that certain manipulations of vehicle pitch could produce lower g levels on the vehicle (Figure 60). It was also quite obvious that by controlling occupant kinematics we could do a better protection job. Such control can best be maintained when vehicle pitch change is kept to a minimum (Figure 61).

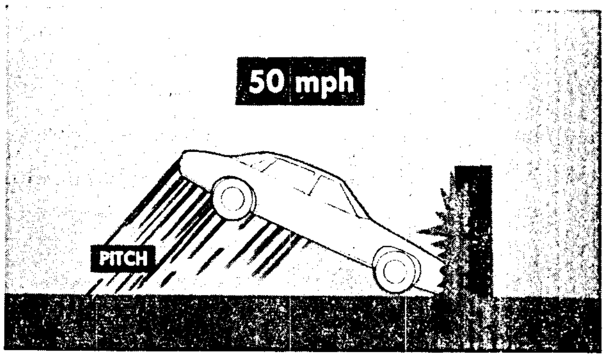


Figure 60

Therefore, we decided to design the structure for this performance by carrying two-thirds of the impact force through the frame and one-third through the front sheet metal and hood to the doors. This permitted much of the development work to be conducted on impact sleds without requiring pitch compensation.

The contract specification curve is well known (Figure 62). We designed the bumper system for 6 g's in

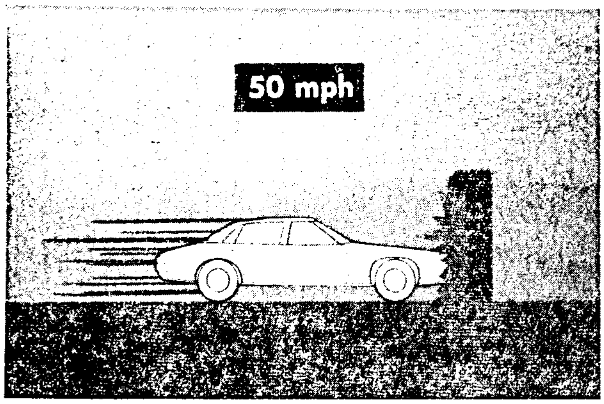


Figure 61

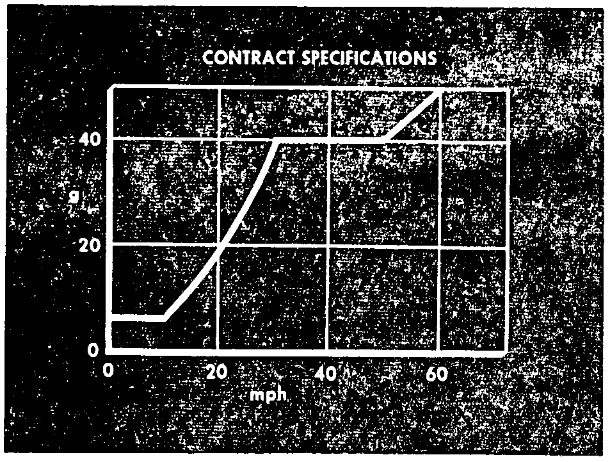


Figure 62

a 10 mph barrier impact. As the trace for the bumper system shows, the desired resistance is obtained up to approximately 15 mph, after which deformation of the structure occurs (Figure 63). The deflection-time curve

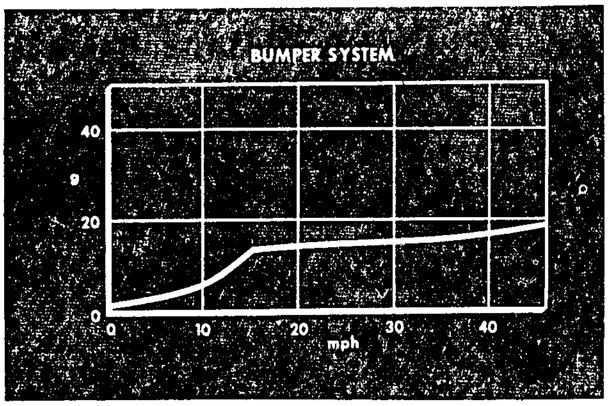


Figure 63

in Figure 64 illustrates the characteristics of the structure. We designed the vehicle structure and component dynamics to produce nearly a square wave deceleration.

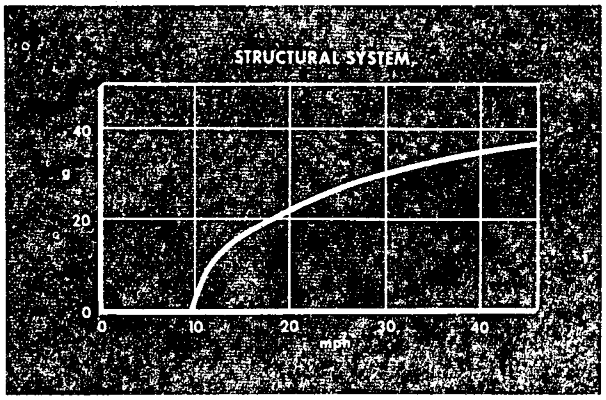


Figure 64

Superimposing these performance characteristics provided us with the overall curve shown in Figure 65.

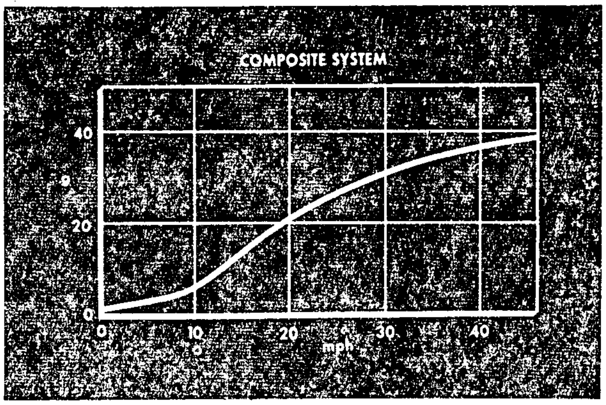


Figure 65

Figure 66 shows the actual performance of the front end of the vehicle in a barrier impact, including the effect of the bumper. It could also be plotted against crush distance instead of time, and similar curves are obviously available for other velocities, such as the one in Figure 67 which shows the behavior at 30 mph.

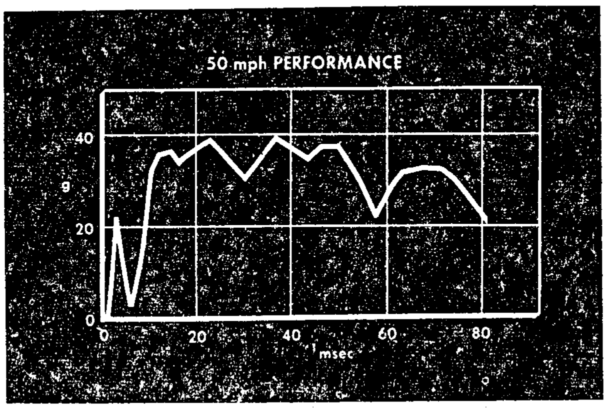


Figure 66

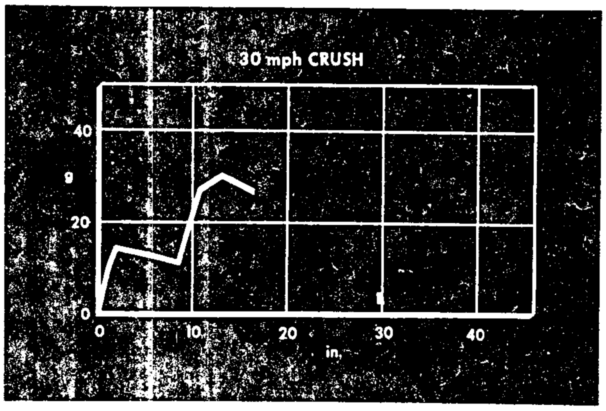


Figure 67

The structure was designed as a statically indeterminate bridge or truss work. Each element was analyzed individually for its behavior beyond the elastic limit (Figure 68). Calculations were verified through slow speed crush tests such as the frame which is being crushed by a ram illustrated at the top of Figure 69. This kind of preliminary testing is valid because we have found that the collapse mode at slow speed is identical to the mode at high speed for all structures normally used in frames and bodies.

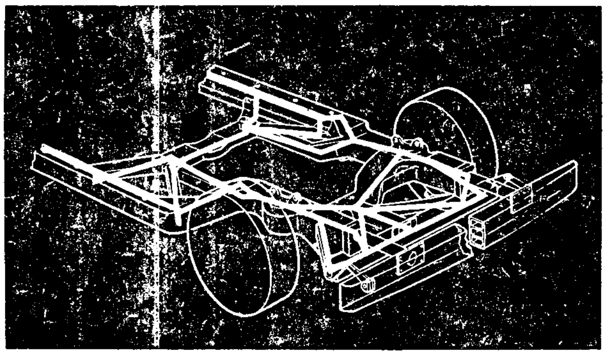


Figure 68

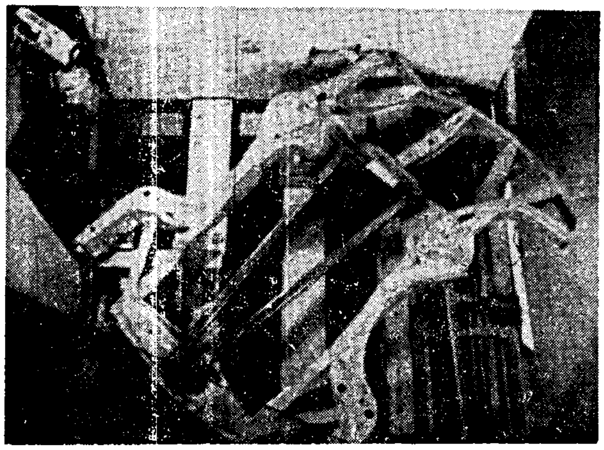


Figure 69

Turning now to our primary goal, occupant protection, the main reason for specifying a certain maximum vehicle deceleration is the relationship to occupant "ride-down" with the vehicle during impact (Figure 70).

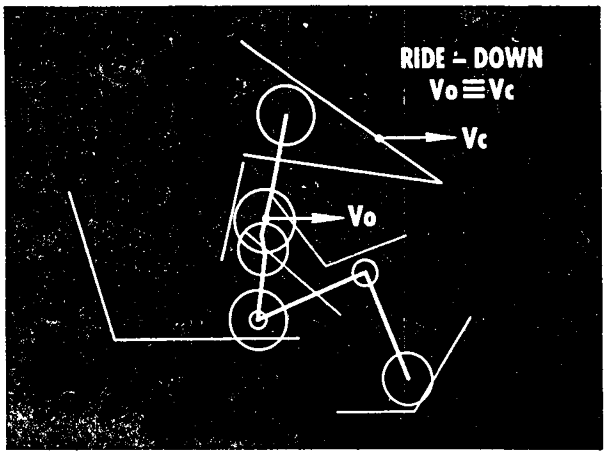


Figure 70

In Figure 71 the solid line indicates the decreasing vehicle velocity during the impact. The dotted line

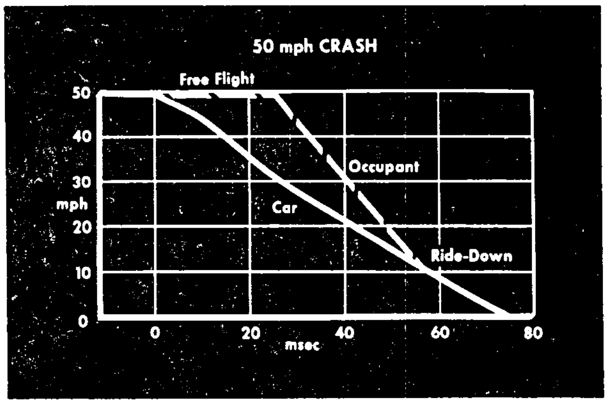


Figure 71

indicates the occupant's actual velocity. This shows the free flight distance or occupant spacing as well as the pure ride-down time or distance. In between, there is the restraining effect of the crush of the interior. There is always some rebound or spring-back of the vehicle and a certain amount of overlap between the interior crush and the ride-down. However, if we for a moment simplify the problem by disregarding occupant kinematics and assume a structure which produces close to a square wave deceleration, we can get a feeling for the potential ride-down which may be obtained at a given impact velocity. The three parameters which determine this potential are: (1) the structural characteristics of the vehicle as represented by the force-deflection curve, (2) the occupant spacing or the so-called free flight distance, and (3) the crush behavior of the interior, including the total deflection or penetration possible (Figure 72).

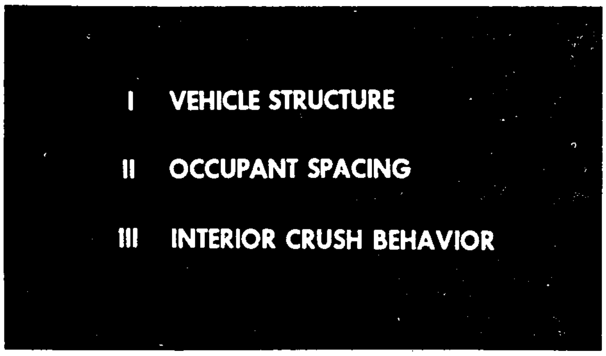


Figure 72

Add now the complexity of occupant kinematics. For the moment, we will consider only one specific dummy. It is quite apparent that the various parts of the dummy have different spacings (Figure 73). The degree to which ride-down is utilized varies accordingly. For this reason, control of the occupant kinematics becomes the most important single factor in designing for occupant protection. A precise definition of the dummy, including the dynamic properties and interactions of the various components, is absolutely necessary to insure the prescribed reactions.

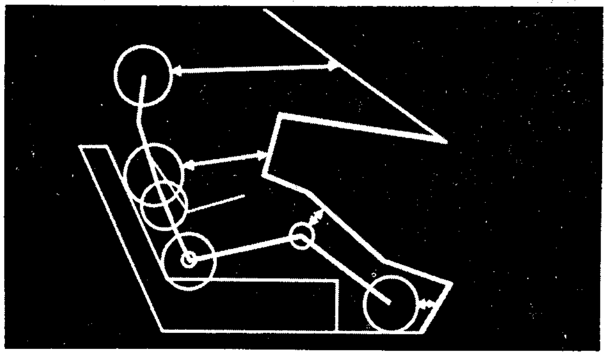


Figure 73

Our solution for 30 mph was to separate, physically, the interior surfaces which support the feet, knees, chest and head (Figure 74). The force-deflection characteristics of the surfaces could then be tailored to provide the desired kinematics. Of course, there are problems concerning the mixture of dummies, ranging from the 5th percentile female to the 95th percentile male – probably enough for another technical paper (Figure 75). We can mention, however, that the necessary deflection of some of the panels is more than double the amount required for a single size dummy design. There is

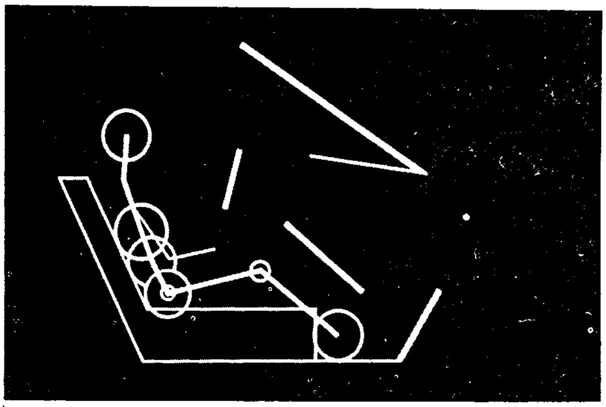


Figure 74

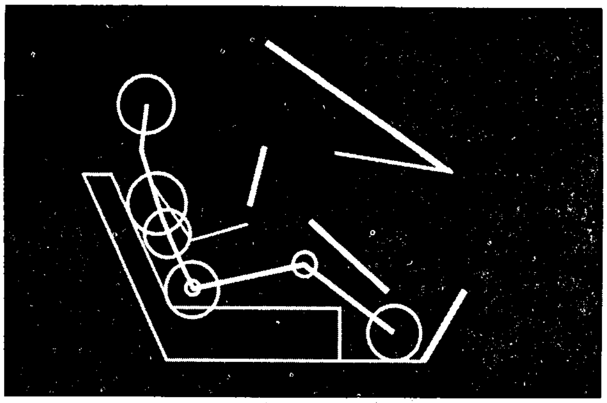


Figure 75

also the very significant question of the ability of these, or any known dummies, to model or reflect human behavior with fidelity.

Having first resolved the problems related to the 30 mph impact, we chose to make use of the air cushion concept for the high speed impacts. Such a system is simple enough in theory in that it provides for two very important functions: (1) it will reduce the free flight distance, increasing the distance over which deceleration forces are applied, provided full deployment can be accomplished quickly enough; and (2) it acts somewhat like a very low rate spring and shock absorber between the body shell and the occupant. This compensates for the effects of fluctuations in the g-t curve from the vehicle front structure.

Figure 76 indicates what is necessary to restrain the driver properly. It includes an air cushion mounted on top of the energy absorbing steering column and another air cushion which acts in unison with the energy absorbing knee panel.

The computer has been of great use in the study of occupant kinematics. In Figure 77, taken from a film sequence of the front seat passenger in a 50 mph impact, time after impact is indicated in the upper left hand

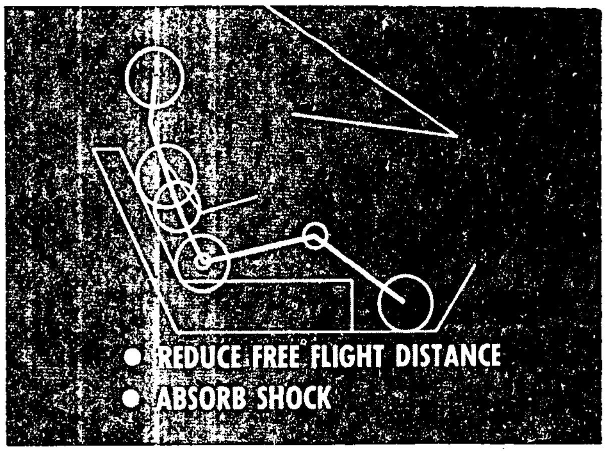


Figure 76

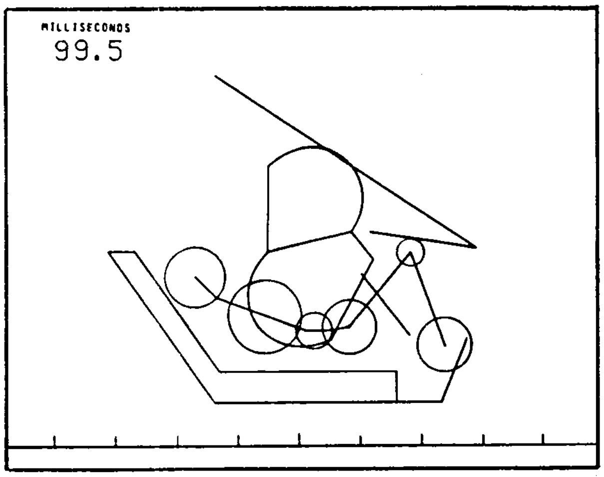


Figure 77

corner. This illustration is of an early design in which knee panel support was not sufficient. The result was submarining and an incorrect rebound trajectory.

In Figure 78 a rear seat occupant, again at 50 mph, has reprogrammed impact surfaces and air cushions. The

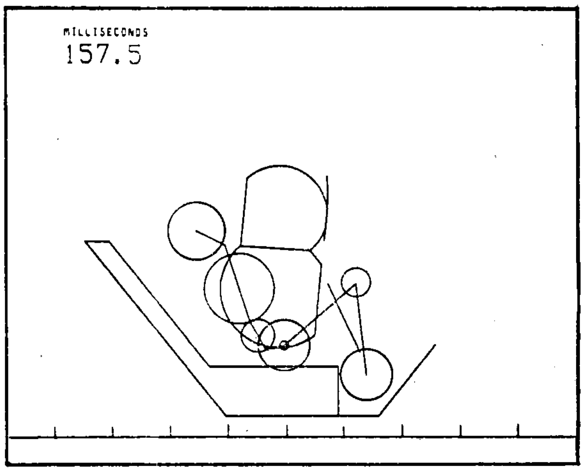


Figure 78

system is generally tailored to provide the appropriate energy absorbing characteristics and the trajectory is maintained so that the dummy can make full use of the system. He is stopped in the air cushion and is rebounded in an erect position. This has proven to be a very useful tool in studying the effects of changing design parameters without having to resort to time consuming and costly fabrication programs.

The air cushion must be in place before the occupant has moved significantly, and collapse must begin soon enough to insure a low rebound velocity.

In a 50 mph impact, you can't waste much time. We found that a deceleration sensor mounted directly on the bumper as shown in Figure 79 would produce the signal for triggering within 5 to 7 milliseconds. This was sufficient to get the air cushions fully extended within about 25 milliseconds.

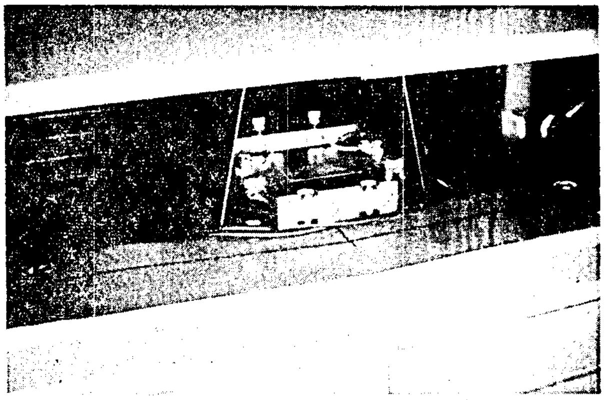


Figure 79

Summarizing the considerations for the design of the interior, I want to emphasize that positive control of the kinematics of the occupant is essential (Figure 80). If this is not done, it becomes impossible to provide the proper characteristics of the impact surfaces for the head, shoulders, chest, buttocks, knees and feet.

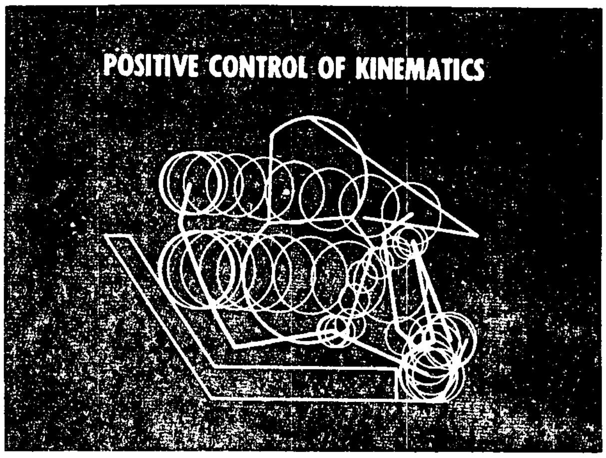


Figure 80

Secondly, as in the before and after cartoon (Figure 81), impact surfaces need to be designed with a minimum spring-back. This also applies to air cushions.

Third, the resisting force of the impact surface must be designed for the lightest weight occupant. In addition there must be tailored resisting forces and unobstructed deflection space for the wider and heavier 95th percentile passenger (Figure 82).

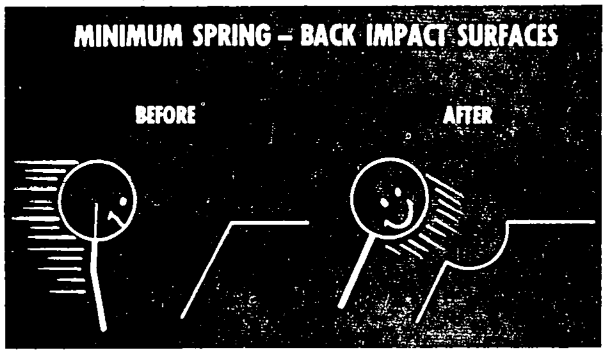


Figure 81

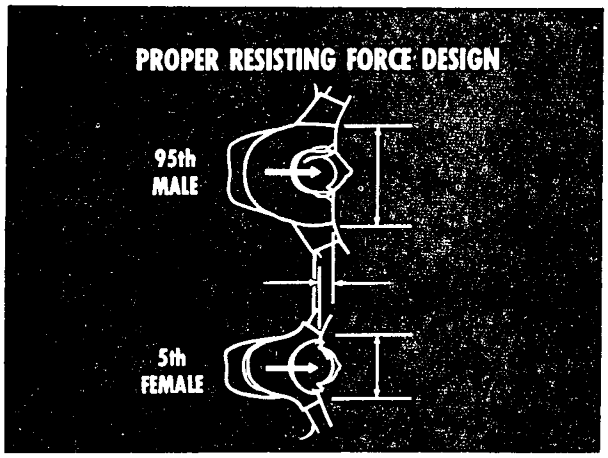


Figure 82

And fourth, there must be a "no protrusion zone" in which no massive objects can be allowed. There must be space into which the instrument panel may displace during the impact (Figure 83). And we should not forget that we have only studied the idealized situation where all the dummies are placed in their proper seating positions before the crash.

An important part of the development of the design has been testing on our impact sled (Figure 84). The theory for this sled testing is very simple: while a barrier crash begins with a high speed and ends at rest, our sled begins at rest and is accelerated to a high speed (Figure 85). However, the reactions of the occupants will be identical, provided the same acceleration versus time is obtained.

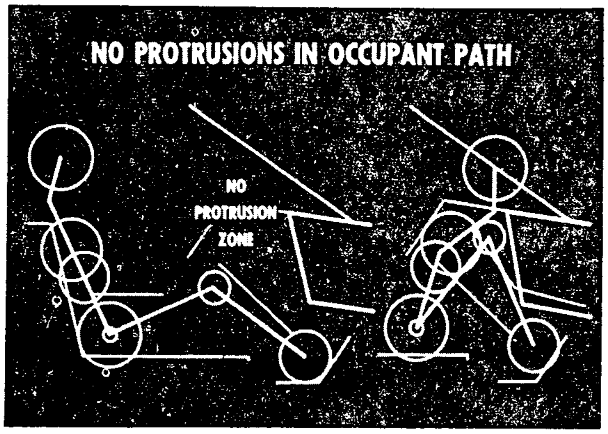


Figure 83

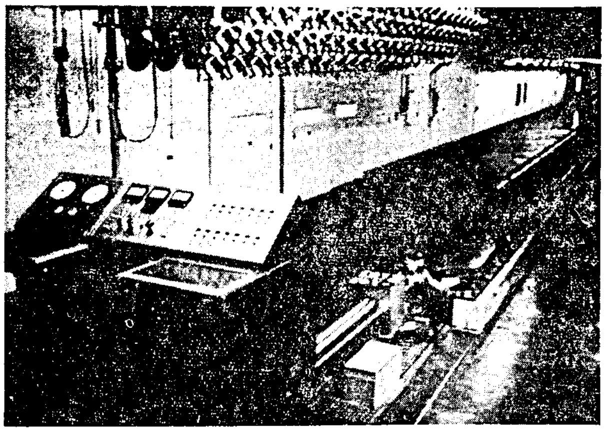


Figure 84

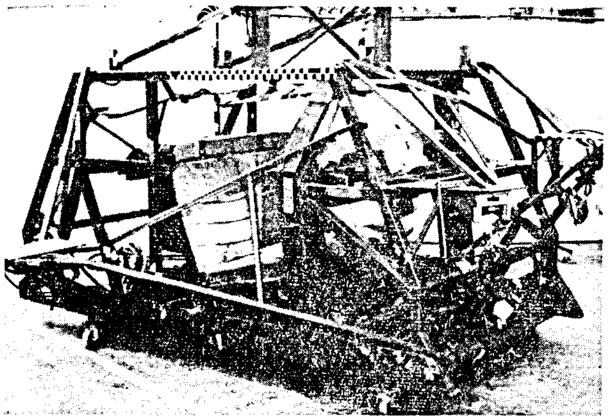


Figure 85

We have made extensive use of our sleds and here are some examples. Figure 86 is from a high speed movie of an early front seat passenger test with a pre-deployed cushion. The submarining problem is apparent. In Figure 87 we have a dynamic deployment and improved tailoring of resistance forces in the system. The occupant

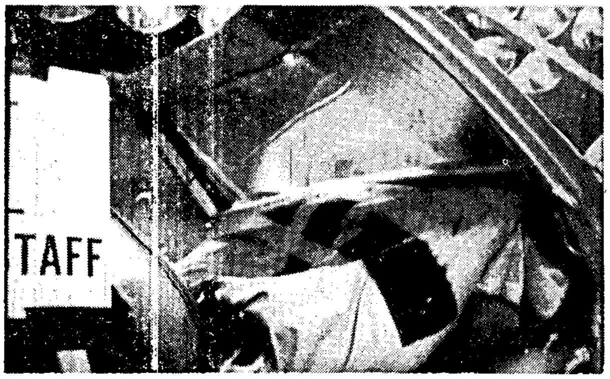


Figure 86

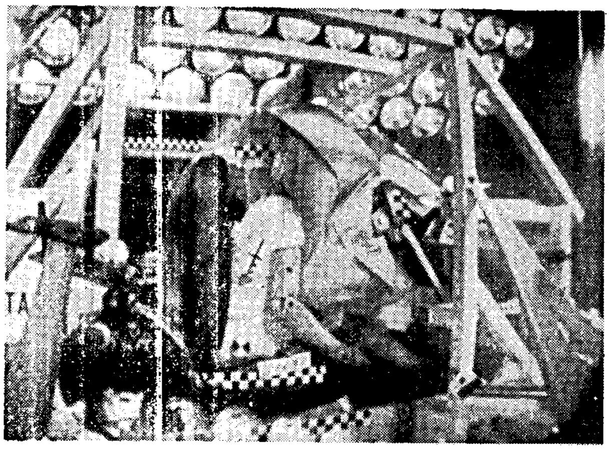


Figure 87

stays erect and has generally good kinematics. It is costly and time consuming to run enough tests of each configuration to insure repeatability. To get a feel for the statistical significance of measured data, a series of nine sled shots were run, three each with three different dummies, and all with identical interiors.

The plot of the driver head deceleration (Figure 88) illustrates some of the results. The mean value for Dummy "C" was 50 percent greater than for Dummy

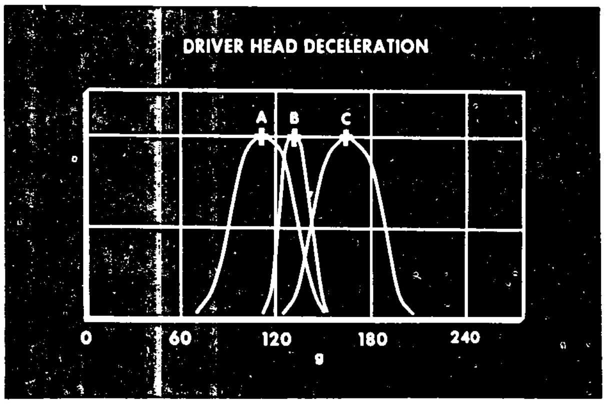


Figure 88

"A," which shows that comparable results can only be expected when everyone uses the same type of dummy.

The spread of data must also be considered in the selection of anthropomorphic test devices. In this test, Dummy "B" showed the best bunching of data, and this happens to be the one we are using, the GM hybrid unit.

I want to stress, however, that this dummy design is not the answer to all fidelity problems. It merely represents the most recent dummy that was available for use in our program. You can appreciate that we had to choose a design early and then stay with it for the course of the program. The design is based on an Alderson model which has been modified in the head, neck and chest (Figure 89).

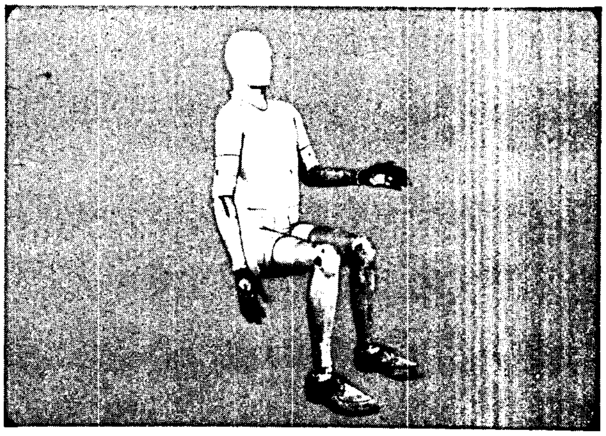


Figure 89

The original head is replaced by a Sierra head which, in turn, has been modified by grinding smooth the parting lines on the skull, removal of the rigid nose, removal of neck below the collar, removal of the ears for ease in targeting, and addition of a spacer for an accelerometer. The neck is replaced by a rubber design and a new mounting plate (Figure 90).

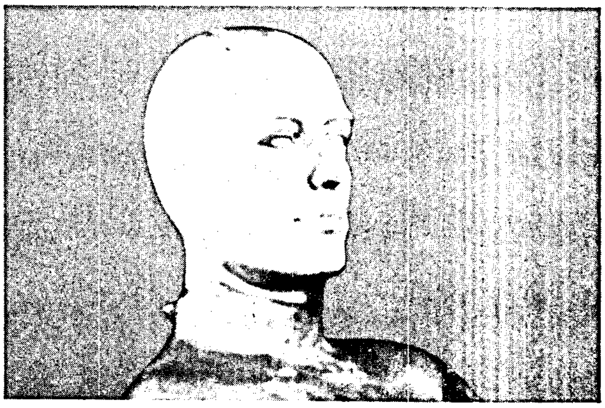


Figure 90

The chest is modified by removing internal braces and padding. The sternum assembly is replaced by a leather sternum with metal stiffeners, while new damping material has been added to each rib (Figure 91).

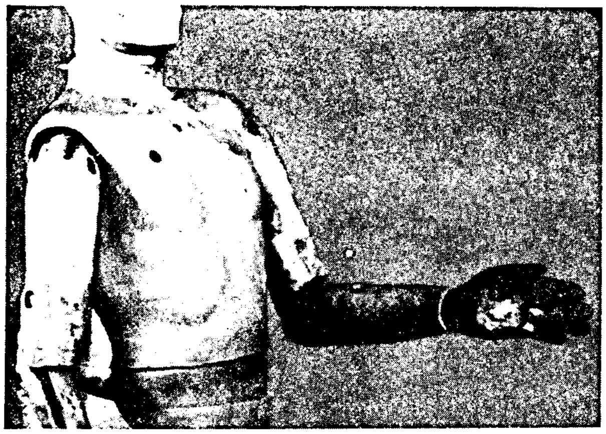


Figure 91

The head is instrumented with three orthogonally mounted, piezoresistive accelerometers with all major axes passing through the center of gravity of the head. Similar accelerometers, aligned to the c.g. of the shoulders, are mounted in the chest. The pelvic measurement system is in the same format and oriented to the hips. Strain gages are mounted in the femurs, and joints are properly tightened. The finishing touch is Sears Roebuck underwear.

However, it takes more than human underwear to simulate human behavior.

Test Results

Figure 92 shows ESV-1 from the passenger side. The car comes to rest in about 90 milliseconds. The front passenger air bag failed to inflate. The front structure successfully handled all the force for which it was designed. Residual crush is 34 inches.

Next we have a detail of the bumper action. It telescopes properly within the fender skin. There was,

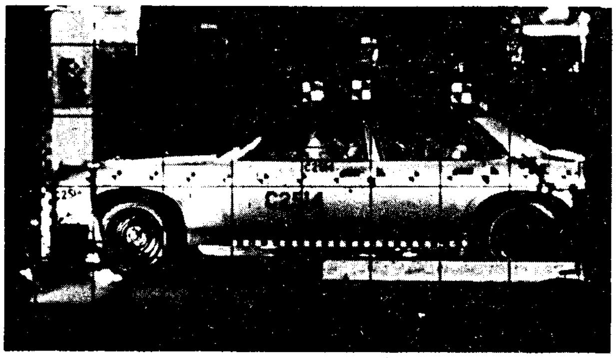


Figure 92

however, a short drop-off in load before the primary impact structure began to absorb energy (Figure 93).

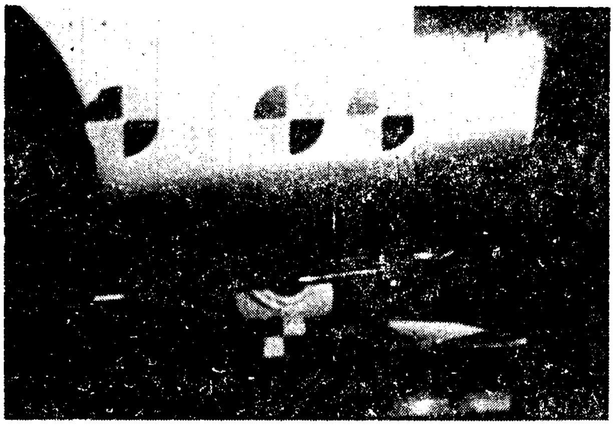


Figure 93

Looking in on the driver, his steering wheel air cushion starts to deploy after five milliseconds and is in position for his impact. The instrument panel displaced rearward more than anticipated and the knee cushions failed to deploy (Figure 94).

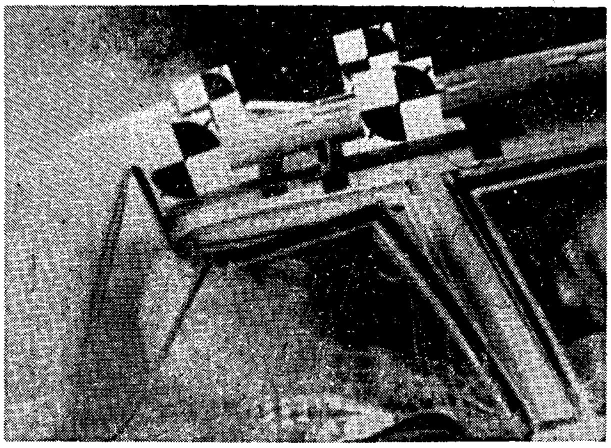


Figure 94

In ESV-2 the front seat passenger had a hard impact due to instrument panel motion. This time his air cushions were properly deployed but were not helped by the door motion when we experienced a failure of the latch system (Figure 95). Figure 96 shows another view of the proper air cushion deployment and windshield breakage.

The three 50th percentile rear seat occupants of ESV-1 essentially survived the crash. They were effectively stopped in the cushion without deflecting the credenza as much as we expected. As a result they rebounded too fast and all struck the rebound surface above the rear seat back at high g levels (Figure 97). In ESV-2 we again had good kinematics and modifications

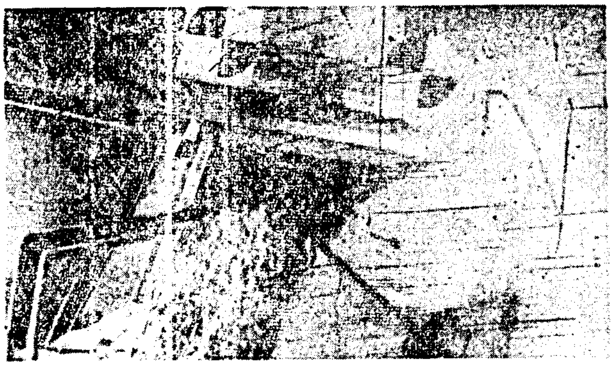


Figure 95

Figure 96

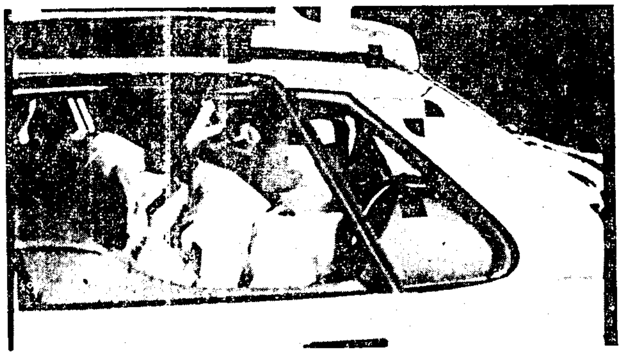


Figure 97

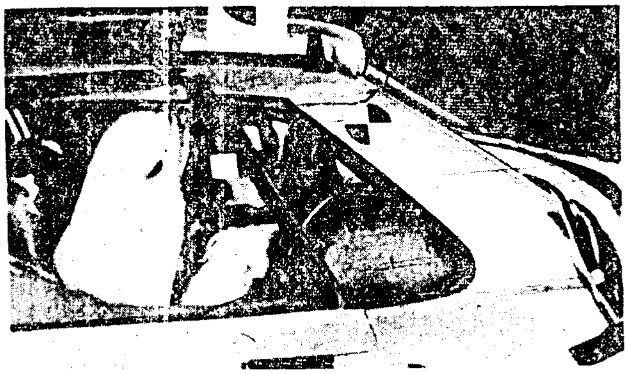


Figure 98

made to the energy absorbing mounts of the credenza provided the action we expected (Figure 98).

The quarter view of ESV-1 in Figure 99 illustrates the cooperative action of the body and frame. Pitch action, and its effect on the occupants, is apparent. In ESV-2 we modified the load path through the doors, which appears to perform properly here, but there is still pitching motion, which is largely due to the failure of the door latch in the passenger side (Figure 100).

From underneath ESV-1 we observe the desired progressive deformation, but there is too much motion in the torque box area. The drive line remained intact, transmitting force to the rear axle in a proper manner (Figure 101).

We were using 86 channels for data collection, 55 of which were used to monitor dummy reactions. In the table of Figure 102, results from the barrier tests are compared to results from the sled test, where we used identical interiors and g-t curves. The upper line indicates the contract specifications which are: up to 80 g's for no more than 3 milliseconds for the head, while chest and pelvis are permitted only 60 g's for 3 milliseconds with peaks up to 100, and a maximum of 1400 pounds on each femur.

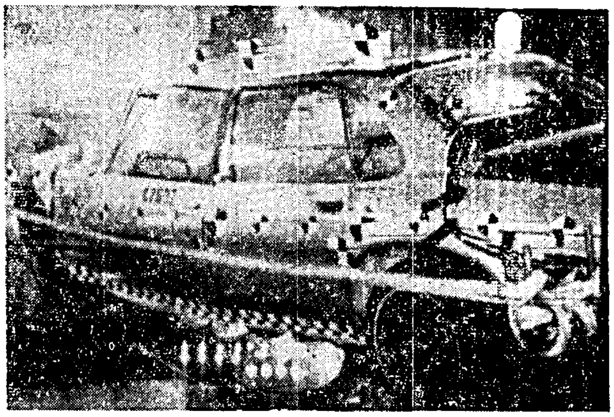


Figure 99

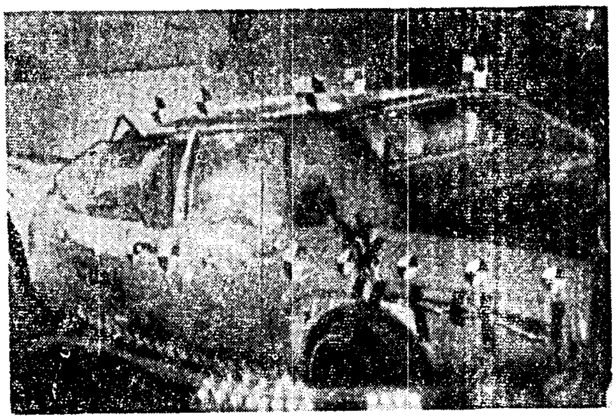


Figure 100

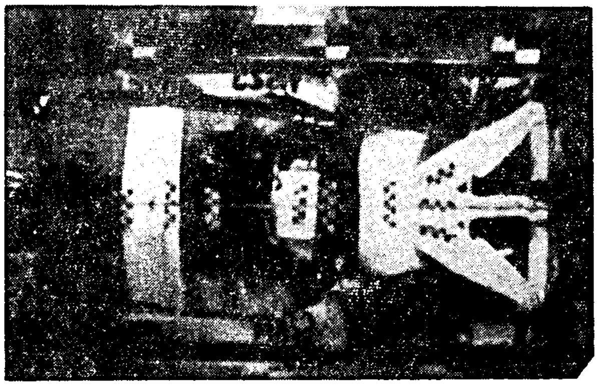


Figure 101

TYPICAL TEST RESULTS
FRONT SEAT

	HEAD, g/msec	CHEST, g/msec	PELVIS, g/msec	FEMUR Left, lb/Right, lb
CONTRACT	80/3.0	60/3.0 (100)	60/3.0 (100)	1400/1400
DRIVER				
SLED	-	67/2.1	86/12.0	1340/1000
BARRIER	-	170/21.1	105/3.4	2800/2350
PASSENGER				
SLED	-	41/0	94/4.5	1250/1050
BARRIER	9.6	110/26.9	140/3.3	3400/3400

Figure 102

The next two lines are typical measurements for the driver from the sled and barrier respectively. The underlined numbers indicate either peak g level or duration values that were greater than specified. The reason for the large differences can be explained as a result of the pitch change, which we have not yet succeeded in eliminating. As an example, the driver's head was properly supported by the steering wheel air cushion and the deceleration did not even reach the 80 g's, but the instrument panel was forced backwards, taking the steering wheel and knee pads with it, to produce too high forces on the chest and knees.

Similar results were obtained for the front passenger. In the barrier test, the roof came down against his head, which brought the g level above 80 for 9.6 milliseconds, and again the instrument panel deflected rearward to bring the femur loads way out of line.

The numbers in Figure 103 are typical for the outboard passengers in the rear seat. Here the vehicle pitch did much less damage, but resulted in a greater tendency to submarining and an increase in rebound severity. We still have a problem with the knee loads.

Also, the center rear occupant had a problem; in this case the g level on the head stayed above 80 for 6.4 milliseconds during rebound.

TYPICAL TEST RESULTS
REAR SEAT

	HEAD, g/msec	CHEST, g/msec	PELVIS, g/msec	FEMUR Left, lb/Right, lb
CONTRACT	80/3.0	60/3.0 (100)	60/3.0 (100)	1400/1400
OUTBOARD PASSENGER				
SLED	-	66/3.0	80/2.5	1500/2200
BARRIER	1.2	51/0	51/0	1620/1050
CENTER PASSENGER				
SLED	1.0	72/2.3	75/10.0	1870/1320
BARRIER	6.4	52/0	44/0	1350/840

Figure 103

All the dummies were killed, so to speak, although some only slightly.

The impact forces were measured on the barrier face, with the distribution shown in Figure 104. It appears that the design goal of carrying one-third of the force through the sheet metal and two-thirds through the frame, was almost obtained. But it also appears necessary to revise the distribution such that the high level force is increased while the low level force can be reduced.

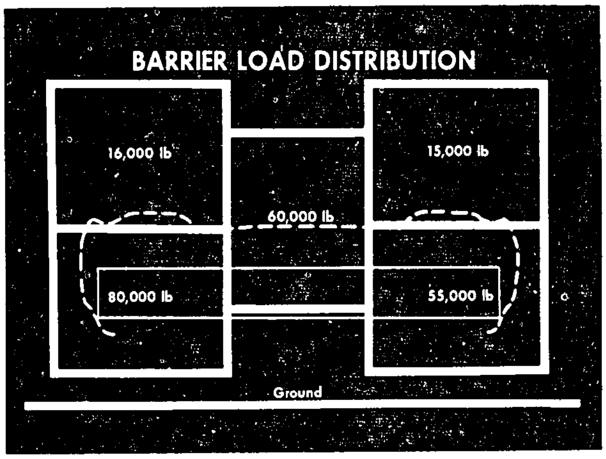


Figure 104

In these barrier tests, the bumper system, frame, engine mounts, drive line and air restraint system performed as expected. Also, there was no fuel spillage.

We have not yet reached the goal completely. But it appears that there is enough evidence that when the structure has been reworked so that proper pitch attitude is maintained, the dummy kinematics will also be controlled sufficiently. This will yield acceptable forces and decelerations in all seating positions.

Conclusions

The ESV program in General Motors is a study in meeting Department of Transportation performance requirements. We have just described slightly over one year's activity in its development, during which time we have designed a basic vehicle concept, reduced it to running hardware and obtained preliminary test results.

Our objective has been to meet or exceed all of the specifications without trade-offs. The emphasis has been on crashworthiness and occupant protection in terms of our contract. Designing for contract accident avoidance involved no new technology.

Our approach represents an effort to accomplish the contract objectives with a newly designed vehicle, conventional in most respects, along the lines of current automotive practice. It is not possible to determine whether or not this approach imposed constraints on the performance of the design. It is obvious, however, that there are many questions of practicability that are not resolved by our program. Such things as interior roominess needs, air cushion hazards, increased weight, and whether or not ESV specifications save lives remain to be resolved.

Because considerable development and testing remain, it is too early to draw any final conclusions. However, it is appropriate at this time to make some observations based on our experiences during the past year:

1. Contract occupant protection objectives have not yet been achieved. However, with design modifications, they are probably achievable.
2. Precise control of occupant kinematics is essential in a totally passive protection system. This is achievable only by development of structural characteristics dictated by requirements of an overall system, including interior components and restraint devices, tailored to accurately program occupant position and velocity during impact.
3. Design for control of kinematics must be restricted to a specific dummy configuration. Designing to accommodate the full size range (5th to 95th percentile) is considerably more complex than for the 50th percentile only.
4. The imposition of structural constraints, such as the specified protective bumpers and intrusion limitations, restricts the ability to optimize structure for occupant protection.
5. The necessary structure can be achieved within the specified exterior dimensions. However, the interior space and entrance and exit accommodations, particularly in the rear, are unacceptable.
6. Structural requirements, if achieved with conventional materials, would result in a vehicle excessively heavy. The resultant use of lightweight materials adds significant cost to the extent that such a vehicle is not marketable.

In reviewing the results of this program, certain qualifications must be kept in mind. Our car is designed for very specific crash test situations. The relationships of our test data to highway crashes is unknown. For example, the correlation between car-to-car and barrier tests, and the subject of the large car to small car crash are not being studied in our program. In fact, it appears that the whole subject of traffic mix may well be the overwhelming factor in consideration of vehicle structures. It doesn't take much imagination, however, to visualize what a large car with substantial structure such as the ESV can do to a small car.

It is important to emphasize that any vehicle designed to occupant protection specifications can only be developed and evaluated with anthropomorphic test devices assuming a normal seating position at the time of impact. It is generally recognized that the fidelity of such devices relative to the human body is questionable at best. Therefore, conclusions regarding human "survival" or injury level are not valid, particularly in light of the limited knowledge of human tolerance factors. It is conceivable that future developments in the fields of dummy construction and bio-mechanics could completely negate test results currently being obtained.

It is apparent that we are not in a position to determine whether or not the specifications have merit in terms of effectively improving the crashworthiness capabilities of marketable cars.

What we now have is a development tool, with which an extensive test program is being conducted. It includes evaluation of crashworthiness in specified crash situations as well as the normal vehicle development activity. Design refinements will be made based on this work.

THE FORD MOTOR COMPANY

Mr. Henry Gregorich
Chief Engineer, Special Vehicles Office

Ladies and Gentlemen:

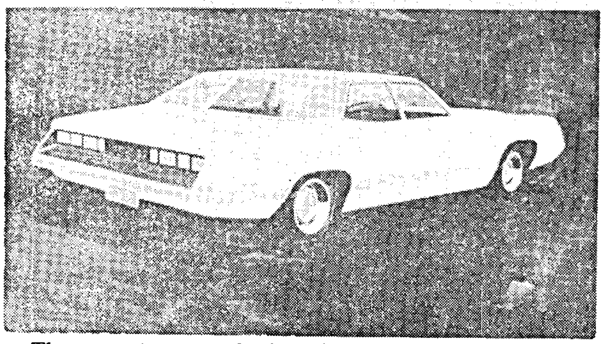
Before we begin the technical part of our presentation, I would like to observe that Ford Motor Company's concern with vehicle safety dates back many years – a fact that is documented by the company's many important product safety innovations.

Our engagement in the current experimental safety vehicle program – the program that we are here today to describe – is not a new involvement for Ford, but only a continuation – perhaps on a more formalized basis and with greater public exposure – of activities that for many years have characterized our company's advanced product engineering program.

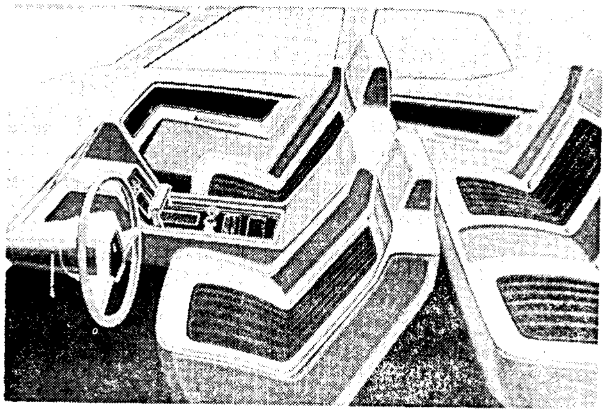
When early in 1970, the United States Department of Transportation sent our requests for bids on the design and construction of experimental safety vehicles in the 4,000 lb. sedan category, Ford responded by submitting a proposal incorporating design features essentially identical to those that will be described in our presentation here. Although our bid was not accepted at that time, the company went ahead with the program as part of our internal advanced product engineering effort. Our major purpose was to meet occupant protection objectives of the levels identified by the Department of Transportation using regular production hardware insofar as possible.

In July of this year, Ford entered into a one dollar contract with the United States government to build and deliver one experimental vehicle prototype to the D.O.T. by the end of 1972. This decision was based on the premise that Ford's participation would make a valuable contribution to the total worldwide ESV effort. The rendering you see before you pictures the Ford car essentially as it will look when completed. It features a longer hood than the current production Ford, but has the same passenger compartment size and basically the same roof configuration.

FORD ESV



The rear view reveals the relatively short trunk, which is a feature we find is necessary in order to remain within the overall length objective of 220 inches.



The interior features include fixed front seats for the driver and front right passenger, separated by a control console, which is an important structural feature of the car. The transmission shift lever and certain other controls are located in the console to provide space in the instrument panel area for restraint devices and associated hardware.

FORD ESV PROGRAM

- FORD APPROACH
- DEPARTURES FROM GOV'T ESV OBJECTIVES
- VEHICLE DESIGN
- SUBSYSTEM TESTS
- VEHICLE CRASH TESTS
- CONCLUSION

Now, with respect to the program we have undertaken – my presentation is divided into six major parts. First, I will explain the approach we are taking to our ESV effort; then point out where we are departing from the original ESV specifications laid down by the DOT. Third, I will describe the vehicle as it stands in its current state of development – particularly with respect to its major systems – and will follow that with a report on the status of subsystem developments. I will then report on the results of vehicle crash tests, using a series of crash test film clips, and will conclude my presentation with some statements with regard to Ford's overall outlook on the ESV program as of the current time.

The approach we are taking to the development of an experimental safety vehicle is to start with a standard production car and modify the design as necessary to meet the objectives of the ESV program. Basic modifica-

FORD APPROACH

OVERALL VEHICLE CONCEPT

MODIFY DESIGN OF CURRENT 4-DOOR SEDAN WITH:

- ENERGY ABSORBING FRAME
- REINFORCED BODY
- FIXED SEATS WITH TRANSVERSE STRUCTURE
- ALL PASSENGER RESTRAINT SYSTEM

tions that we believe will be required are an energy-absorbing frame with front and rear impact bumpers, a reinforced body incorporating restraint systems for all five occupants, and fixed seats with adjustable foot controls for the driver.

FORD APPROACH

CRASH AVOIDANCE:

<u>BRAKING</u>

- FRONT DISC BRAKES WITH SEMI-METALLIC LININGS
- 12" REAR DRUM BRAKES WITH ORGANIC LININGS
- HYDRAULIC POWER BRAKE BOOSTER WITH RATIO CHANGER
- REAR TWO WHEEL SKID CONTROL

In the crash avoidance area, we will meet the DOT objectives for brake system performance by modifying production designs of brake system hardware to accommodate the heavier weight of the vehicle. A new development program will not be required. We will use front disc brakes with semi-metallic linings and twelve inch rear drum brakes with organic linings. These linings on the rear brakes will permit us to meet the desired parking brake operational levels of 90 pounds for hand operation and 125 pounds for the foot.

To meet the requirement for stopping with booster power-off or with partial system failure, we will provide a hydraulic brake booster featuring a ratio change during the power-off mode and will install a 4x2 redundant brake system. A rear two-wheel skid control system will also be included.

We are confident that we can meet the handling performance requirements outlined in the DOT contract. We plan to resort to wider wheels and tires to meet lateral acceleration limits. We also believe it will be

FORD APPROACH

CRASH AVOIDANCE

<u>HANDLING</u>

- INCREASE IN TIRE AND RIM SIZES
- STRENGTHENING AND RETUNING OF SUSPENSIONS

<u>STEERING</u>

- STRONGER STEERING LINKAGE FOR ADDED WEIGHT

necessary to strengthen and retune the front and rear suspensions. Similarly, the steering linkage will have to be beefed-up to carry the added force levels imposed on the system by the added vehicle weight and wider tires.

FORD APPROACH

ADDITIONAL CONSTRAINTS

- DESIGN TO COMPLY WITH:
  - CURRENT FMVSS REQUIREMENTS
  - FORD PRODUCT DURABILITY STANDARDS
  - FORD PRODUCT ACCEPTANCE STANDARDS

As an integral part of the ESV program, the vehicle should and will include all applicable 1972 FMVSS standards.

In addition, in keeping with our approach of production feasibility, the vehicle will be designed and developed to meet our internal product acceptance standards regarding durability, performance, handling, braking, N.V.H. and ride characteristics.

ADVANTAGES OF FORD APPROACH

- **DEVELOP VEHICLES CAPABLE OF MASS PRODUCTION BY PROVEN TECHNIQUES.**

We believe that the Ford approach to the development of an Experimental Safety Vehicle offers several important benefits.

In the first place, developing the car from a production vehicle gives us a better chance of coming up with a final ESV design that can be mass produced – manufactured and assembled by techniques of proven feasibility.

ADVANTAGES — FORD APPROACH

EFFICIENT APPLICATION OF MANPOWER:

- STEP-OFF FROM EXISTING COMPANY SAFETY PROGRAMS:
  - AIR BAGS
  - BUMPERS
  - FUEL TANK INTEGRITY
  - VISIBILITY
  - ROLLOVER

Second, working from a vehicle design that is familiar to our entire product engineering force, and having within that capability the expertise for development of all of the currently available and proposed vehicle safety features for Ford production cars, we are able to exploit these special talents to great advantage in our ESV program. Our engineering groups engaged in the development of air bags, damage resistant bumpers, improved fuel tank integrity, visibility, and rollover, for instance, are available to assist the ESV task force.

ADVANTAGES — FORD APPROACH

- FACILITATES ESTIMATION OF COST ADDITIONS FOR SAFETY IMPROVEMENTS

Furthermore, the Ford approach will facilitate more realistic estimation of the cost additions in our experimental safety vehicle over the base production car which we modify. This could be an important consideration in measuring the success of the ESV program – if success means identifying worthwhile vehicle safety improvements which can be provided at reasonable cost to the car buyer.

Departures From Government ESV Objectives

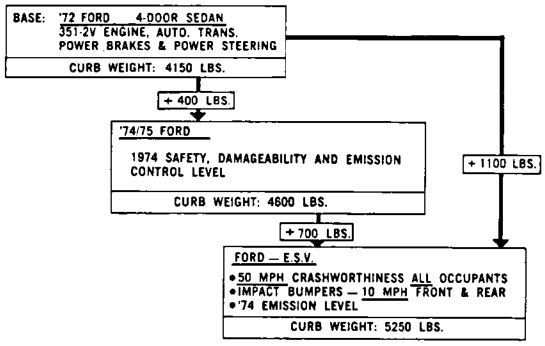
Now, let me call your attention to the fact that our ESV program involves departures from some of the objectives laid down by the DOT. Two major differences are in the weight target for the vehicle and in the visibility requirements.

DEPARTURES FROM GOVERNMENT ESV OBJECTIVES

- WEIGHT PROJECTIONS
- VISIBILITY REQUIREMENTS
- INJURY CRITERIA
- INTRUSION LIMITS

In addition, we have certain reservations in accepting the injury criteria specifications and the definition of intrusion limits and may arrive at determinations other than those advanced by the DOT with respect to the best ways of effectively improving occupant protection.

EXPERIMENTAL WEIGHT INCREASE PROJECTIONS



Since our approach is to step off from a current production vehicle, it is inevitable that we will exceed the ESV weight objective.

The current production Ford sedan that is our base vehicle has a curb weight of 4150 pounds. This is near the 4200 pound upper limit of the ESV weight objective.

Modifying the base vehicle to meet the safety and emissions requirements for 1974 and 1975 automobiles marketed in the United States imposes a weighty penalty on the vehicle of approximately 400 pounds.

Based on our current estimates, an additional weight increase of 700 pounds will be required to reach the 50 mph barrier impact objective of the contract and the 10 mph front and rear no-damage bumper requirements. This adds up to a projected curb weight of 5250 pounds, or 1100 pounds over the base car.

EXPERIMENTAL WEIGHT PROJECTIONS DETAIL: ESV VS. 1972 BASE CAR

BODY REINFORCEMENTS	414
FRAME REINFORCEMENTS	210
RESTRAINT SYSTEM	126
IMPACT BUMPER SYSTEM FRT. & REAR	100
EMISSION SYSTEM '74 LEVEL	90
CHASSIS UPGRADING	80
ENGINE—(400 CID OVER 351)	80
TOTAL ADDITION	**1100**

A closer examination of the weight addition reveals that body reinforcements and passive restraint systems for all occupants make up approximately one half of the total. Frame reinforcements and general chassis reinforcement account for approximately 25 percent. A larger engine is required to meet the passing performance of 12 seconds from 30 to 70 mph with the increased weight of this vehicle.

Obviously, these projections are based upon our current design knowledge. We are making every effort to hold down these additions as we refine our design.

VISIBILITY REQUIREMENTS

		D.O.T. OBJECTIVES	FORD ESV OBJECTIVES	
FORWARD VISION	UP ANGLE	17°	11.5°	WOULD REQUIRE • 7" ROOF RISE • SLOPED-DOWN HOOD
	DOWN ANGLE	8°	3.2°	
REARWARD VISION	VERTICAL FIELD OF VIEW	8°	4.5°	WOULD REQUIRE • 6" ROOF RISE

The second major departure from the DOT objectives is with respect to visibility. This table compares the ESV objectives with those we have established for our car. Since we are retaining essentially the production roof configuration of our base car, the vision angles forward and rearward are very much the same as current production.

To meet the ESV requirements, the roof would have to be raised 7.0 and 6.0 inches respectively, which could drastically reduce the structural integrity of the roof unless compensating structural changes were made. Our concern is more fundamental, however, in that we question the validity of the requirement.

To establish realistic visibility requirements for safe driving, Ford is engaged in a comprehensive study on this subject. We are periodically reviewing the results of this study with the DOT as an alternative to working toward meeting the visibility requirements in our ESV car.

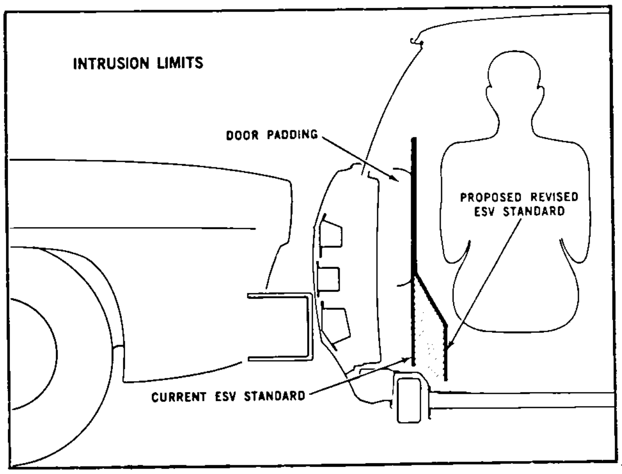
INJURY CRITERIA

	GOVERNMENT E.S.V. POSITION	FORD POSITION
ALL CRASH MODES	CHEST: 60 'G'S MAXIMUM RESULTANT HEAD: 80 'G'S MAXIMUM FOR 3 MILLISECONDS FEMUR 1400 LB. MAXIMUM LOAD	SAME, BUT WITH RESERVATIONS. NOT YET PROVEN AT THIS TIME ARE: SURVIVABILITY AT THESE LOAD LEVELS ATTAINABILITY OF THESE LOAD LEVEL OBJECTIVES
SIDE IMPACT CRASH MODES	SAME AS ABOVE WITH ADDED: 20 G OBJECTIVE FOR OCCUPANT	FURTHER TESTS NEEDED TO ESTABLISH A MORE REALISTIC OBJECTIVE

Injury Criteria

In our ESV program, we are accepting with reservations, the g-level objectives specified in our contract. Our reservations stem from the fact that the tasks involved are monumental, and perhaps impossible, while there is no conclusive evidence that these levels represent human survivability limits or correlate to human response to impact.

With respect to values for human tolerance to side impact, we know of no data reliably establishing acceptable head and chest g-loads. We believe that the 20 g objective for side impact, for example, is not an achievable target within the design parameters specified in the contract, and that further refinement of these specifications is necessary.



With respect to intrusion, rather than setting a three inch limit, we believe that it would be more realistic to define a side envelope around the occupant that would protect against his entrapment under the test impact conditions. Therefore, our program is designed to provide minimum g-levels even if this requires localized intrusion in excess of those specified.

VEHICLE DESIGN

- DESIGN RATIONALE
- ENERGY MANAGEMENT
- FRAME
- BODY
- BUMPER SYSTEM
- RESTRAINT SYSTEMS

Vehicle Design

We will now discuss the design parameters of the Ford ESV. At this point, we would like to stress the fact that our approach has been to put primary emphasis on improved occupant protection. The items affected by this rationale are the energy management between the frame and the body, the frame design, the body front end, the bumper system and the restraint system. A detailed discussion of these items follows.

VEHICLE DESIGN

RATIONALE FOR VEHICLE CONSTRUCTION:

- RETAIN BODY-ON-FRAME CONCEPT
- MAINTAIN FEASIBILITY FOR MASS PRODUCTION
- UTILIZE CONVENTIONAL MATERIALS

Rationale For Vehicle Construction

The design and assembly of this car is basically similar to our full size Ford which is made up of a separate body and a frame.

Also, we have attempted to retain techniques of proven feasibility for mass produced automobiles. Except for the bumper, conventional materials were selected to keep the cost down and maximize the likelihood that we can utilize proven production techniques.

VEHICLE DESIGN

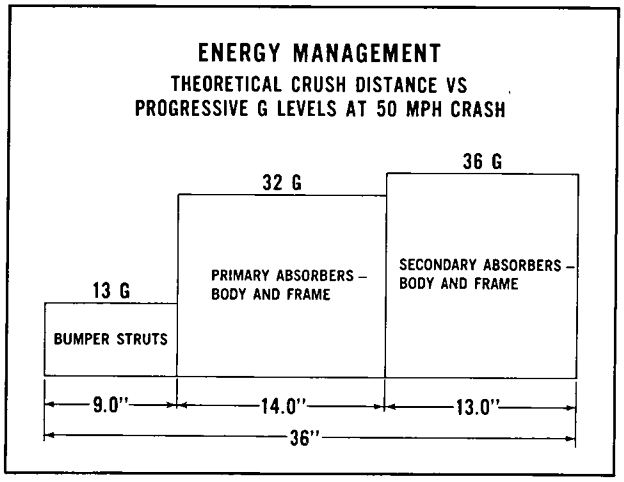
RATIONALE FOR CRASH PERFORMANCE PARAMETERS:

- EFFECTS OF CAR-TO-CAR CRASHES BETWEEN ESV AND
  - — OLDER VEHICLES
  - — LIGHTER VEHICLES
- EFFECTS OF CRASHES AT SPEEDS LOWER THAN "DESIGN SPEED" OF 50 MPH

Rationale For Crash Performance Parameters

To design the ESV for improved occupant protection over a wide range of impact speeds, our objective has been to provide some degree of collapse under any crash mode. This approach suggested a front end design that collapses progressively under increasing force levels.

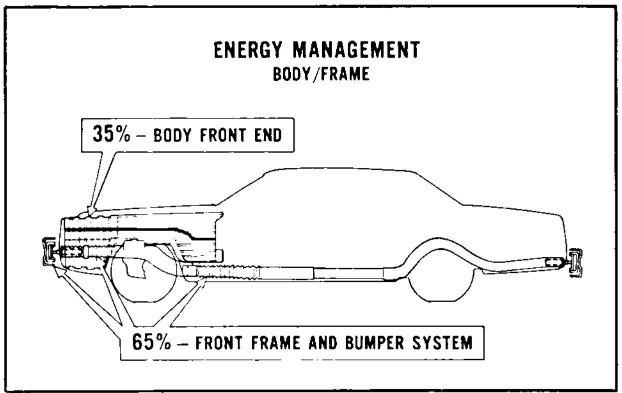
In addition to providing some degree of collapse and, thus, some energy absorption at low speeds, this technique reduces the impact forces imparted to the older and lighter vehicles that might be struck by the ESV.



Energy Management

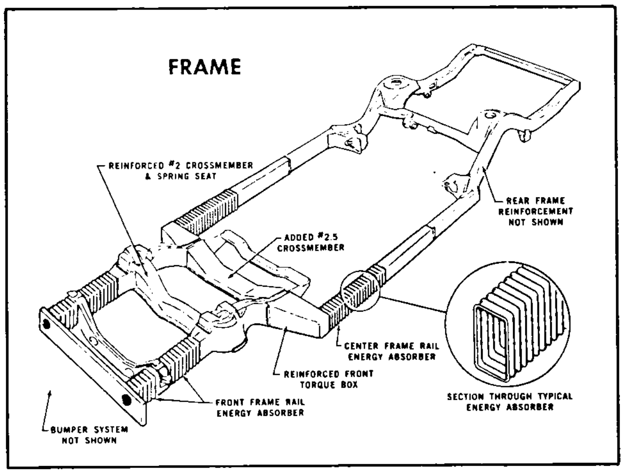
We have taken advantage of the maximum dimensions for overall car and the vehicle wheelbase which are 220 inches and 124 inches respectively. To provide crush distance for front barrier impact, and still satisfy the angle of approach requirement, the front overhang was set at 45 inches. This allows 36 inches of front crush distance with acceptable engine intrusion into the firewall.

The front end is designed to sustain increasingly higher g-levels, from 13 g to 32 g and 36 g. This offers greater predictability of collapse. It also reduces crash loads at lower impact speeds.



The initial front end designs had 90% and 10% for frame and body energy absorptions respectively. This later was revised to 65% frame and 35% body in order to reduce frame frigidity and raise the center of impact resistance line closer to the vehicle center of gravity.

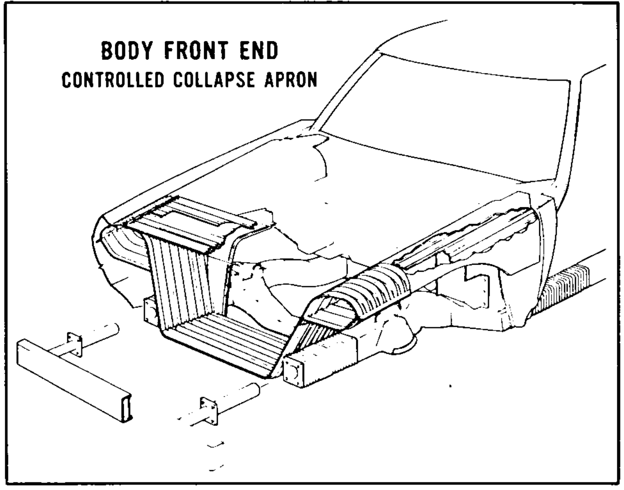
The lower frame force levels result in lower bumper bar loads and improved conditions to cope with pole impact forces while the attendant shifting of the resistance line reduced the tendency of the rear end to kick-up during impact.



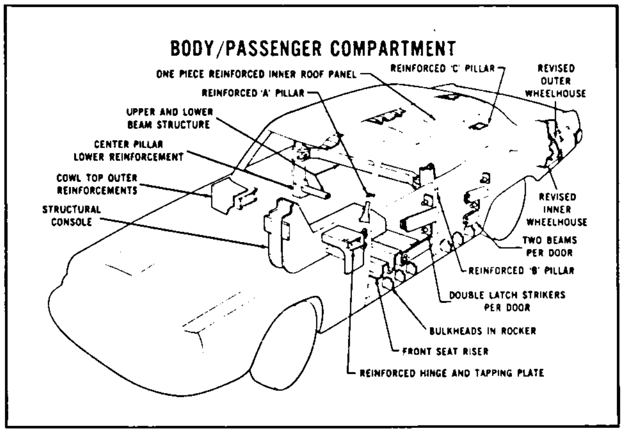
ESV Frame

The general configuration of the ESV frame is similar to the current full-size Ford frame.

The major frame modifications which were implemented to achieve the 65% energy absorption level consist of added convoluted sections ahead of the spring pockets and on the side rails, and adding two cross-members, one ahead of the Number 1 and one at the torque box area (Number 2½). These enhance the lateral rigidity of the front and center frame rails. In addition, the torque box and frame center rail sections were reinforced to withstand the higher level g-forces without bending.



The body front end shown here was designed and developed to absorb 35 percent of the total energy by means of an arrangement, which could best be described as a "controlled collapse apron." It features corrugated sheet metal integrated into the apron. The forward section with transverse corrugations forms a complete hoop after the top section has been bolted on. The bolt-on feature facilitates engine decking. Side structure continues then with longitudinal corrugations toward the firewall for load support.



This slide shows the major structural components of the passenger compartment intended to improve compartment integrity under all crash modes. The basic principle, of course, is to effectively create a "roll-cage" for the compartment to protect the occupants regardless of the crash mode encountered.

The modifications shown here, along with the controlled collapse apron shown in the previous slide, represent the total body changes required to meet the contract objectives for passenger compartment integrity and g loading.

BUMPER FACE BAR PROPOSALS
50 MPH POLE IMPACT DESIGN

	MATERIAL	BUMPER BAR WT.
ORIGINAL CRITERIA – 80,000 LB MAX. FRAME LOAD PER SIDE		
8 x 8, .5	ASTM A500 GRADE B STEEL 46,000 PSI YIELD	300 LB
6.5 DIA., .5	4142-H HEAT TREATED STEEL	160 LB
PRESENT CRITERIA – 40,000 LB MAX. FRAME LOAD PER SIDE		
3.5 x 7, .20	HIGH STRENGTH STEEL 180,000 TO 240,000 PSI YIELD	90 LB

Bumper Face Bar Proposals

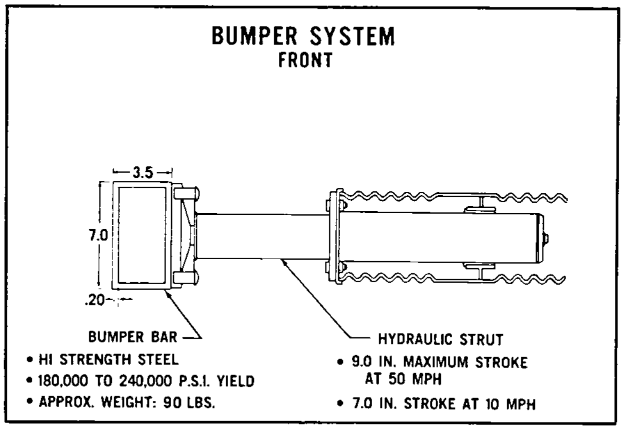
The most extreme test requirement in the entire ESV program is the 50 mph pole impact. In this respect, the design of the bumper system represents a significant design challenge. For instance, if the bumper is designed with conventional materials and a rigid front end, the bumper could weigh as much as 300 pounds. This, of course, is impractical both from a weight standpoint as well as its effect on front end approach angle and structural integrity. Also, this high concentration of mass up front would be detrimental to our design objective of considering the effect of crashes between ESV and older or lighter vehicles.

Our design approach, therefore, is to arrive at a low bumper weight as follows: we increased the portion of energy going into the body appreciably (from 10 percent to 35 percent), and applied the progressive collapse frame design described earlier, which reduces the force level to 40,000 pounds. The resulting bumper design is shown on the last line. The cross section is approximately 7x3.5 inches. Using high strength steel of 180,000 to 240,000 psi yield stress, the bumper face bar weight is approximately 100 pounds.

Tests are underway to develop this design, and the level of success we achieve will be the greatest single influencing factor of our ESV program, particularly with respect to the pole impact requirements.

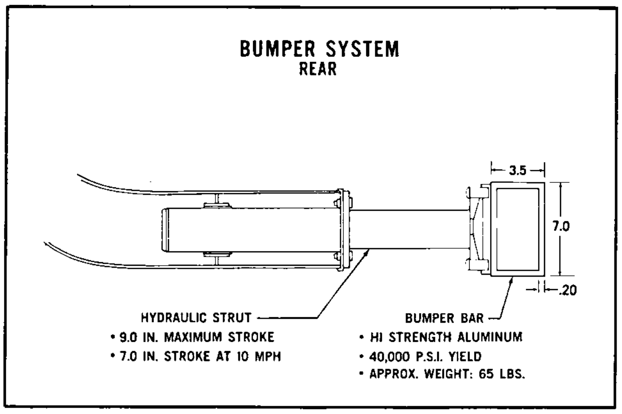
Bumper System – Front

The total front bumper system is depicted on this schematic drawing. The bumper face bar is supported by two hydraulic struts attached to the frame.



This face bar is expected to incur minimum plastic deformation during the pole test and will transmit the impact forces directly to the frame. The hydraulic struts are velocity sensitive and exhibit a low reaction force level at 10 mph for the no-damage feature. They provide a higher reaction force level at 50 mph for effective energy dissipation during the 9 inches of bumper stroke.

As stated previously, the success of the bumper pole test will depend almost entirely on the ability of the face bar to transmit impact forces to the frame.



Bumper System – Rear

The rear bumper system was designed to meet the 10 mph "no-damage" objective during impact. Because the requirements for the rear bumper system are less than the front, we selected an aluminum alloy with a projected weight of 65 lbs. The supporting struts are smaller and lighter than the front bumper struts.

To meet the ESV program objectives, Ford is pursuing development of a passive restraint system employing air bags. In addition, we are pursuing parallel design programs on active restraint systems with energy absorbing belts and a system combining lap belts with passive upper torso restraints.

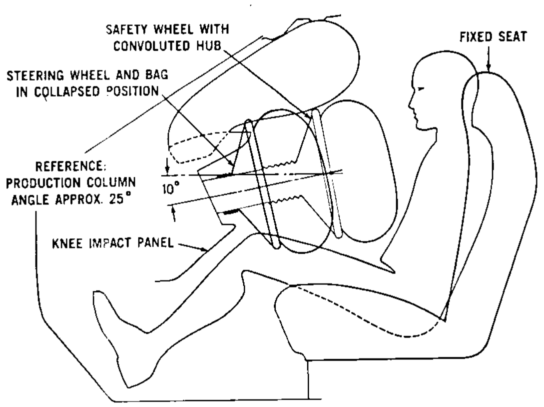
VEHICLE DESIGN

RESTRAINT SYSTEMS

- PASSIVE RESTRAINT
- ACTIVE RESTRAINT

All these systems are a take-off from Ford's current development programs on restraint systems.

PASSIVE DRIVER RESTRAINT SYSTEM

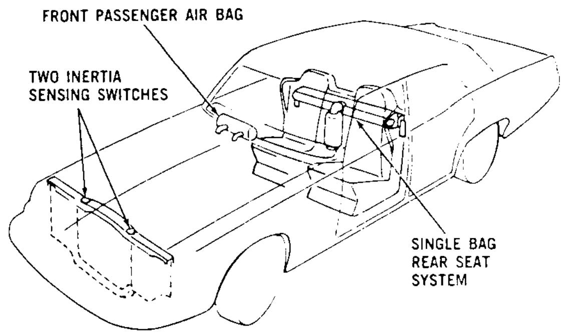


The design and development of this system presents a far greater challenge than the passenger restraint system because of severe space limitations and the complexity of this multiple component arrangement. It consists of one air bag in the steering wheel, a second bag in the cluster, and a controlled collapse steering column. A knee panel augments the system to prevent submarining.

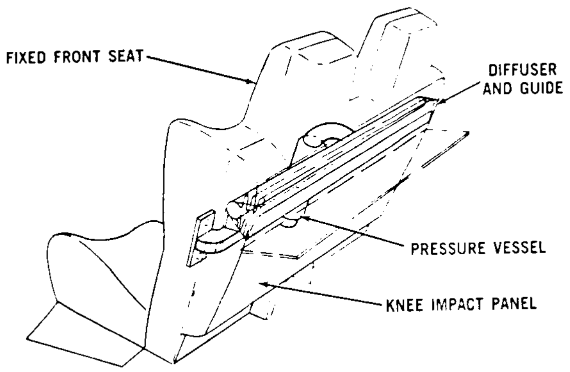
For optimum performance, a rather flat column angle with close coupled steering wheel is required, impairing driver comfort and entry/egress.

The passenger air bag system consists of a single air bag for the front passenger and a common air bag for protection of all rear passengers. Deployment probably will be triggered by two inertia sensing devices mounted on the radiator support, tied in parallel to a 1 g sensor mounted at the firewall to prevent inadvertent firing.

PASSIVE PASSENGER RESTRAINT SYSTEM
ARRANGEMENT



PASSIVE PASSENGER RESTRAINT SYSTEM
REAR BAG DETAILS



Passive Passenger Restraint System – Rear Bag Details

The fixed front seat design allows for direct mounting of the rear air bag, diffuser and knee impact panel rigidly to the seat back. The pressure vessel with gas generator is located at the center of the seat.

Although the passive restraint system remains the primary objective of the ESV program, Ford is developing an active restraint system for 50 mph crashworthiness as a parallel program.

Provided a satisfactory active system can be developed, certain advantages will acrue, such as protection for secondary impacts, prevention of ejection, protection for a wider range of crash modes, positive positioning of occupants, and no noise problem. In addition, the system would be inherently less costly and would weigh less.

VEHICLE DESIGN

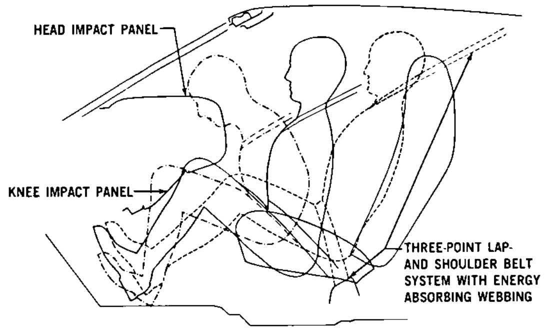
ACTIVE RESTRAINT SYSTEM

- PARALLEL PROGRAM WITH PASSIVE SYSTEM
- COMPARISON WITH PASSIVE SYSTEM

The active restraint system on which we are concentrating consists of impact panels and bolsters coupled with 3-point harness and belt made of energy absorbing webbing. Progress made in energy absorbing webbing has been encouraging at speeds up to 42 mph.

Development will continue to determine impact speed limits of the belt system within package limitations of the interior space available.

ACTIVE RESTRAINT SYSTEM
WITH ENERGY ABSORBING BELTS



This slide shows the movement of the occupant restrained by 3-point lap and shoulder belt system made with energy-absorbing webbing. The movements depicted are from kinematics recorded by actual tests.

The success of this system is based on the development of two factors:

1. Development of energy-absorbing webbing with a quick onset rate to constant force level with large elongation.
2. The design and positioning of impact panels for head and knee.

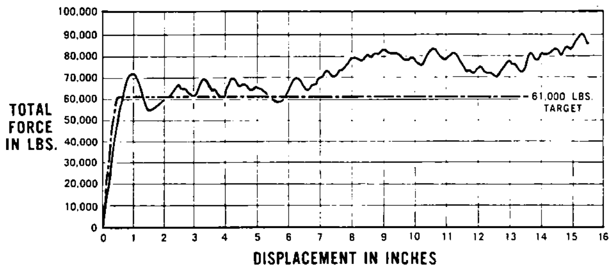
Essentially all the occupants including the driver have the same belt and impact panel system. The steering wheel and column are designed to move forward out of the way at a certain g-level to clear space for the driver movement during the crash.

SUBSYSTEM TESTS

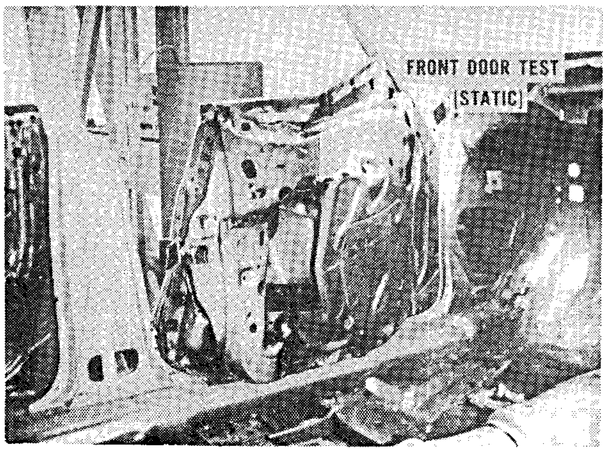
- FRAME AND ENERGY ABSORBERS
- BODY — FRONT END, ROOF, DOORS
- BUMPER SYSTEM — CART TESTS
- RESTRAINT SYSTEMS — SLED TESTS

In this segment, we will discuss a sampling of subsystem tests, both static and dynamic, that were performed before incorporation of that subsystem into completed vehicles. These tests are used to develop subsystems to expected performance levels.

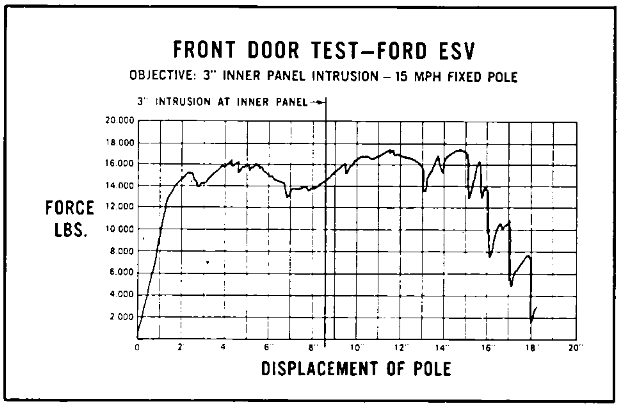
FRONT RAIL & SIDE ABSORBER TEST



This graph shows a typical force versus displacement curve of a frame sample. The objective was to generate a square wave curve – the absorber section loading up within a short distance and then displacement continuing with application of a constant force level. This sample came close to that objective.

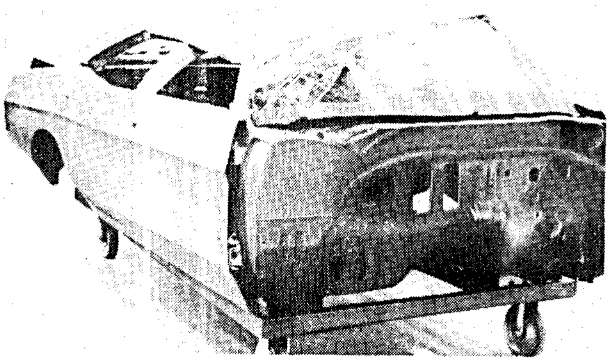


Here you see an early test of the front door to check side loading. A pole impactor of the same size and configuration as the pole for the side impact test was utilized. This particular door was loaded to failure and as you can see, the door latch broke.



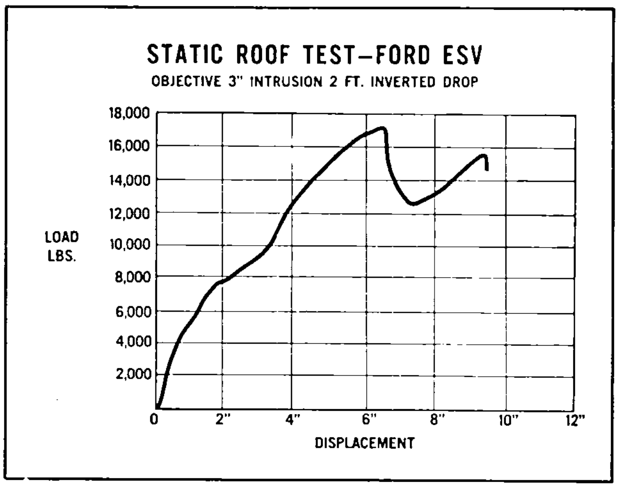
This slide represents the results of a static test conducted on an interim design of strengthened door structure to meet the 15 mph pole test intrusion requirements. The force levels shown here are significantly higher than current production and approach our objectives for force levels compatible with the intrusion requirements.

ROOF CRUSH TEST



Static crush tests were also performed on the roof corner to determine the capability of the roof and pillars to withstand rollover loads within the allowable intrusion limits.

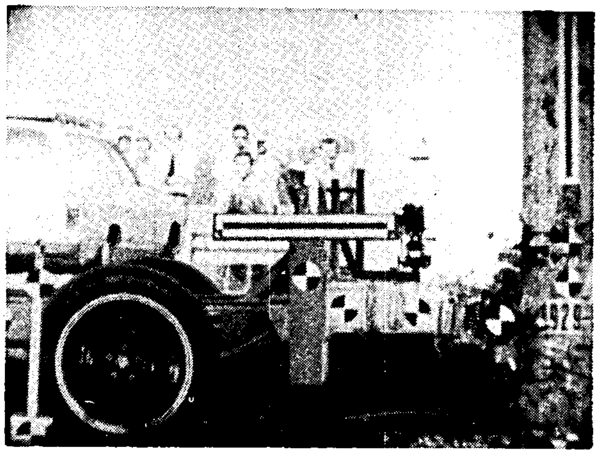
This slide shows a typical static load deflection curve of a reinforced roof and pillar structure of an interim design, to meet the rollover requirements. Test results showed that additional reinforcements were required to meet the three inch intrusion objectives.



Movie Segment A – Narration

Pole Test – 40 MPH

This movie shows a bumper pole test run with a cart at 40 mph. The force level of the struts and the frame convolutions were selected to approximate 50 mph impact loading.

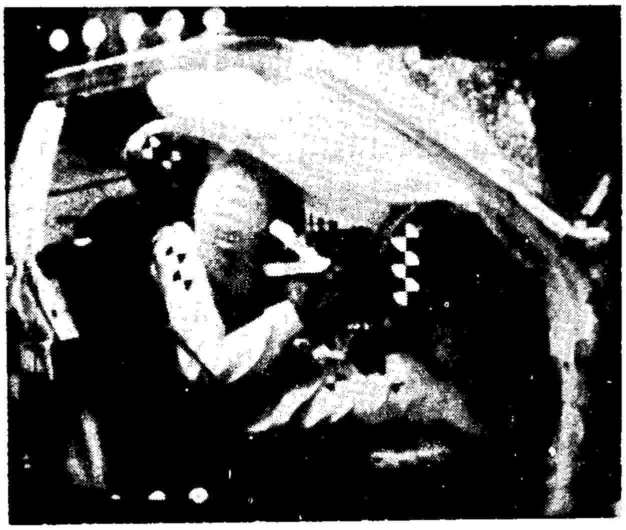


This is a verification of analysis, which showed that a steel forged tube with 6.5 inches in diameter and .5 inches wall thickness would be the sort of device needed to meet the pole test requirements. Obviously, it is not a practical bumper proposal.

As mentioned before, our objective is to develop a bumper face bar of high strength steel with a 90-pound weight target. Work on test samples is currently in progress.

Movie Segment B – Narration

Hy-Ge Sled – Driver System With Air Bags

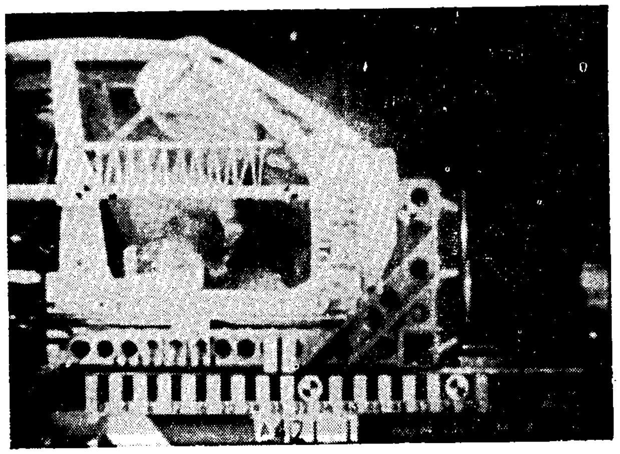


We shall now show several film clips on the development of restraint systems. This first sequence is the unrestrained driver on Ford's "Hy-Ge" accelerator. The test was conducted at 50 mph. The passive system consists of both a steering column and a cluster air bag. We have not been able to as yet meet the g-level specifications in a 50 mph impact. This is apparently due to the short time the bag has to inflate to the pressure required to reduce the relative velocity between the vehicle and occupant. The windshield fracture in this test was due to cluster bag inflation and not to occupant head impact. At the present time, these bags are sensitive to the occupant's position which has made it difficult to develop a complying design.

Movie Segment C – Narration

Right Front Passenger
Passive Restraint System

These tests were conducted on the linear accelerometer at the University of Michigan. At only 42 mph



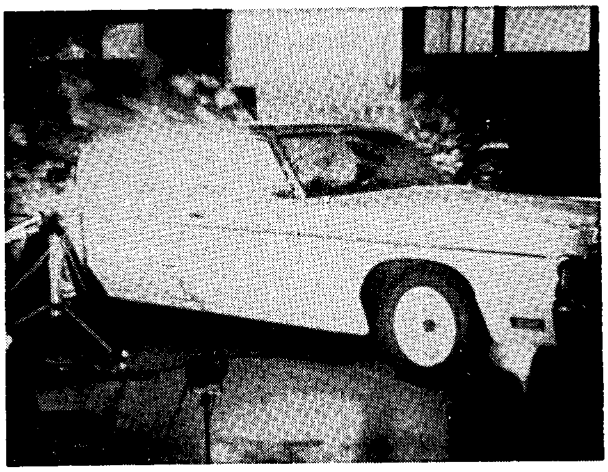
the 50th percentile dummy testing series has met all the contract requirements for head and chest g's in forward impacts, but not for femur loads.

Note the complete encapsulation of the occupant. The checkerboard flag attached to the occupant's head is only a marker used for film analysis and in no way interacts with the air bag. There was some rotation of the occupant during this test. This is due to the positioning of the occupant, and will be corrected in the next test series. Rebound is very minimum and has not produced head deceleration levels above the tolerance criteria.

Movie Segment D – Narration

Air Bag Sound Test

This film sequence is a static sound pressure test in the proposed interior of an ESV. As you can see, all the



tempered side windows are blown out. The rear view mirror twisted and broke during inflation of the cluster bag. The vehicle roof was deformed approximately two inches.

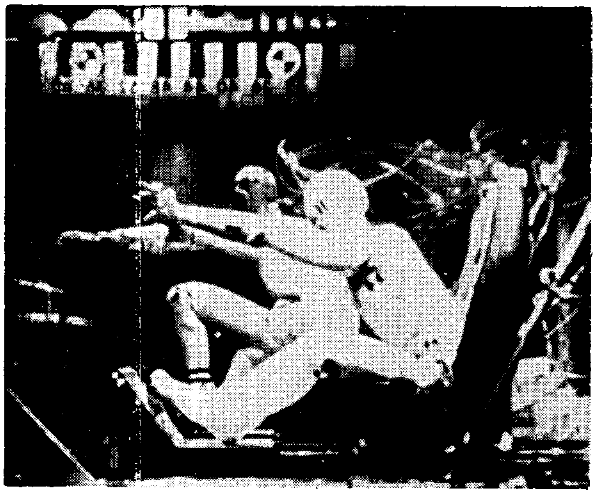
A full complement of dummy occupants was placed inside the car. Microphones and pressure transducers were located approximately one inch away from the dummies' ears. The sound levels ranged from approximately 174 to 176 db. When analyzed according to the criteria recommended in the Bolt, Beranek and Newman Report, it appears that approximately 15-25 percent of the population would incur hearing impairment.

In previous tests, tempered side windows were retained in frames and did not blow out, but vehicle doors and window frames incurred approximately two inches of permanent deformation.

A considerable amount of additional work will be necessary to bring the sound pressure levels within the human tolerance range, and still maintain the required inflation times to reduce the occupant's relative impact velocity.

Movie Segment E – Narration

The next film will show tests with energy absorbing shoulder and lap belts. The test was run in a sled at 42 mph in the absence of windshield and roof header. The test run shows a comparison between the dummies with the current production belt on the left side and the energy absorbing webbing belt on the right side. Notice that the production shoulder belt broke while the energy absorbing webbing on the right side elongated and retained the dummy. Notice also the absence of severe rebound of the dummy restrained by the energy absorbing shoulder belt.



RESTRAINT SYSTEMS
STATUS OF DEVELOPMENT

42 MPH SLED TESTS — PASSENGERS ONLY

HAVE ESV CRITERIA BEEN MET?

	AIR BAGS		E.A. BELTS	
	50TH PERCENTILE	95TH PERCENTILE	50TH PERCENTILE	95TH PERCENTILE
HEAD	YES	YES	NO	NOT YET TESTED
CHEST	NO	NO	YES	
FEMUR	YES	NO	YES	

This table summarizes the status of current development with restraint systems at 42 mph impact speeds.

Head loads with E.A. belts were slightly over the specified limits. We suspect this is a function of test dummy kinematics, rather than a reflection of exposure to hazardous load levels.

Chest criteria were slightly exceeded with air bags for both the 95th percentile dummy, but were acceptable with energy absorbing belts.

Femur loads pose a problem for the 95th percentile with air bags: The load far exceeded specified limits. Much more development with impact panels will be needed to bring these loads down.

Testing of the 95th percentile dummy with energy absorbing belts is planned for the near future.

It should be pointed out, however, that the sled test serves primarily as a tool to improve restraint systems, but the test results do not necessarily reflect system performance in a vehicle crash test.

VEHICLE CRASH TESTS

BARRIER
- 50 MPH BARRIER — BASELINE '71 FORD
- 50 MPH BARRIER — FORD ESV
- 50 MPH REAR MOVING BARRIER — FORD ESV

POLE
- 50 MPH FIXED POLE — FORD ESV

SIDE
- 35 MPH ESV TO ESV SIDE IMPACT
- 15 MPH SIDE IMPACT — FIXED POLE — FORD ESV

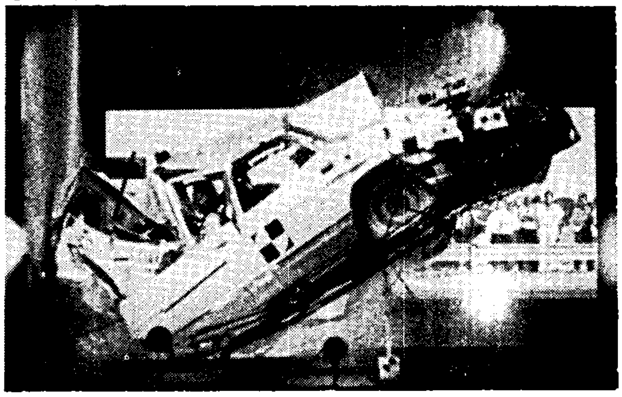
Vehicle Crash Tests

We are now going to show you film clips of complete vehicle crash tests, which were conducted at our Dearborn test facilities during the preliminary phases of our program. These clips include 50 mph barrier crashes, one pole impact test aand side impact tests at 35 and 15 mph respectively.

Movie Segment F – Narration

50 MPH Barrier – Ford Baseline

The first film shows a 50 mph barrier crash of a production Ford to establish a baseline. Notice in this



slow motion shot the kick-up at the rear end, which results in imparting a severe bending moment into the system.

This test clearly demonstrated the tremendous energy levels generated in a 50 mph crash. It further demonstrates the magnitude of the task ahead of us.

Movie Segment G – Narration

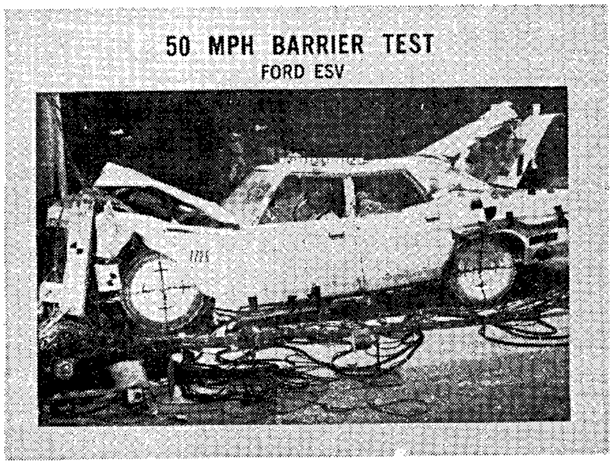
50 MPH – Barrier ESV

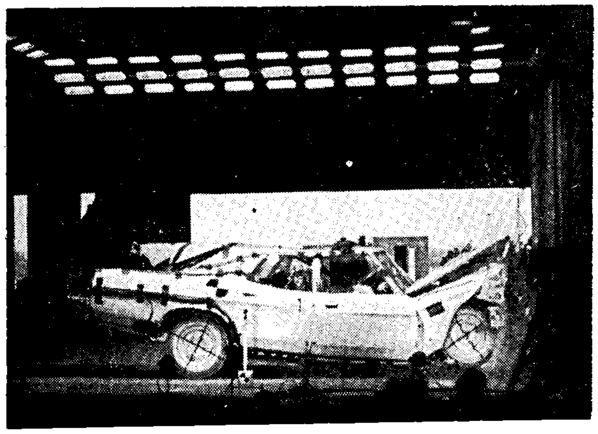
This is the first 50 mph barrier crash of our safety car. Notice the energy absorbing convolutions in both the front and side rails of the frame. It is also evident that the rear end kick-up has been controlled considerably. The occupants were restrained by energy absorbing belts. Since our primary interest at this time was the occupant kinematics while restrained with active systems, the steering column system was removed.

Compartment integrity was maintained and instrusion was greatly reduced. The fuel cell did not rupture. Although the frame crush mode did not quite perform as designed, crush distance was very close to prediction.

We believe that our efforts have been successful with respect to passenger compartment integrity and vehicle rebound from the barrier. As far as g-level readings are concerned, our analysis indicated that relatively "soft" frames would not withstand a 50 mph barrier crash satisfactorily because of a high spike at the end of the sequence when the frame ran out of crush distance. On the other hand, this initial attempt at stiffening the structure resulted in g-levels much higher than desirable for an acceptable ESV.

A review of these findings led us to adopt the design approach in which we are attempting to incorporate design features in our ESV that would produce controlled crush progressively increasing energy absorption in order to limit the g-levels on the occupants.

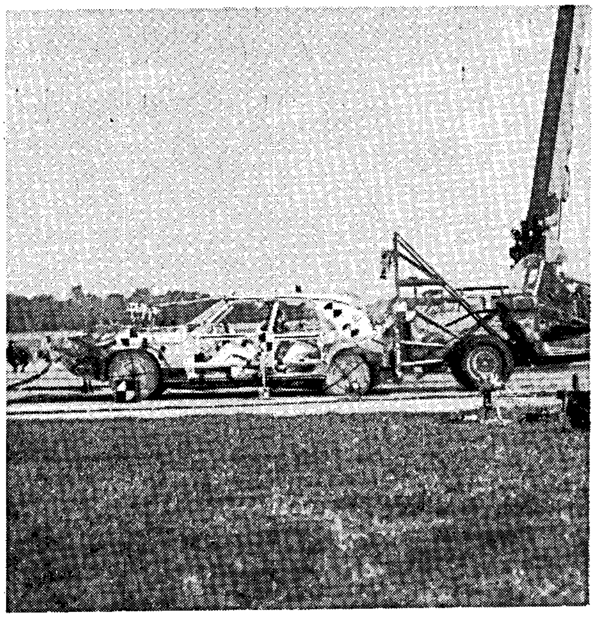




Movie Segment I – Narration

50 MPH Rear Moving Barrier – Ford ESV

The next film shows the rear impact of our ESV by a movable barrier at 50 mph. The frame and the reinforced rear end sheet metal absorbed all of the energy as projected. The fuel cell was located above the axle in a space completely enclosed by sheet metal. There was no fuel spillage during this test. As the vehicle was turned over to one side for undercarriage inspection, there was slight leakage through the filler cap, which was caused by a faulty filler cap gasket and not by the crash.



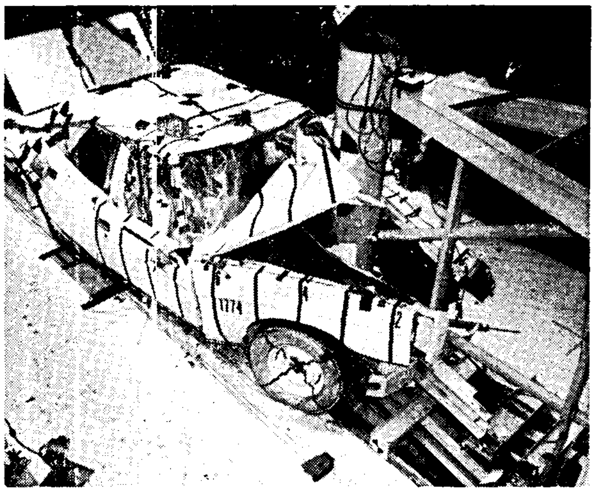
The collapsable spare tire is located in a horizontal recessed well below the trunk floor level.

The g-levels of the front dummies were within specifications. The unbelted left and right rear dummies moved up, which caused contact with the backlight header resulting in high g loads.

Movie Segment J – Narration

50 MPH – Pole – Ford ESV

This film shows the first 50 mph pole crash with our initial high impact bumper system concept. The vehicle had the same initial, rigid frame design seen in the preceding barrier crash film. It demonstrates once again that the bumper face bar design is the key to the success of the pole test.

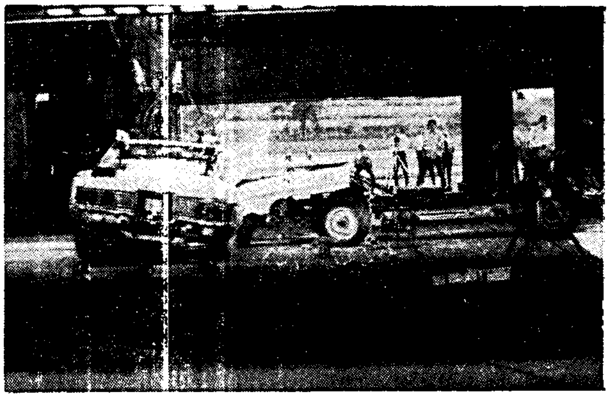


Our bumper development program described earlier, along with the approach of controlled front body sheet metal and frame crush, should permit us to improve pole crash performance significantly. We have seen no evidence to date, however, that would allow us to conclude that a 50 mph pole impact objective can be achieved with a practical design.

Movie Segment K – Narration

35 MPH – Car To Car – Side Impact

This is the first 35 mph safety car to safety car side impact crash test. The struts collapsed to their stroke, thereby absorbing all of the impact energy; con-



sequently, there was no collapse of the front convoluted frame of the bullet car. The bumper impact covered the entire length of the body between the "A" and "C" pillars. Compartment intrusion was moderate, although it was slightly above ESV specifications. The tempered side windows were blown out due to inertia loading rather than vehicle contact. The occupants were unrestrained in this test which accounts for the excessive rolling toward the impact site. There was severe head "banging" in the rear seat. The 50th percentile right rear occupant's head severely impacted the center right occupant's head. The occupants were not entrapped by the intrusion of the inner panels.

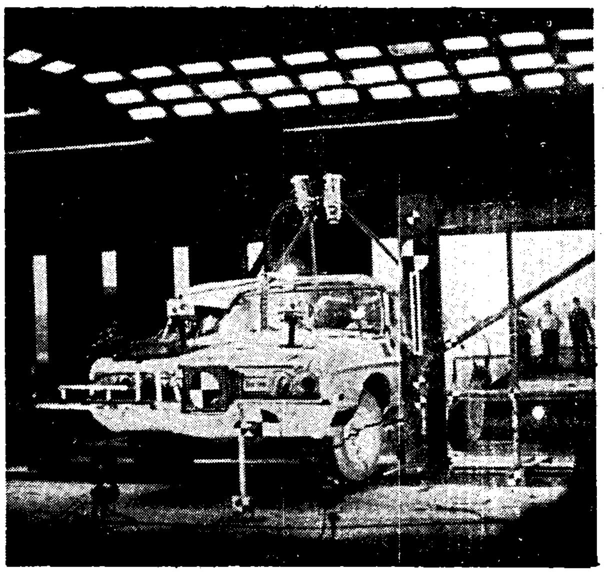
Movie Segment L – Narration

15 MPH Side – Fixed Pole – Ford ESV

This film shows an ESV side impact into a pole at 15 mph; this was the second test of this type. The first indicated the need for additional side structure, which were incorporated here. All doors remained closed, and there was no excessive amount of compartment intrusion, nor was there very much frame side rail deformation.

The occupants in this test were lap belted. In our previous test the occupants were not restrained, and severe head banging between rear seat passengers resulted. This was considerably reduced in this test due to the restricted occupant movement with lap belts.

This test is considered a success, since there was no entrapment of the occupants. However, we did not meet the objective of a maximum 20 g for occupant lateral impact loads, and we do not expect to meet this objective within limitations of the ESV package with regard to width and three rear passenger seating.



FORD ESV PROGRAM

CONCLUSION

Conclusion

Now, in conclusion, let me make some general observations which come to mind as a consequence of our recent experience in the ESV program and offer one or two constructive suggestions as to the course that future efforts ought to take if experimental safety vehicles are to play a significant role in the realization of the highway safety goals we hold in common.

First of all, I'm sure my report on our efforts to date must have sounded promising in terms of reaching the objectives set for the program, for we have, indeed, made progress. Lest anyone be misled with respect to the significance of our accomplishments, however, I must emphasize that we have not yet developed designs that satisfy the contract objectives, nor have we achieved the additional Ford goals of manufacturing feasibility in mass production and acceptable safety in real world highway operation. As we all must recognize, it is one thing to develop a theoretically adequate solution to a design problem and quite another matter to make it work effectively, time and again, in practice.

It is also appropriate to note that the analytical processes that must go into responsible design of an experimental safety vehicle will necessarily identify areas of performance that deserve additional attention. The solutions that must be found in order to achieve meaningful occupant protection in a 50 mph barrier crash without resorting to designs that actually endanger occupants in lower speed collisions is a good example of invaluable by-products that should come from experimental safety vehicle research. Data recently generated by Ford studies of the distribution of speeds at which fatal accidents occur have highlighted the critical importance of the designer's task in maintaining occupant protection in lower speed crashes while striving for improvements in 50 mph impact protection. We are confident that recognition of the overriding importance of "real world" safety performance will lead to the addition, in future safety experimental vehicle programs, of cross-checks aimed at assuring that one or another goal of a development contract is not achieved at the sacrifice of occupant protection in real-world highway accidents.

Similarly, much of our optimism about experimental safety vehicles stems from our confidence that all involved parties – development contractors and contracting agencies alike – will maintain open minds toward the refinement of project objectives to recognize and accommodate the latest developments in safety technology. We expect, for example, that the intensive efforts now underway in government and in industry to identify a realistic means of correlating instrument readings derived from test manikins with the responses of human beings who are subjected to collision impacts may yield data from which it will be possible for the first time to honestly predict the significance of such instrument readings in the real world of highway accidents. The same can be said about the design and use of our basic working tool, the manikins themselves.

As information of such fundamental importance develops, we intend to share it, and we have every confidence that DOT will not only encourage the other contractors to do likewise, but will facilitate the refinement and application of such knowledge so that it does, in fact, contribute to further reductions in the rate of highway deaths and injuries.

Finally, the formidable challenge of designing a vehicle that is both suitable for widespread highway use and feasible for volume manufacture deserves to be mentioned again. We are sure that Ford is not alone in imposing on itself the basic design constraints of compatibility of its experimental safety vehicle design with older and lighter vehicles it will encounter on the highways, as well as feasibility of its designs for economic, mass production.

Whether or not we can successfully meet all of our goals remains to be seen. But I can assure you, we intend to give everyone a run for his money.

SECTION 2

PART 2

THE GERMAN TECHNICAL PRESENTATION ON ESV DEVELOPMENT

THE VOLKSWAGENWERK A.G. – *General View about Progress and Problems Concerning ESV*

Prof. Dr. E. Fiala

Work on the ESV of Volkswagenwerk was begun in Autumn 1971 with the object of investigating the realisability of the specifications by means of the laws of physics. The first investigations have led to the following information which has subsequently been verified by basic tests.

1. CONSTANT DECELERATION OF PASSENGERS AND VEHICLE
2. BEGINNING OF DECELERATION OF PASSENGERS WITH THE SMALLEST POSSIBLE TIME DELAY

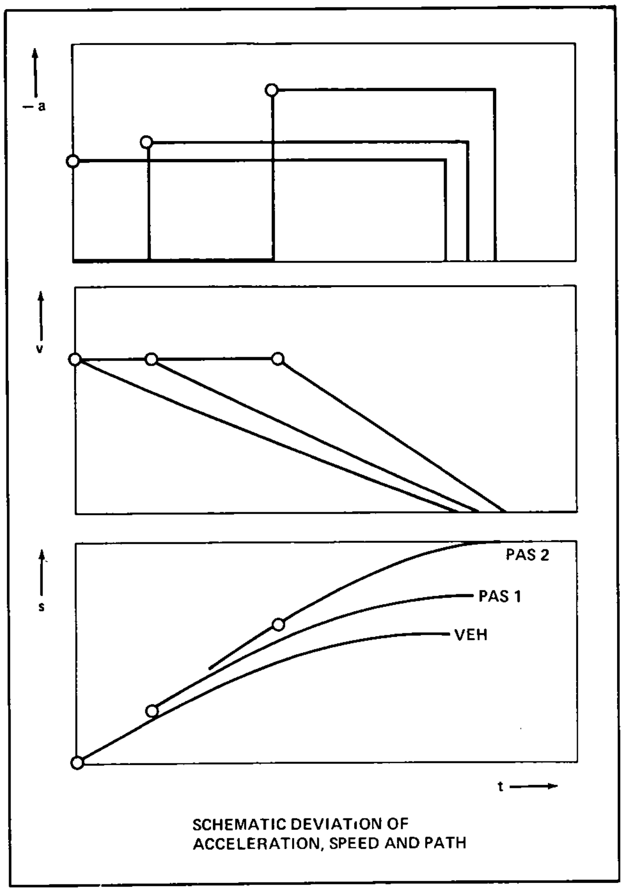
Slide 1

1. Constant deceleration of both occupants and the vehicle must be aimed at.
2. The commencement of the occupants' deceleration must follow the commencement of vehicle deceleration with the minimum delay possible.

Slide 2 shows that a later time of commencement of deceleration of the occupants (red curve compared with the green one) leads to an unacceptable great forward displacement of the occupant also at raised rates of deceleration. This means that the restraint elements must be either rapidly effective (e.g., by preloading belt) or already in action prior to the commencement of vehicle deceleration (airbag).

These two basic findings have resulted in furthei theoretical investigations on acting together of vehicles with different weights and of various restraint systems. These will be reported on at the meetings.

A short film is used to show the stage reached in these basic trials which are also for ESV component development.

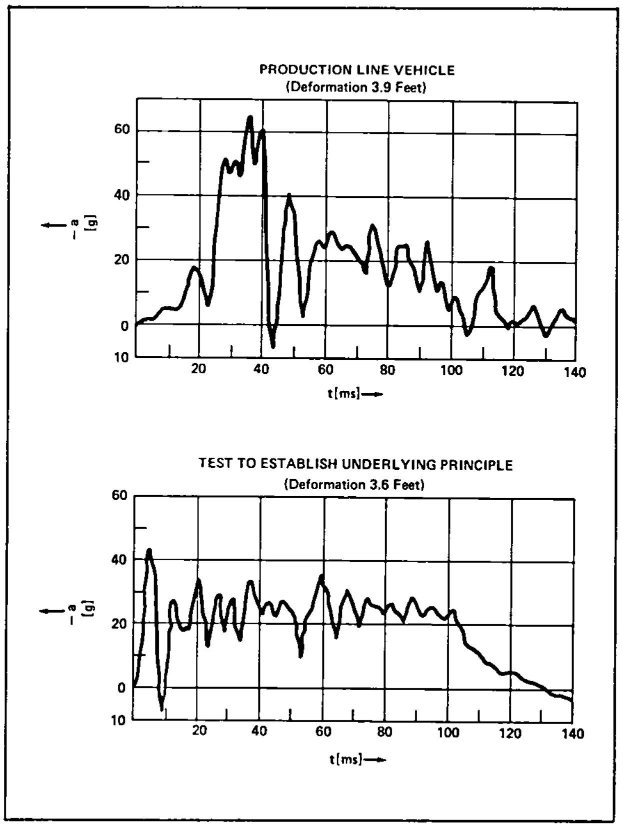


Slide 2

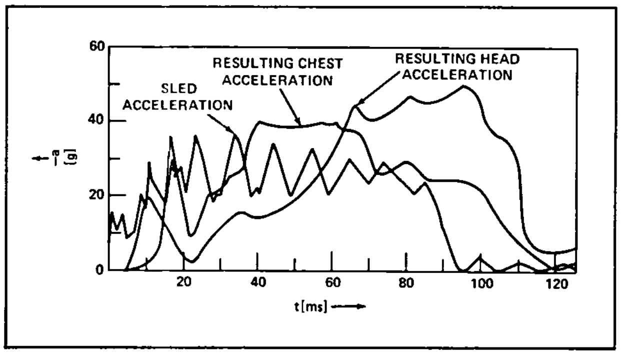
Film

a. 3 scenes of a pole-crash at 50 mph
b. 2 scenes on the effectiveness of the water damper at 30 mph
c. Sled tests at 50 mph with 50% dummy and shoulder and knee belts with preloading and force limiting.

Slide 3 shows the deceleration versus time of a vehicle made up to the ESV specifications as compared with a vehicle of 1070 kg which is no longer in production. Resulting from the constant acceleration a much lower peak acceleration is reached with less total deformation.



Slide 3



Slide 4

Slide 4 illustrates the resultant chest and head accelerations on a 50 mph sled test. In this test a 50% Alderson dummy was used and the restraint was comprised of a belt with pretensioning and force limiting. The relative displacement of the chest was 260 mm and of the head 380 mm. The resultant accelerations have an adequate safety margin within the ESV limits.

Equivalent considerations and tests have been also conducted on other specifications (side and rear impact) with the aim of developing serviceable components to meet the details of ESV specifications.

These basic considerations however, led only to the real problems of the ESV, that is

1. Integration of the components developed into the conception of the ESV, taking into account the feasibility of manufacture and the price economics, and
2. The question for the cost-benefit-ratio of such a safety vehicle.

Cost-Benefit-Ratio

Although a detailed study will only be possible after the development work on the ESV is complete and further statistical material is available, a rough estimate based on statistics already on hand and on optimistic assumptions should provide a general picture.

COST-BENEFIT ANALYSIS

Safety Measures		Reduction In Injuries %	Estimated Use Of Effect %	Effectiveness %	Benefit (N) (Relative)	Cost (K) (Relative)	N/K
30/20/30	4 Hipbelts	35	30 30	10.5	1	1	1
	4 3-Point Belts	45	30	13.5	1.28	1.2	1.07
	4 3-Point Belts With Forced Application	55	70	38.5	3.67	2.0	1.83
	Passive Belt	55	90	49.5	4.81	3.0	1.6
	Airbag	55	90	49.5	4.81	6.0	0.8
Passive Backholding Systems	45/30/45	57	90	51.3	5.14	10.0	0.51
	ESV	60	90	54	5.43	15.0	0.36
	60/40/60	61	90	55	5.53	20.0	0.28
NHTSA April 71	30/20/30	–	–	–	~2	~3	~0.67
	45/30/45	–	–	–	~4.83	~4	~1.21
	60/40/60	–	–	–	~5.83	~5	~1.16

Slide 5

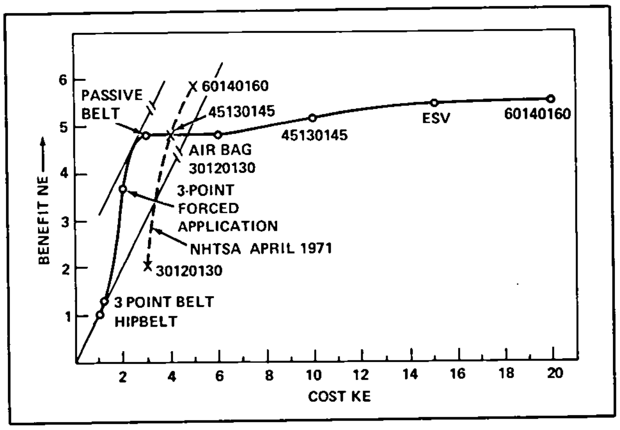
In line with NHTSA studies in April 1971 the following figures have been assumed for the area of the United States:

40,000 fatalities per annum
1,800,000 injured per annum
10,000,000 new vehicles per annum

Benefit: The value lost through one fatality is rated for economics purposes as equivalent to that for 20 injured. The basis used is that of a vehicle which complies with the 1970 US Standards but which is not fitted with safety belts. The first investigations are on the effects of measures taken for the various types of accident in 30 mph rear-end collisions. It is, for example, assumed that the lap belt can prevent death or injury in 35% of typical accidents. The effectiveness of the belt is reduced from 30% to 10.5%, due to the frequency of use. Benefit and costs of these measures will be used as unit term for the remainder of the proceedings.

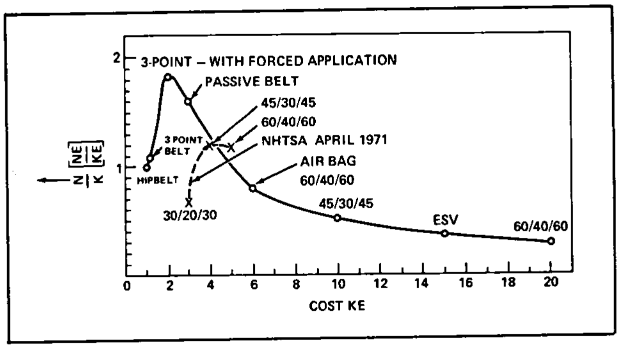
With regard to the requirements at higher rates of impact (e.g., 45 mph head-on, 30 mph side-on, 45 mph rear-end) an optimized passive restraint system has been assumed. The values so estimated are then compared with the results in the NHTSA studies.

The results are detailed in Slide 6. The estimations illustrated here show a marked increase in benefit in consequence of improved restraint systems under the currently customary speed requirements (30-20-30). The



Slide 6

increase in benefit through increased speeds is limited compared with this, whereas there is a vast increase in costs. These results are in contradiction of these of NHTSA according to which it is anticipated that there will be a considerable increase in benefit for only slight increase of costs with increase of the speeds.



Slide 7

Finally in Slide 7 the cost-benefit-ratio is demonstrated. According to these estimates a maximum is obtained for compulsory wearing of a 3-point safety belt. Even the passive belt shows a lower cost-benefit-factor because the increase of costs by more than 50% over the compulsorily-worn 3-point belt is not balanced out by the greater frequency of use. There is however undoubtedly an increase in comfort which could not be taken into account in these investigations. The NHTSA study shows a maximum for a vehicle more or less corresponding to the ESV specifications.

Because of the essential differences in these comparative investigations and the importance given to these problems for social reasons further work on them is urgently necessary.

In conclusion it may be stated that the investigations so far conducted on the ESV by the Volkswagenwerk have indicated that the engineering problems appear to be soluble but the economic and social aspects urgently require further investigation.

THE DAIMLER-BENZ A.G. – *The Development of the ESV as seen by Daimler-Benz*

Dr.-Ing. Hans Scherenberg

Outline of Technology in the Federal Republic of Germany

The effort towards safety must involve people, the road and the vehicle. Automobile engineers can only influence the last factor. The Daimler-Benz AG has been endeavoring for more than four decades to increase both active and passive safety of its Mercedes-Benz vehicles. Initially, these efforts were concentrated primarily on improving driving safety in accordance with the then existing level of vehicle technology. The introduction of independent wheel suspension, double-action shock absorbers and the first version of a dual circuit vacuum power braking system as milestones of this development should be mentioned in this connection. A highlight in the development of active safety was the introduction of the Mercedes-Benz/Teldix Anti-Bloc-System in December 1970.

In the years after 1946 the continuing further development of driving characteristics was accompanied by numerous improvements of the interior safety, such as safety door locks, crashworthy passenger compartment, elimination of sharp edges in the interior, safety steering system, etc.

Utmost Safety for Production Vehicles

The efforts of Daimler-Benz toward safety were always and still are characterized by the fact that all proven concepts were and are introduced into regular production as soon as feasible. The aim was not and is not to produce a safety vehicle as a demonstration object, but to achieve continuous progress which can be used to the benefit of drivers on the increasingly overburdened roads in as short a time as possible.

This progressive vehicle concept proved its worth in 1967 when the first "Motor Vehicle Safety Standards" for the 1968 US model year were published. After a few minor technical modifications those specifications were met by Mercedes-Benz production passenger cars – export of these vehicles to the USA was never affected. The changes of production, however, simply on account of minor changes in the corner radii of instrument panels, or mirror bezels for example caused considerable difficulties and tooling costs.

In November 1970 the well-known "Memorandum of Understanding" between the Federal Republic of

Germany and the United States was established. This posed the important question as to who in the Federal Republic would be in a position to organize and finance this project. Unfortunately the German automobile manufacturers could not expect financial support from the authorities to undertake such a project.

The German automobile industry therefore founded the working committee for the "safety vehicle" which, in the space of a few months, formulated the specifications for a safety vehicle of the lower middle range – a document which it submitted to the German Federal Minister of Transport in December 1970.

The Mercedes-Benz Experimental Safety Vehicle

It proved impossible to create a joint German project. It was only possible for Daimler-Benz to commence with a certain amount of exchange of experience and division of effort together with BMW in the field of component-development. It was therefore decided in February 1970 to extend the on-going work in the safety area by developing our own Experimental Safety Vehicle. The basis was to be a production car – the Mercedes-Benz 250.

This fundamental decision was followed by the conclusion that one should proceed according to a step-by-step concept, so that here too, any interim results could be put into practice in regular production and the separate stages of the experimental safety vehicle would not develop too far away from production applications.

In the field of active safety the decades of safety-oriented development, particularly of handling characteristics, have brought Mercedes-Benz production vehicles close to the limits of the physically possible optimum. It was therefore only a question of tuning in order to achieve the handling characteristics required by the Specifications. The safety requirements for occupant environment, visibility and operational control systems were achieved within a few weeks, even though the views of the Daimler-Benz engineers concerning the optimum solutions in some of these areas and in part also the handling characteristics varied greatly from those defined by the Specifications. Strict criteria had always been applied in this regard which necessarily led to a very definite design. At Daimler-Benz the safety concept of an automobile has always started with active safety. Hence also the successful efforts in the development of the Anti-Bloc-System.

The degree of passive safety achieved in the first prototype did not meet the requirements of the Specifications in all respects, and in fact no one had expected the possibility of increasing passenger protection–taken as a whole – by a factor of 2.5 within just a few months.

Even today the final target has not yet been reached completely with the latest ESV (Figure 1) despite

Figure 1

extreme weight and design effort. The passenger compartment stands up to the enormous impact forces in a head-on collision against a fixed barrier at 50 mph (80 km/h). The crush structure in front of and behind the passenger compartment – a principle applied also to this vehicle – has been shown to absorb the impact energy in a satisfactory manner. The passenger compartment deceleration rate is lower than the American requirements but Daimler-Benz considers that these values do not necessarily constitute an optimum.

Investigations concerning other possibilities of absorbing energy, instead of deformation of car body parts, are being carried out parallel to this work. These include, for example, very large volume hydraulic shock absorbers as already proposed by other firms. Such elements promise more favorable and more easily controlled deceleration characteristics, but at the present stage of technology they impose considerably greater weights and higher costs. Therefore these methods are at present only conceivable for an experimental safety vehicle in as much as the reliability of proper operation of such units over a longer period of time is yet completely unknown. Such units must remain functional for 5 or 10 years, i.e., the lifetime of a vehicle, perhaps even being required to operate for the first time after such a long period.

Against a Wall at 50 mph (80 km/h)

Head-on collisions in street traffic are responsible for more than 50% of the deaths and injuries. Therefore the requirements for the Experimental Safety Vehicle are particularly stringent in this regard.

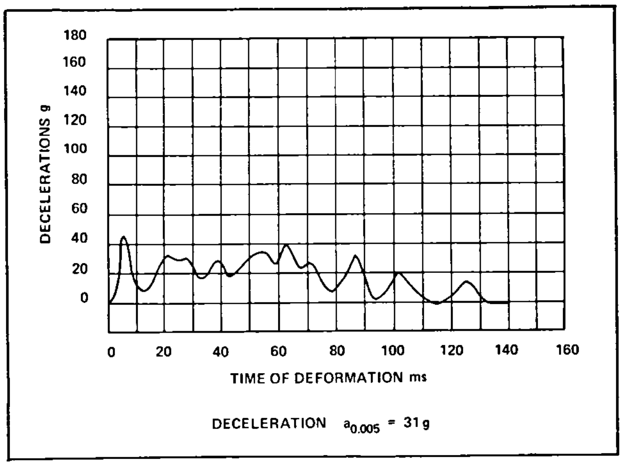
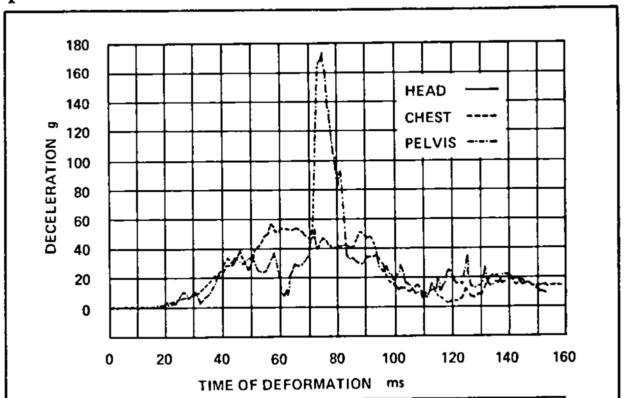


Figure 2

The values obtained during a crash test with the ESV at 50 mph (80 km/h) convey an impression of the level achieved at this time. Figure 2 shows the deceleration of the passenger compartment versus the deformation time. With 31 g the value remains below the requirements set by the American Specifications, but the required front end crush is then relatively great.

The injury criteria of the occupants have been established in the Specifications for the head (max. 80 g), for chest and pelvis (max. 60 g) and for the femurs (max. 640 kp). The values obtained with dummies for the occupant positions (Figs. 3 to 6) vary greatly from each other. This may be due partly to differing adjustment of the restraint systems and partly to shortcomings inherent in the dummies – which will be dealt with later. The restraints combined the use of belts and air bags.

Figure 3 shows that the pelvis deceleration and the force acting on the left femur of the driver exceed the permissible limit, since the three-point safety belt and



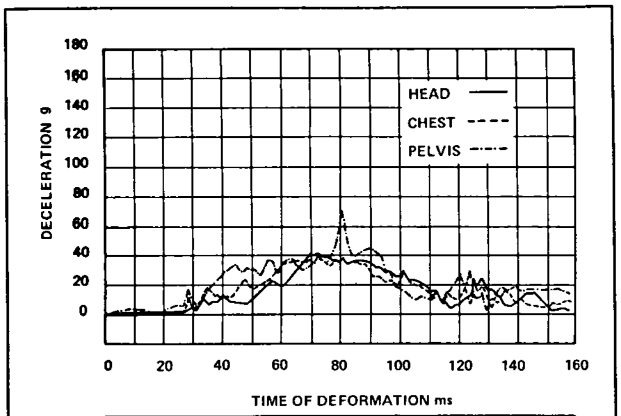
DECELERATION $a_{0.003}$		THIGH FORCES	
HEAD	*		
CHEST	54 g	LEFT	1080 kp
PELVIS	157 g	RIGHT	600 kp

* MEASUREMENT INCOMPLETE

Figure 3

the air bag located in the steering wheel both failed at the same time. (The head deceleration failed to be recorded since one of the three signal amplifiers had failed and the resulting deceleration could not be evaluated.)

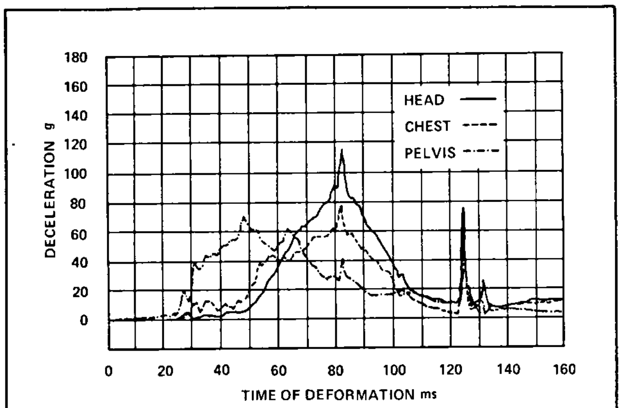
In the case of the front passenger, who was protected by a lap belt and air bag, all requirements of the Specifications were complied with (Figure 4).



DECELERATIONS $a_{0.003}$		THIGH FORCES	
HEAD	64 g *		
CHEST	36 g	LEFT	520 kp
PELVIS	54 g	RIGHT	440 kp

Figure 4

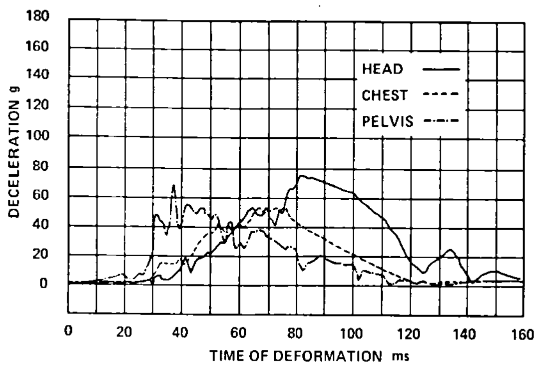
Also in the case of the left rear occupant the deceleration values are relatively favorable (Figure 5). Only the maxima of the head and pelvis deceleration values are a little too high. All data recorded for the



DECELERATIONS $a_{0.003}$		THIGH FORCES	
HEAD	91 g		
CHEST	60 g	LEFT	320 kp
PELVIS	64 g	RIGHT	440 kp

Figure 5

right rear passenger were lower than the injury criteria (Figure 6).



DECELERATIONS $a_{0.003}$		THIGH FORCES	
HEAD	73 g		
CHEST	51 g	LEFT	520 kp
PELVIS	52 g	RIGHT	480 kp

Figure 6

If the results for these two rear passengers are compared a discrepancy is apparent which is probably attributable to shortcomings in the dummies. Both rear passengers were protected in exactly the same manner with lap belts and air bags. Even so different deceleration values were recorded.

During this test and in many previous tests some restraints, air bags as well as belts, failed to function as required. None of these has yet been developed to a satisfactory level to meet these high impact speeds, while the safety belt is known to function reliable up to about 30 mph (50 km/h) and analysis of collisions on the road has confirmed that it offers a satisfactory degree of protection in actual accidents.

Injury Criteria and Biomechanics

The values obtained with dummies partly exceeded the injury criteria for occupants even though the restraints functioned as intended. This poses the questions as to whether the presently specified values have been adequately substantiated by biomechanical research. The aim of this research is to ascertain the degree of mechanical stress the human body can stand. The aids used are mathematical models, experiments with animals, volunteers and finally also human cadavers. Unfortunately each process imposes limits on the researcher. The validity of mathematical models and the conclusions drawn from experiments with animals are under dispute; volunteers can usually only be subjected to a degree of stress far below that required for accident research. Except for certain medical purposes, the use of cadavers is generally forbidden by law and also by moral principles.

Automobile manufacturers can only hope that medical institutes will carry out biomechanical research within the scope of their possibilities and above all with the support of governments, calling upon the assistance of automobile engineers, and that this research may soon produce the urgently required knowledge. Daimler-Benz has endeavored to help in this respect and important information has been gained but the call now goes out to the government to play its part in taking the appropriate measures.

Problematic Dummies

In the meantime, the automobile engineer makes do with dummies which unfortunately often do not provide reproducible results. These dummies today constitute a serious problem within the scope of development work for passive safety. They are supposed to help in determining the risk of injury to passengers in terms of exact measurements. Is that really possible at the present stage of development of these dummies? The answer must be, no. They fail to meet two basic prerequisites:

1. The correlation between the dummy and the human body is not known.
2. The results obtained with dummies are not reproducible.

Despite this, dummies are to be used to prove compliance with ESV Specifications or even legal requirements – a totally unsatisfactory situation.

It is therefore a supremely urgent present day task to standardize a dummy according to the very latest knowledge, to define the correlation between dummy and the human body and to ensure that its behavior and indicated values are reproducible.

The shortcomings of the dummies are naturally also reflected in the development of restraints. The automobile engineer develops and compares safety belts, padding and air bag systems. The functional efficiency of these devices does not differ in orders of magnitude. How therefore are we to determine a conclusive difference of 10% or 20% in the injury level when the values of the dummies vary by ±35%?

The legal deadline for the introduction of passive restraints in the USA has meanwhile been postponed. It is to be hoped that with the belt restraint systems, thus coming into the foreground – with warning systems and ignition interlocks if the belt is not fastened – more people will actually use their safety belts and that eventually clear statistical evidence can be obtained of the success of this measure. This would leave open the possibility that passive restraints would not be necessary in the near future.

Side and Rear-End Collisions

Lateral collisions with trees are usually of devastating effect. The side impact on the middle of the door at 15 mph (25 km/h) against the pole as required by the Specifications produced a 4 inch (10 cm) deep intrusion of the inner surface into the passenger compartment of the Mercedes-Benz ESV. The remaining decisive factors in the risk of injury are the restraint systems and interior side padding. The injury criteria of the German Specifications are fulfilled.

While the development of the front vehicle structure and restraints for the head-on collision was very difficult, the requirements of the German Specifications for the rear-end collision could be met with the very first prototype. When the rigid, movable barrier was driven into the rear end of the car at 50 mph (80 km/h) the structure was shortened by 3 ft. (90 cm), the passenger compartment remained almost completely intact (rear bulkhead intrusion of 2 in./5 cm). The doors could be opened, the dummies be taken out without any damage. This also meets the criteria of the German Specifications. But naturally these results have not been achieved without considerable added weight and correspondingly higher costs. It is obvious that a certain technical progress can be achieved. However, how this can be transferred to mass production at an economically justifiable cost is quite a different question.

Checking Specifications for Feasibility

Both the American as well as the German Specifications for Experimental Safety Vehicles have been under discussion for months. Many shortcomings have been recognized but there are certain difficulties involved in removing these, at least with the American Specifications. A way must be found here to rectify recognized shortcomings as quickly as possible; for specifications and regulations are only meaningful when they are adapted in a short space of time from the original ideal concept to the practicable state of the art. The German Specifications are subject to frequent revision and we hope to make this a continuing process.

There will be detailed discussions in work symposiums on special modifications of certain limit requirements. But, quite apart from these changes, the basic fact must always be faced that we must reckon with considerable increases in weight and costs. For this reason weight itself should not be kept as one of the requirements in the Specification.

The main reason for the considerable increase in weight and cost is having to comply with the requirement in the Specifications that all occupants must have clear survival chances in a head-on impact at 50 mph (80 km/h) against a rigid barrier. In principle the engineer will not shy away from this task. He has good theoretical and experimental aids available to him. What's more: special technical solutions have already been presented, both in the USA as well as in Europe.

However, one must ask: is there any point in reaching this goal? Are the solutions indicated anything more than a very interesting, but probably utopian, experiment? Are they feasible in practice? In other words, can passenger cars with the qualities of the experimental safety vehicles be successfully produced in large quantities? Can they take their place in modern road traffic? Will the motorist of the 80's be able and willing to buy such vehicles? Will there be room – particularly in Europe – for such monstrous vehicles on all roads? This must be doubted for several reasons: The laws of physics demand dimensions and strength values of an order which are considerably beyond that of the present European passenger car. This inevitably leads to considerably higher weights and costs. Many motorists will no longer be able to afford such vehicles–they will perhaps be forced to ride a motorcycle again, which would be a step backward as regards safety. The larger dimensions will make the vehicles more difficult to handle and impede the flow of traffic. There will be more risks of collisions on narrow, winding roads; the available parking space will be sufficient for still fewer cars.

Only a limited number of road users will be able to profit from the greater safety in these vehicles.

A Step-by-Step Plan for Technical Feasibility

From all these considerations, the aim emerges not necessarily to strive to meet all the demands of the Specifications at once, but rather to indicate in several steps the solutions which are technically feasible. Only then will it be possible to use the great efforts and financial and personal capacities not only for an experimental safety vehicle, but also to apply them step by step to regular production. The periods until individual steps can be introduced will thus be shortened, and motorists can in each case make use of progress which may be less spectacular but contributes to their safety at an earlier date.

An important prerequisite for determining the efficiency of this measure, however, would be reliable statistics for Germany which give information on both the frequency of the individual types of accidents as well as the numbers of fatalities, serious injuries and lesser injuries in relation to the actual driving as well as effective speed at the time of impact. This statistical analysis cannot be provided by the automobile companies but must be initiated and directed by the government, so that the whole traffic scene may be covered. Attempts to get such statistical evaluations are indeed already well known from the accident analyses of Cornell Aeronautical Laboratories in the USA. However, there is considerable reason to doubt whether these could be directly applied to the European traffic conditions. Fortunately, the Minister of Transport, Georg Leber, has declared himself willing to discuss this special matter of statistics with the German industry.

Summary

In conclusion the Requirements, which in the opinion of Daimler-Benz should be met before development of Experimental Safety Vehicles continues are summarized as follows:

1. Discussion of the targets which may be reached in the forseeable future with a justifiable use of people and money. Only if this choice of targets is reasonable, can the development take place in a "good atmosphere" without coercion caused by the possibility of sudden extreme legal requirements.
2. Working out a step-by-step plan for the experimental safety vehicle project which sets reasonable targets at sufficient time intervals.
3. Promotion and extension of bio-mechanical research.
4. Compilation of statistical data which most importantly will clarify the relationship between accident severity and impact speeds.
5. Setting up a well-founded cost-benefit analysis.

The automobile engineers welcome the cooperation of all bodies in achieving these requirements. Within the limits of what is possible and justifiable, Daimler-Benz AG will render its contribution. This company has never shunned the investment of considerable funds nor the use of its technical know-how in the interests of increased safety. Safety was never a mere slogan for Daimler-Benz. It was and remains a design principle which takes high priority not only in the interest of the Mercedes-Benz name and its customers, but also in the service of the general public and engineering progress.

Figure 1. Mercedes-Benz ESV 05

Figure 2. Deceleration of passenger compartment at 50 mph (80 km/h) head-on barrier impact

Figure 3. Deceleration of dummy in driver position at 50 mph (80 km/h) head-on barrier impact

Figure 4. Deceleration of dummy in front passenger position at 50 mph (80 km/h) head-on barrier impact

Figure 5. Deceleration of dummy in left rear seating position at 50 mph (80 km/h) head-on barrier impact

Figure 6. Deceleration of dummy in right rear seating position at 50 mph (80 km/h) head-on barrier impact

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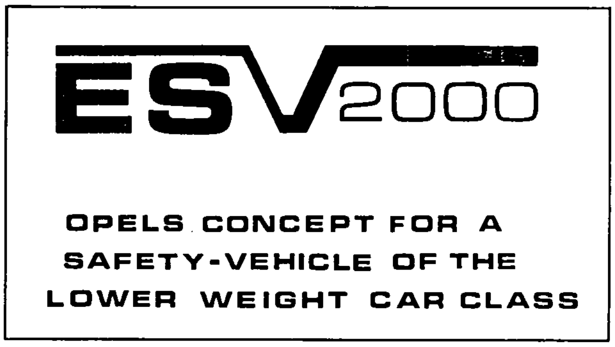
THE ADAM OPEL A.G. – *The Opel Conception of an ESV in the Low Weight Category*

Mr. Karl Brumm

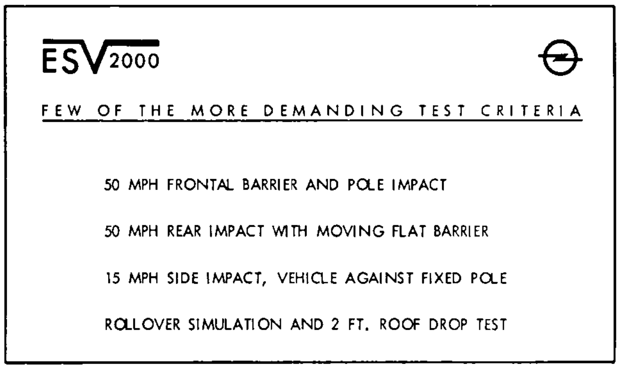


Slide 1

Ladies and Gentlemen,

Our program to develop a 2000 lbs. experimental safety vehicle has initially been directed towards achievement of the proposed performance levels developed by the German Automobile Manufacturers Association which are closely parallel to the 4000 lbs. ESV concept being developed in the USA.

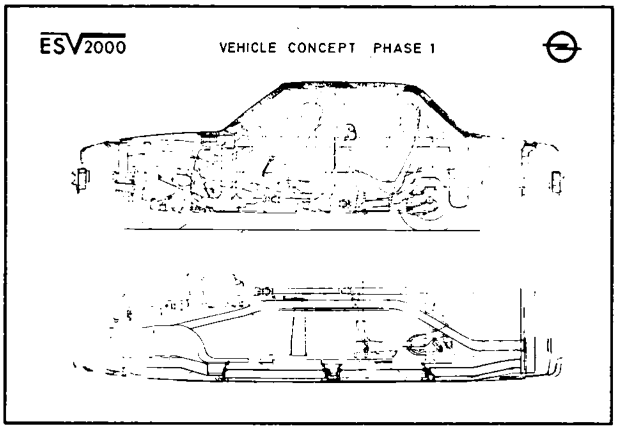
A few of the more demanding test criteria are as follows:



Slide 2

- 50 mph frontal barrier and pole impact
- 50 mph rear impact with moving flat barrier
- 15 mph side impact vehicle against fixed pole
- Rollover simulation and 2 ft. roof drop test

In addition to withstanding these severe accident simulations structurally the vehicle must also provide occupant protection systems which meet certain injury criteria under these test conditions.

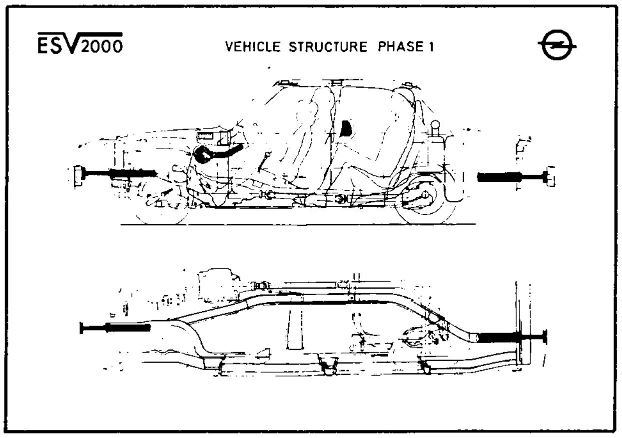


Slide 3

The vehicle configuration upon which our initial ESV studies were based consisted of a four-door sedan version of the Kadett, featuring four seating positions and a curb weight between 2,000 and 2,430 pounds, as specified by the German Automobile Manufacturers Association.

The total realization of the magnitude of the challenge was brought to bear when we subjected a current production Kadett to a 50 mph barrier crash test to establish a baseline of performance.

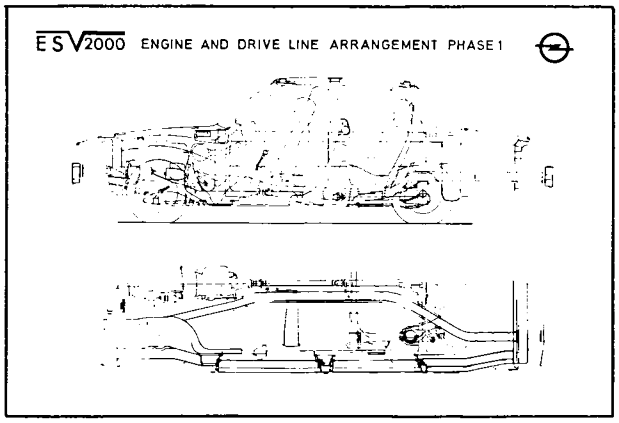
The 50 mph barrier crash performance level is equivalent to almost 2.8 times the energy content of the 30 mph level met by the current Kadett.



Slide 4

Based on the results of this test our improved structure consisted of the incorporation of door beams, rollover bar, front and rear upper frame members with strategically located cross braces. In addition reinforcements running along the tunnel area connecting the front and rear frame structure were incorporated.

A self-restoring 10 mph EA-bumper system in front and rear, and an air cushion restraint system for all seating positions have been provided.



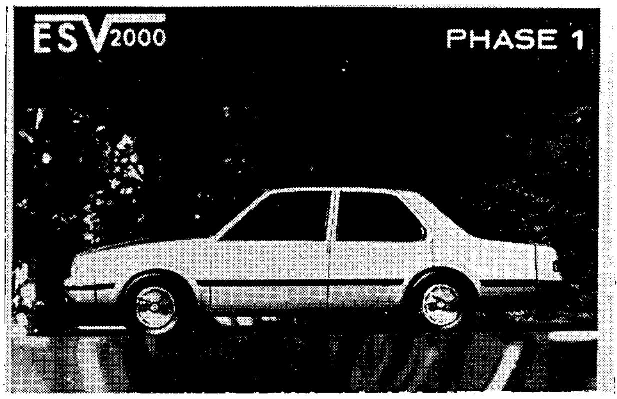
Slide 5

To power this structurally improved vehicle we planned to install an emission controlled 1.9 ltr. engine with increased performance characteristics capable of accelerating the car from 30 to 70 mph in less than 12 seconds.

As shown in this sketch the vehicle package finally consisted of a conventionally located engine and drive line arrangement using a reinforced Kadett rear suspension.

Various front suspension configurations for the vehicle with improved crush behaviour and weight saving characteristics have been studied.

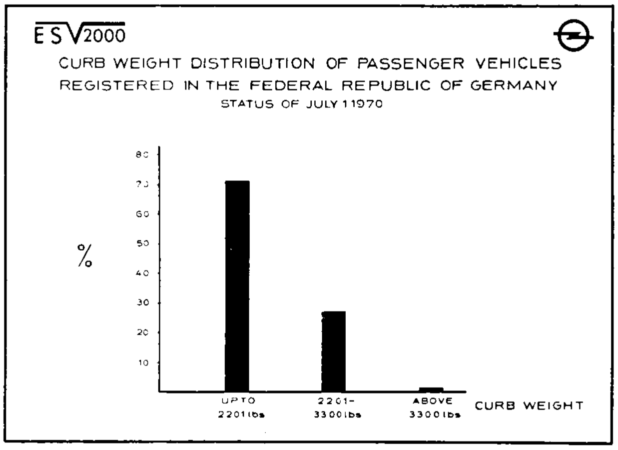
Usage of both manual and automatic transmissions were proposed.



Slide 6

The evaluation of the concept indicated that to achieve the performance criteria would require a vehicle configuration longer, heavier and more expensive than our Commodore model and at best would provide utility space equal to the current Kadett.

We actually ended up at 2,600 pounds, exceeding the given weight limit due to the degree of added structure required to meet the injury criteria. For cost reasons we did not consider the usage of any unconventional material, although we could have solved the weight problem by such means.



Slide 7

From statistics we know that over 70% of all passenger cars in the Federal Republic of Germany belong to the small and intermediate car class up to 2200 lbs. and that during the first quarter of 1971 almost 60% of all new vehicles registered have fallen into the same category.

We feel that it is essential to protect the majority of all passenger cars on the roads from potentially being eliminated by law due to barrier crash test capabilities.

ESV2000

PHASE 2

UPPER WEIGHT LIMIT: 2200 LBS
MATERIAL : CONVENTIONAL
MANUFACTURING: HIGH VOLUME PRODUCTION

Slide 8

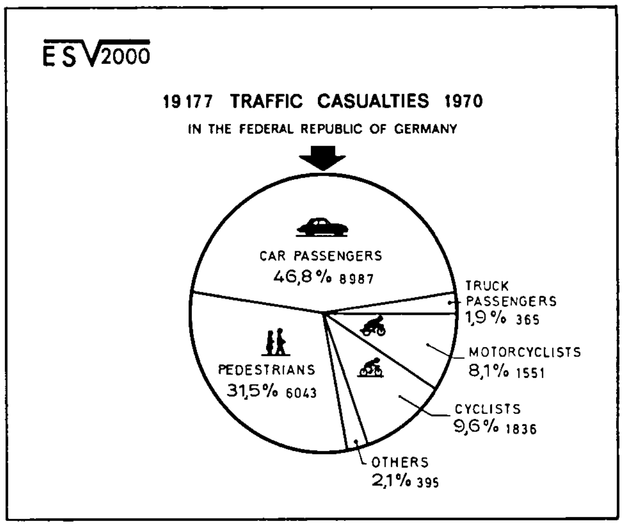
Several months ago we have therefore started phase two of our program which is directed towards the development of a 2000 lbs. passenger car concept with an upper weight limit of 2200 lbs., based on high volume production technology and the utilization of conventional materials to achieve the highest level of safety performance possible within these parameters.

Our objective therefore is not the creation of a show car far removed from the real world of automobile manufacture but rather to provide the customer in the shortest time possible a safer passenger car which he can afford to purchase.

It is our opinion that a significant improvement in the current European traffic casualty situation can be realized if these safer vehicles get into the hands of the driving population.

With this direction firmly established our program now consists of further improving existing safety systems and the development of additional safety features in both the chassis and body field.

It should be mentioned that we are closely cooperating with Vauxhall Motors, the British daughter of General Motors.



Slide 9

In order to set the proper priorities we have carefully studied statistical material published by the German Automobile Manufacturers Association (VDA), the Federal Office of Statistics and other sources.

This slide shows in what kind of accidents the 19,177 people have been killed in the Federal Republic of Germany during the year 1970. The main portion with 46.8%, which equals almost 9,000 people, is the section we have to be most concerned about, because these people died as drivers or passengers of automobiles.

The second largest section represents 31.5% of fatally injured pedestrians where the influence of the vehicle exterior design may improve the situation to a minor degree.

All other areas will practically not be changed by safer and better passenger cars.

The next slide is based on statistical accident research results compiled by Opel, Folksam, MIC (a US insurance corporation) and Volvo, giving a good survey about the priorities to be set for safer vehicles.

Concerning the relation between accidents and impact directions it is quite evident that the frontal impacts are ranking in the first position followed by side impact, rear impacts and rollover.

ESV2000

ACCIDENTS RELATED TO IMPACT DIRECTIONS IN %

	OPEL	VOLVO	FOLKSAM	MIC
FRONT	55,85	35,7	42,2	34
SIDE	16,76	33,5	41,9	15
REAR	7,27	8,7	13,4	14
ROLLOVER	20,2	4,9	2,5	2
OTHERS	—	17,2	—	35

Slide 10

It should be mentioned that the Opel data are based on severe accidents only and vary somewhat from the other data.

ESV2000

FATAL ACCIDENTS RELATED TO IMPACT DIRECTIONS IN %

	OPEL	MIC
FRONT	33,7	42
ROLLOVER	33,9	19
SIDE	22,04	19
REAR	6,76	3
OTHERS	—	11

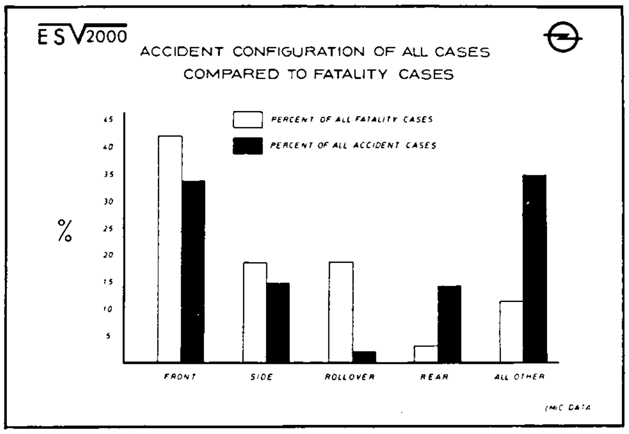
Slide 11

Looking at the few fatal accident data sources on hand which are related to impact directions we will recognize a very interesting shifting. The highest percentage of fatalaties occur in frontal impacts followed by rollover cases. Side impact and rear end collisions are ranked in positions three and four.

The percentage of fatalities can be reduced considerably if we will be able to increase the frontal barrier capabilities of our vehicles and if the occupants participate in the vehicle deceleration process by application of adequate restraint systems.

This next slide has been taken out of material published in a General Motors Proving Ground Report and it indicates the relation between fatalities in the red columns and the type of accident in blue columns in the USA.

It is obvious that rollover accidents which occur at a rate of 2% cause 19% of the fatalities, whereas rear accidents occurring at a rate of 14% cause only 3% of the fatalities.

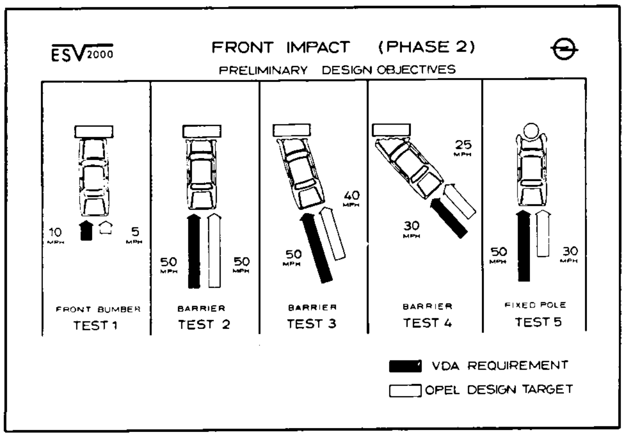


Slide 12

As far as the position of the passengers is concerned 91% have been killed on front seats and only 9% on rear seats.

These figures are reflecting the situation in the US whereas the situation in European countries will probably be different due to occupation rate, car size and traffic conditions, which are presently being investigated.

Here it should be mentioned that additional and improved statistical data are required to enable us to concentrate our development work on areas where improvements are most effective.



Slide 13

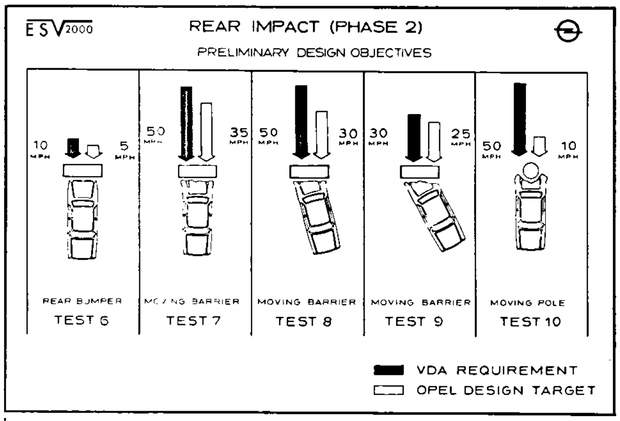
Having all the aforementioned material in mind we have set preliminary design objectives which deviate from the specifications issued by the Automobile Manufacturers Association as shown in the following slides.

The blue arrows represent the VDA requirements, the red ones the preliminary Opel targets.

In test 1 we have reduced the bumper impact speed from 10 to 5 mph because we are of the opinion that the energy absorbing bumper feature is of minor importance as a safety feature as will be explained later.

Test 2, the 50 mph front barrier, remains unchanged for reasons given earlier.

Test 3, 4 and 5 will be made at a reduced speed, however, the final target will remain to meet the VDA requirements.

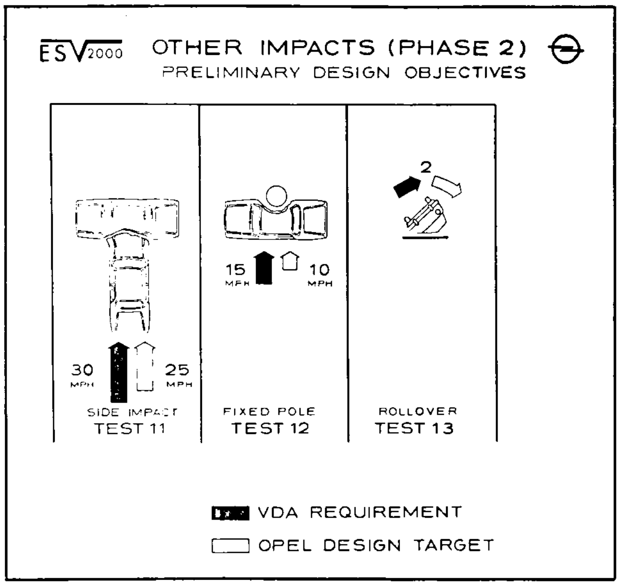


Slide 14

Test 6 is the low speed rear bumper impact which will be treated similarly as test 1 for the front bumper, i.e., the impact speed has been reduced from 10 mph to 5 mph.

The rear impacts under various angles in test 7, 8 and 9 will be made at reduced speeds as indicated. For reasons which have been discussed earlier concerning the reduced danger of rear impacts we do not intend to increase the Opel specifications.

In test 10 the rear pole impact speed has already been reduced from 50 to a more reasonable speed of 10 mph in both the US and the German requirements.

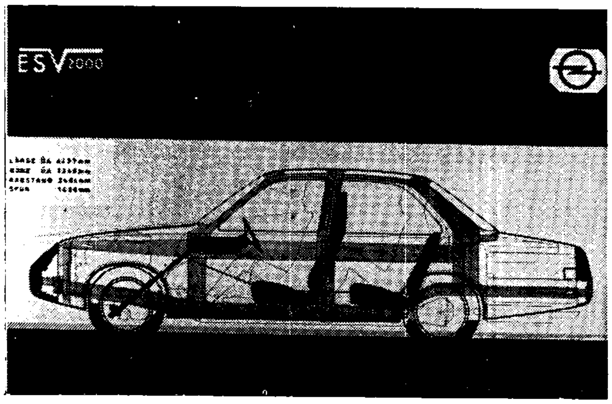


Slide 15

The preliminary target for the car to car side impact in test 11 has been reduced to 25 mph knowing that most side impacts occur in city traffic below city speed limits.

Test 12 has also been reduced where we start with a preliminary test speed of 10 mph.

The rollover test number 13 will remain unchanged versus the VDA specifications.



Slide 16

The safety vehicle now proposed will also be a car with conventional engine and drive line arrangement powered by a 1.9 ltr. 4 cyl. engine with an increased performance output and an exhaust emission control system to meet future specifications.

A foam filled sheet metal fuel tank located on the kick up above the rear axle in combination with a self sealing fuel line system will insure a high degree of protection in this respect.

An improved lock control brake system with fluid level warning device will be employed and manual as well as automatic transmission will be provided.

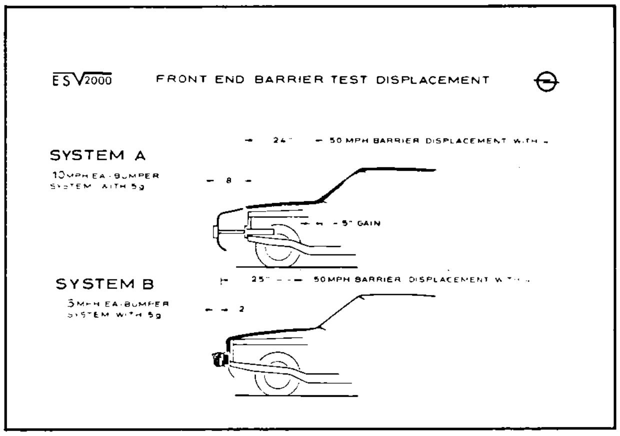
It is recognized that to meet the injury criteria will necessitate a concentrated effort in the development of new crush behaviour characteristics. A new unconventional body structure concept has been developed, which not only absorbs energy but also maintains the integrity of the passenger compartment at impact speeds higher than the present ones.

In combination with the new structure passenger protection will be guaranteed through the utilization of newly constructed and shaped seats and a passive restraint system for each occupant.

We are also continuing our development of an air cushion restraint system which could also be incorporated into this vehicle.

The concept of energy absorbing bumper systems is currently receiving a significant amount of attention and we have considered this feature in our studies.

Our findings indicate that a self-restoring energy absorbing bumper system designed to meet 10 mph front and rear barrier performance criteria as shown in the upper portion of the slide absorbs only 4% of the total energy content of a 50 mph barrier impact when

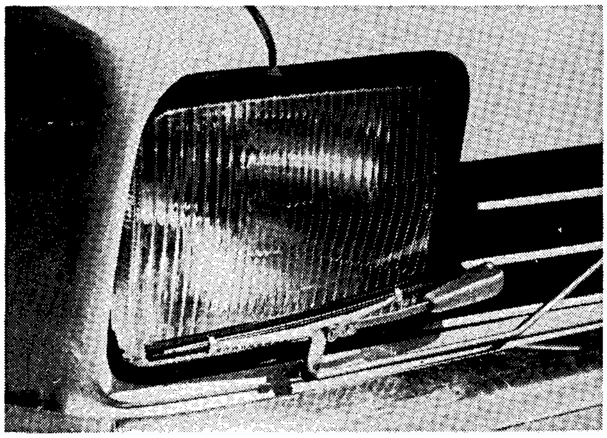


Slide 17

utilizing a full bumper travel which is equivalent to about 25% of the total theoretical crush distance.

Based on this evaluation we feel that it will be a better trade off to use the system shown above where we gain a space of five inches for high level energy absorption since the self-restoring bumper systems under discussion are directed towards the reduction of property damage and should not be overestimated with respect to actual vehicle safety.

A new bumper system is under development to provide a 5 mph property damage protection considering cost and weight factors in relation to overall crash behaviour improvements.



Slide 18

Another feature receiving prime attention is the development of cleaning systems for headlights.

When driving under adverse weather and road conditions the headlight lenses are being contaminated gradually and as a normal consequence the driver does not recognize the reducing visibility and the increasing danger.

In order to demonstrate the status of our pretest work concerning future body structures I will show you now a short movie. Current production Kadett vehicles which meet the present safety standards are being subjected to higher barrier impact speeds and you will recognize the magnitude of the challenge to fulfill the requirements of a 50 mph barrier impact with a passenger vehicle of this size.

For comparison we will show you then one of our ESV pretest cars in the 50 mph barrier test.

Comments To The Movie

The pretest vehicle you have seen in the 50 mph barrier impact test was not fully functional because, e.g., the window mechanism had to be taken out completely in order to provide sufficient space for the inner door structure.

In order to prevent any optimistic speculation, it must be emphasized that all structural development work being conducted today and in the near future will not reflect production earlier than in the late seventies.

In summary we can say that a higher degree of safety can be achieved and also be sold if simultaneously the customer's wishes with respect to styling, comfort, performance and economy are approximately met.

For this reason we feel that it is our duty to not only offer the customer more safety, but also to preserve his ability to buy and to drive such a vehicle without creating any physical or psychic compulsion feelings.

Such a compulsion could give vent to other not foreseeable emotions, since we must also remind you of the following fact: Approximately 90% of all traffic accidents are caused by human failures. These human failures are not always based upon a lack of abilities, but very often – perhaps in most cases – upon motions which escape the rational control. These defects of control occur especially during times of tension or stress.

For this reason, the safe motor vehicle of the future must not only be adapted to traffic but also to the human being.

THE BAMERISCHE MOTORENWERK A.G. (BMW) –

Tendencies of Development Concerning Vehicle Safety at BMW

Director Bernhard Osswald

Outline of Technology in the Federal Republic of Germany

The number of accidents in road traffic in Germany, as well as in all other highly industrialized countries of the world is alarming, and among those who bear responsibility, there can hardly be anyone who would not want to reduce these figures to a minimum for humanitarian, ethical, sociological and also for economic reasons. Quite understandably, however, there are considerable differences of opinion as to the ways which will lead to this target. There are proposals exclusively concerned with protecting vehicle occupants, and there are others which mainly protect the other road users. All of these proposals, as far as they are technically practicable, are likely to be successful to a certain degree. However, a decision to make use of one or the other proposal can be taken only on the basis of very detailed and exact knowledge of traffic and accident structure. Such knowledge is available, and it is also known that there are considerable differences from country to country. Thus, for example, in the USA the number of accident victims among vehicle occupants is higher, whereas in Germany the great majority of accident victims are other road users. Therefore, all measures intended to reduce the number of accidents in highway traffic must be differentiated accordingly.

In the previous lectures, it has repeatedly been pointed out that in Europe, due to the many urban agglomerations with a high traffic density, active safety has for decades played a particularly important role, and it is certainly not by coincidence that, in this respect, the legal requirements of various countries as well as the requirements of Statements of Work have mostly been met *a priori* by our vehicles, if not, for reasons of principle, compliance with certain requirements was dispensed with, in which connection I am particularly thinking of requirements concerning vehicle dynamics.

Seen from this angle, the requirements on the active safety of passenger cars, as laid down in the Statements of Work, only confirm that during decades of development the right course has been followed, also by my company. If I say decades of development, this encompasses the gradual progress which for the vehicle user has become apparent in the form of solutions which were both technically practicable and economically feasible.

This being so, we are now of the opinion that also for implementing the increased requirements on passive safety, such a gradual procedure should be chosen, whereby particular care should be taken to achieve practicability in high volume production and efficiency to the consumer within periods of time that are acceptable for all concerned. In this connection, I do not want to enlarge once more on the fact that, in particular, our understanding of the load carrying ability of the human body which, after all, forms the basis for passive safety, is still unsatisfactory. What I should rather like to do is to interpret the course followed by my company and to explain its motives.

More than a year ago we, too, were faced with the decision of developing and building prototypes of a special experimental safety vehicle. We have, for the time being, decided not to adopt this course, because it is our belief that our entire research and development capacity should be put to work in an effort to introduce the already developed safety devices as quickly as possible into our production vehicles and that, with the actual distribution of accidents in Germany, the present concept of the experimental safety vehicle which overemphasizes occupant safety at relatively high speed, would harm all the other road users more than it would help them.

We have further assumed – and we believe this to be realistic – that the development of such safety vehicle prototypes would have taken from one to two years, and that another year would have been necessary to complete testing. If we then assume that these vehicles could be produced economically and could also be sold, another 2 to 3 years would be required for developing, designing and testing them to the point where they could go into production. It would only be then that the exchange of the, let us say, conventional vehicles against these safety vehicles could begin, and under European conditions, this would take at least 5 years. However, during this phase which would last for about 12 years, general safety on the roads and highways will certainly not improve since, no doubt, the possession of a safety vehicle will be conducive to aggressive driving behaviour. Moreover, accidents involving a heavier safety vehicle and a conventional vehicle will become much more serious for the conventional vehicle and its occupants. Consequently, when adopting this course, we could not expect any improvement in accident statistics for the next 10 years. You may now object that, of course, one could in the meantime incorporate the results from the prototypes into production vehicles, and you are certainly right, but it should be borne in mind that these results can also be obtained step by step with sample vehicles taken out of production, without constructing an experimental safety vehicle prototype which will meet requirements which by themselves are still controversial.

Thus, for the time being, we deliberately follow the course which Dr. Scherenberg has shortly mentioned in his lecture, i.e., that of gradually improving our production vehicles, whereby our objectives are in keeping with the progress of science and technology and with existing economic conditions. In adopting this course, we are creating development capacity for those vehicles which will dominate the traffic scene within the next 10 years, and we shall use this capacity to make these cars, as we have already done with our current models, progressively safer in any respect. We shall further profit from this capacity by planning, within the indicated period of 10 years, systems which, independent from the human factor, will help to reduce accidents in road traffic.

SECTION 2

PART 3 THE UNITED KINGDOM TECHNICAL PRESENTATION ON ESV DEVELOPMENT

PASSIVE SEAT BELT SYSTEMS

Mr. J. A. Shingleton, Auto
Restraint Systems Limited

Gentlemen

One factor that clearly stands out in the safety programme is the need to restrain the vehicle occupant at the time of impact in some way or other. Even in the so called cushion car as envisaged by Dr. Foster et alia it is recognised that within the terms of a feasible and acceptable interior design some form of restraint is essential.

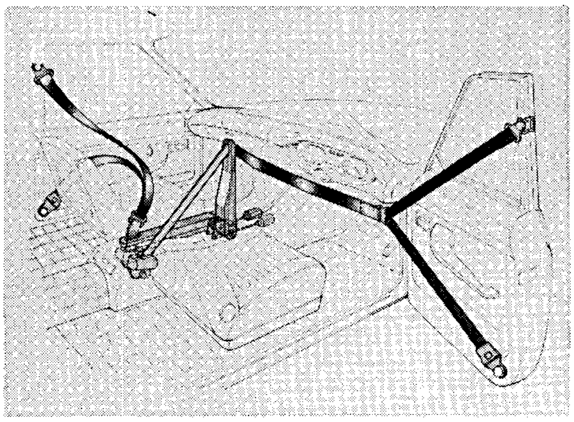
Substantial work has already been undertaken in the field of inflatable bags, a field in which, whilst very promising results have been achieved, a number of important problems still require an acceptable solution. It is important, also, to note that this approach does nothing to protect the occupant in impacts below a predetermined speed at present 15 m.p.h. (24 K/hr) or even in heavy braking conditions when injuries can occur.

The present lap and diagonal seat belt system has already proven itself to be a very valuable form of restraint and a substantial volume of data is available to support this statement. The U.K. Road Research Laboratory has, over a long period, carried out an accident investigation programme with particular reference to the wearing of seat belts which programme reveals conclusive results in support of seat belts of the type described. It would be a fundamental error of policy if such a proven system was allowed to be discarded without further study and effort in that area of development. No one can deny that whatever form the ultimate solution takes it must be cost effective.

The present problem with seat belt systems is the reluctance on the part of the public to use them. This arises partly from the inherent dislike of any form of restraint but in particular from the inconvenience of use arising from the need of adjustment to individual occupants.

These problems, have to a large extent been overcome by the development of the modern automatic inertia reel belts which by definition virtually eliminate the adjustment problem and allow the occupant a reasonable degree of freedom in use. Nonetheless utilisation of the system – whilst slowly improving – still falls a long way short of universal use. It is, therefore an urgent requirement to find ways and means of removing the optional element of their use. The U.K. Road Research Laboratory is actively investigating, by contract, various methods of automatically applying the seat belt system to the occupant.

The problem is one of removing the belts out of the occupants' way to ensure unhindered ingress and egress to and from the vehicle, whilst at the same time not destroying the integrity of the system by interference with the point of attachment where stress will occur. Following my comments we will be showing a short film of one possible approach to this problem, although we must emphasise that the development programme is still at an early stage and we do not offer this as a final solution.



In this system the arms which move the belt out of the way employ "running loops" and do not carry any stress in use. At the point of attachment to the door, steps are taken to transfer the stress from the door to the B post.

We have not overlooked the question of freedom at rest when, for example, on a picnic, and provision has been made to override the system on such occasions. However, release of the hand-brake will automatically cancel any such overriding action.

Problems that still require a solution are ones such as egress across the vehicle and situations where only restricted door opening is possible.

Whilst conducting this development we are also examining the ability of the belt system to meet the criteria as laid down by the United States Authorities.

It is readily recognised that this is a field of study in which there is much imprecise data ranging from the actual tolerance capacity of the human body to present lack of adequate correlation between the dummies in use and the human body with particular reference to the neck structure. Considerable doubt has been cast on the ability of seat belts to meet the criteria and yet, we repeat, the seat belt has proven itself in actual use.

It is also recognised that seat belts might well not meet the high speed crash requirement. Here again the U.K. Road Research Laboratory is conducting an intensive study into actual impact speeds. Only with factual data can a true cost/effective relationship be established.

Passive seat belts, therefore, is an area of development to which a concentrated effort is being applied without prejudice to and in parallel with work on crash deployed systems. These latter developments are also being supported by the U.K. Government through the Road Research Laboratory.

FACTORS AFFECTING THE CHOICE OF STANDARDS FOR ACCIDENT AVOIDANCE

Presented By
Mr. A. W. Christie, Road Research Laboratory

1. General Considerations

The problem about which I am going to speak is that of setting realistic standards for primary safety. By that I mean standards which really will improve safety on the road and which are acceptable from other points of view such as the traffic capacity of roads and the cost of the vehicles themselves. For a number of reasons standards for primary safety are more difficult to establish than standards for secondary safety.

Firstly, it is usually easier to decide what happened after the initial impact in an accident than before.

Secondly, it is usually easier to suggest ways of reducing the severity of injuries sustained in any type of accident than to suggest ways of preventing such accidents in the future. For example, the value of collapsible steering columns can be assessed by a combination of physical and medical science, whereas to estimate the value of improving the cornering performance of a car requires a much better knowledge of driver psychology than we have at present. Drivers may be tempted to use improved cornering capability to drive faster than they did before with the result that some or all of the potential safety value of the change is lost.

Thirdly, it is more difficult to foresee *all* the consequences of changing the response characteristics of a car than of changing its structural features. For example, modifications which produce desirable changes to steady state performance could conceivably produce undesirable transient responses.

The main difficulty is probably that of determining what use will be made of improved performance capabilities by the human operator. It is possible that, from the point of view of safety, a high performance capability is less important than a predictable response and a gradual failure with adequate warning to the driver as limiting conditions are approached.

It is difficult to see how such questions can be answered without turning to accident information. Ideally standards for primary safety should be based on adequate accident evidence. We, in the UK, believe that a thorough programme of accident analysis is necessary for a successful safety car programme and are making a substantial effort in this field.

2. Evidence Available From Accident Studies

At present the evidence available from accident studies is small. I should like now to review briefly evidence relating to primary safety.

We would expect handling characteristics to have the greatest effect on "loss of control" accidents. Estimates (Fig. 1) of how many of the cars involved in accidents

LOSS OF CONTROL AS A FACTOR IN ACCIDENTS

Proportion of cars involved which went out of control :-

POLICE ESTIMATE	(National fatal and serious accidents, 1968)	13%
RRL ESTIMATE	(Pilot on-the-spot investigation, 1968)	23%

Figure 1

are out of control vary considerably (13-23%). It is hoped that by expanding on-the-spot investigations that a more reliable estimate can be made. Even so not all of these accidents can be blamed on faulty handling characteristics – driver behaviour is almost certainly of great importance.

We would like to know where loss-of-control accidents occur. Again information is available at present from only a very small number of accidents (Fig. 2).

TYPES OF LOSS-OF-CONTROL ACCIDENT INVOLVING CARS
(RRL Pilot investigation 1968)

	Surface condition: Dry	Wet or damp	Snow or ice	All
Car diverged from straight road	9%	9%	3%	21%
Car spun round on straight road	9%	11%	1%	21%
Car spun round at bend	4%	6%	0%	10%
Car left road on outside of bend	6%	29%	3%	38%
Car left road on inside of bend	3%	8%	0%	11%
Totals (79 accidents)	30%	63%	6%	99%

Figure 2

From this it may be seen that drifting out at a bend was the most common type of loss of control (38%) and that a wet road was involved on a surprisingly high proportion of occasions (63%), bearing in mind that the road is wet for only about one third of the total time. Handling standards should therefore give due importance to cornering and to performance on wet surfaces.

Braking is known to be involved in about half of the loss-of-control accidents even on dry surfaces. The adoption of anti-lock systems could probably eliminate a substantial proportion of the total.

We would like to know also what types of car are most likely to go out of control. Here again (Fig. 3)

RELATIVE LOSS-OF-CONTROL ACCIDENT RATES
FOR DIFFERENT TYPES OF CAR

∗ Travel estimated by different methods
Ø Relative rates adjusted to give mean of 1·00 for each investigation

			National ∗ accident statistics 1961 - 1963	RRL Pilot ∗ 'on-the-spot' investigation 1968
SMALL CARS	Front engine / rear drive	Car A	1·16	
		Car B	·86	
		Unspecified		·94
	Front engine / front drive	Car C	1·02	
		Unspecified		·64
	Rear engine / rear drive	Car D	1·54	
		Unspecified		1·16
MEDIUM CARS	Front engine / rear drive	Car E	·79	
		Car F	·60	
	Layout unspecified	Unspecified		·76
LARGE CARS	Front engine / rear drive	Car G	·91	
		Car H	1·12	
	Layout unspecified	Unspecified		1·50
Mean for the investigation Ø			1·00	1·00

Figure 3

there is little evidence at present and there are no clear indications from it. Perhaps rear engined cars are more difficult than cars with other layouts. Perhaps large cars are more difficult to control than small cars. Much more evidence and a stricter examination of it is required.

Vehicle stability, especially liability to roll over, must also come under the heading of primary safety. The USA data (Fig. 4) indicate that small cars, particularly rear engined small cars, are most likely to roll over. However rollover accidents are less frequent in the UK than in

ESTIMATES OF PERCENTAGES
OF CARS OVERTURNING IN ACCIDENTS

		In USA*	In GB †
Imported cars	Small rear engined A	45%	11%
	Small rear engined B	62%	
	Other sedans	36%	
USA cars	Rear engined	28%	
	Light conventional	23%	
	Medium conventional	21%	
	Heavy conventional	16%	
British cars	On motorways		30 %
	On A and B roads		10 %
	Other roads		7 %
	On all roads		10 %

∗ Data - cars in which occupant was injured
Source - CAL (1952 - 1968)

† Data - car drivers injured
Source - GB national statistics 1969

Figure 4

the USA though this frequency varies with the class of road (Fig. 4).

3. Use Of Practical Handling Tests For Standardisation Purposes

In the absence of fuller accident evidence it seems natural to turn to practical tests in which situations, which arise on the road, are simulated.

The first problem is the choice of situations to be studied. So many can be suggested that their relative importance must be estimated so that a realistic selection can be made. From what is known of "loss of control accidents" it seems likely that performance on wet as well as on dry road surfaces should be considered and performance with low tire pressures as well as normal tire pressures.

I should like to discuss briefly some tests of this type. Two tests are used (Fig. 5) – a cornering test and a lane change (chicane) test. The test courses marked by cones (pylons) were as in the figure. Two types of road surface are included – a dry high coefficient surface and a wet slippery surface. The tests were performed at constant speed so far as possible. There were two criteria – a performance criterion (maximum speed) and a warning

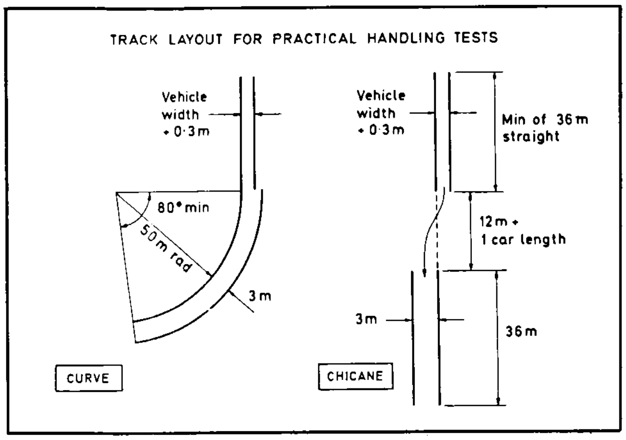


Figure 5

criterion (which is defined later). The tests were all made with a single expert driver.

In figure 6 maximum speeds for the curve on the dry surface have been plotted against vehicle size (the diagonal dimension of the vehicle). There is a significant

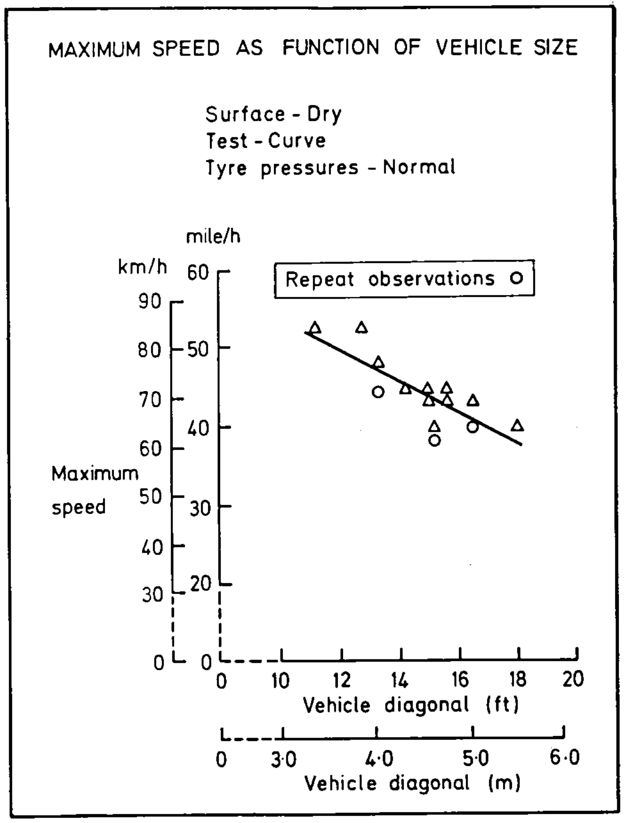


Figure 6

correlation with vehicle size – the larger vehicles being the slower. It is not surprising that there is a considerable scatter about the line fitted to the data because a wide range of vehicle types was covered. A considerable amount of scatter undoubtedly arises from various forms of experimental error as can be seen from the repeat results obtained after a period of several months. Somewhat similar results were obtained in the chicane test on the dry surface.

Figure 7 shows the maximum speeds obtained for the curve test on the wet slippery surface plotted in the

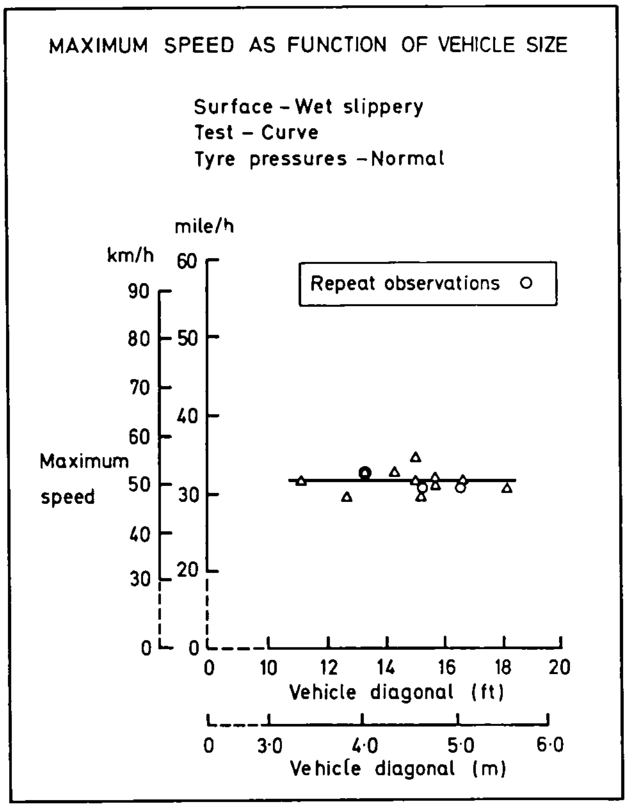


Figure 7

same way. In this case there is no correlation with vehicle size. Speeds are much more constant, probably being limited by the available friction between tire and road. Similar results were obtained in the chicane test on the wet slippery surface.

Most of the reductions in tire pressures gave significant reductions in maximum speeds (Figs. 8 and 9). However the speed reductions were small considering that the pressures were reduced by 50%.

I now come to the second criterion. The driver was asked to estimate the speed at which he felt he was just losing control of his vehicle. This he called his first sensation speed. The difference between this speed and the maximum speed is therefore a measure of how much warning he had. The results for the warning criterion (maximum speed minus first sensation speed) have been plotted in the same way as before. In figure 10 there still appears to be some dependence on vehicle size in the dry – apparently there was more warning with the small vehicles than with larger vehicles. In the wet (Fig. 11) there was little warning with any size of vehicle.

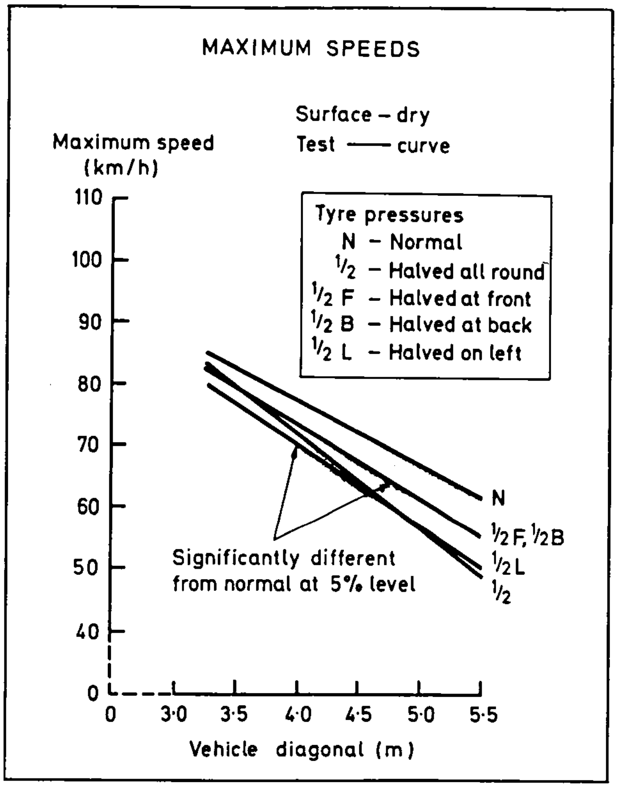


Figure 8

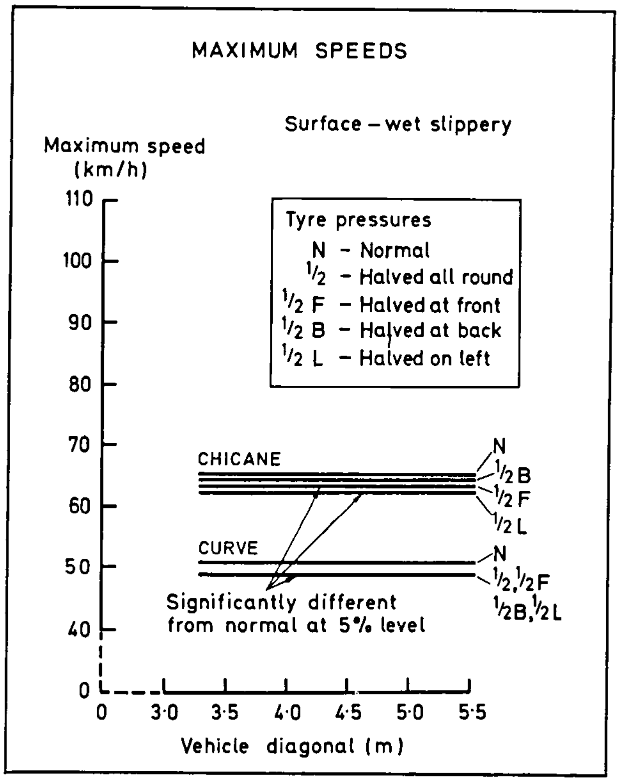


Figure 9

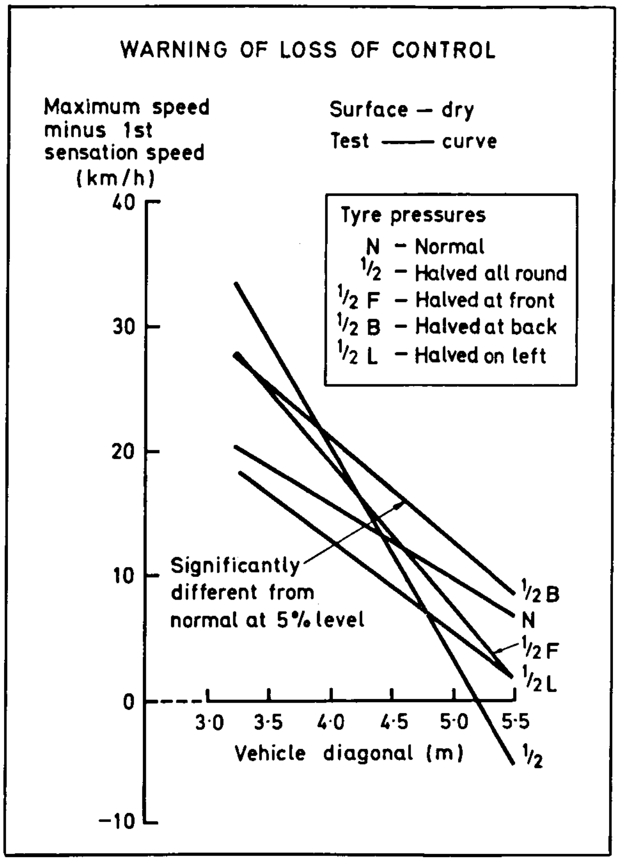


Figure 10

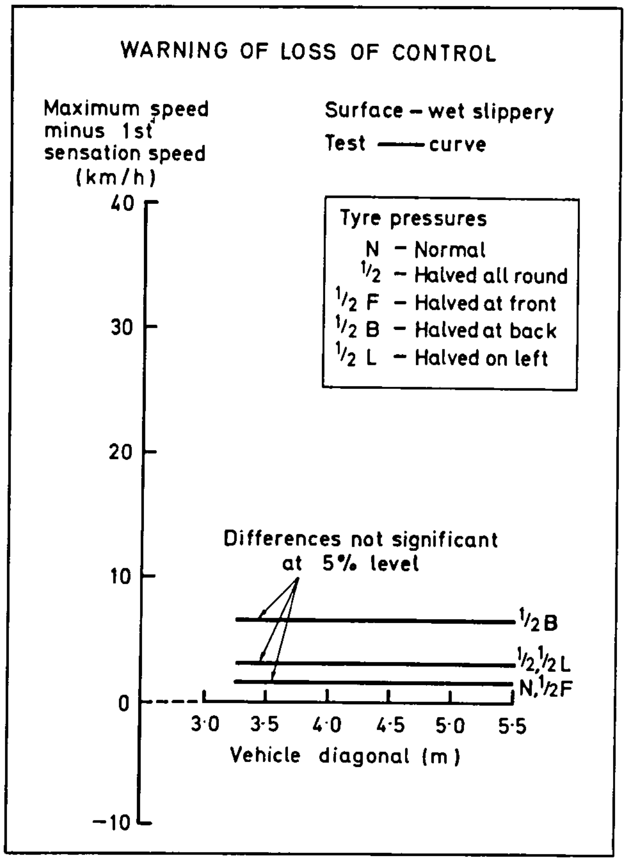


Figure 11

It would not be justifiable to try to draw conclusions about the warning signals noticed by the driver. First, sensation speeds are much less definite than maximum speeds. They are subjective and affected by unintentional bias on the part of the driver which can only be avoided by taking very strict precautions; this could not be done in these preliminary tests. In addition, warning sensations are likely to vary considerably over the range of types of driver. To study them many drivers would have to be used. These results are introduced today merely to indicate possible ways of developing criteria for accident avoidance.

The main aim of the tests was to find a means of comparing the handling characteristics of different types of car in a way which is relevant to safety. The order of merit of the cars however tends to change according to the test, the surface on which the test is carried out and the criterion of performance chose. This fact illustrates the dangers of setting arbitrary standards. Ideally the results of practical tests such as these should be compared with the accident rates of the same vehicles. It is hoped to do this when more information becomes available.

4. Use of Basic Response Characteristics For Standardisation Purposes

Another form of testing consists in the measurement of basic response characteristics under idealised conditions. The steady state and transient yaw tests in the American ESV specification are examples. Some of these tests have been carried out on three British cars.

One of these cars, a medium sized car by British standards, with front engine and rear drive gave steady state results generally in line with the USA ESV requirements especially if some allowance is made for the reduced wheel base (Fig. 12). In the case of a second car (a slightly smaller one with front drive) the results lie mainly above the band labelled acceptable (Fig. 13), although the steering characteristics of this vehicle are highly praised in the UK and the vehicle does not appear

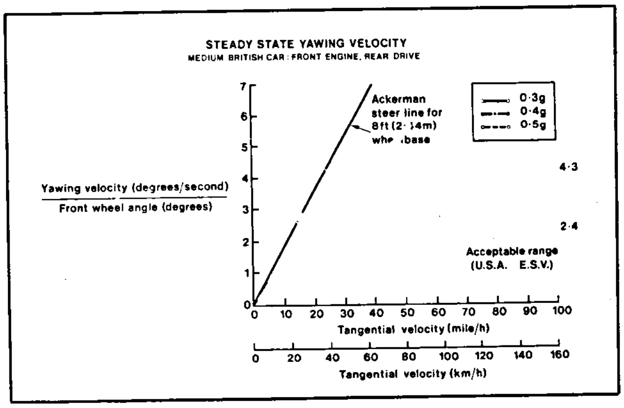


Figure 12

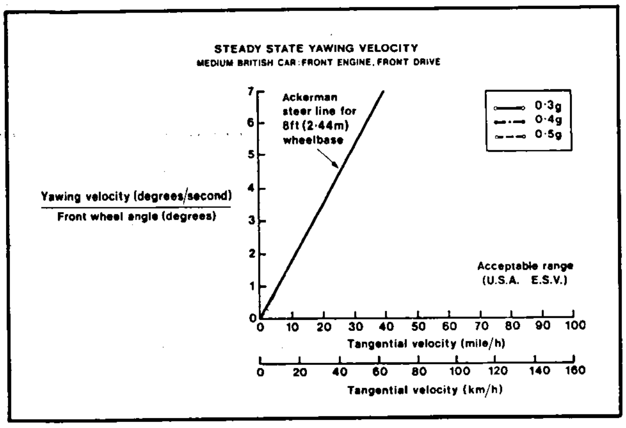


Figure 13

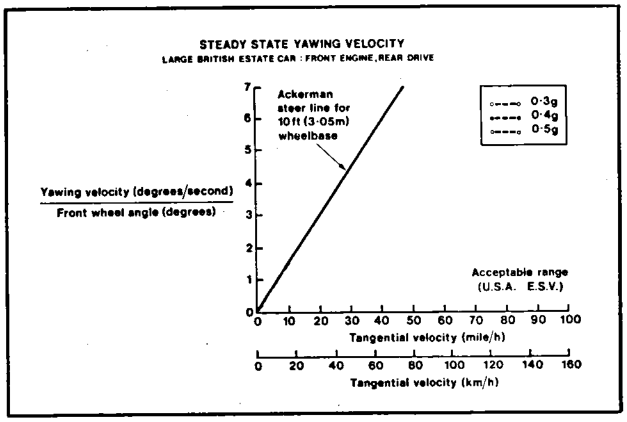


Figure 14

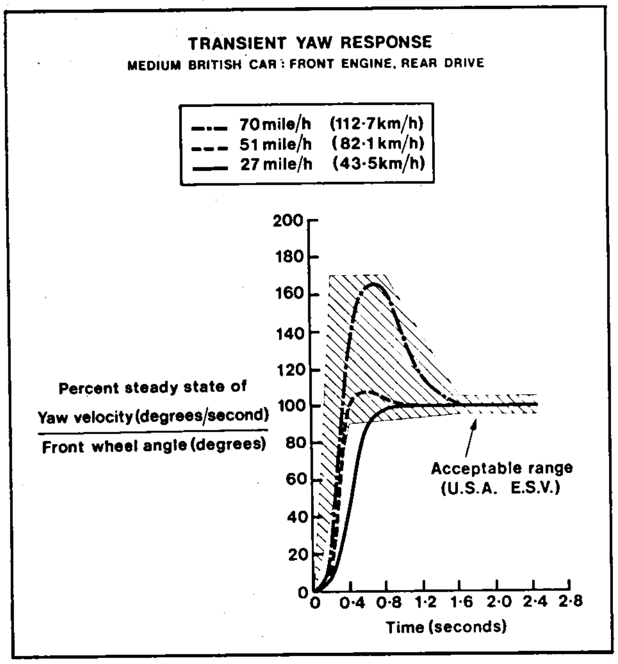


Figure 15

to have an unusually high accident record. A larger vehicle, an estate wagon with front engine and rear drive, gave steady state results somewhat below the acceptable band (Fig. 14). The steering characteristics of this car are probably less well liked than those of the other cars but there are no accident data to quote either for or against it.

The transient yaw responses of all three vehicles are generally within the acceptable band of the US ESV specification (Fig. 15).

5. Summary of Main Points In The Presentation

5.1 Use Of Accident Evidence As A Basis For Specifications

(a) Ideally specifications for primary safety should be based on evidence from accident analyses.

(b) At present such evidence is inadequate and a substantial effort is needed to rectify this situation.

(c) It is not even known whether it is better to design for the utmost in handling capabilities or to design for a predictable response under limiting conditions together with a clear warning to the driver when loss of control is imminent.

(d) There is some evidence, by no means conclusive, that, in the UK, it may be more important to specify handling response on wet surfaces than handling response on dry surfaces.

(e) Braking is involved in about half of the accidents in which loss of control occurs. Anti-lock braking systems could probably eliminate a substantial proportion of these.

(f) In accidents in which car occupants are injured roll over appears to be involved less frequently in the UK than in the USA.

(g) USA data indicate that small cars, particularly rear engined small cars, are the most likely to roll over.

(h) There is a slight indication, worthy of further investigation, that large cars and small cars with engines at the rear may be more frequently involved in loss-of-control accidents than are small cars with other layouts.

5.2 Specifications Involving Practical Handling Tests

(a) It is difficult with practical handling tests which simulate accident situations and involve the use of drivers to obtain precise and repeatable results.

(b) There are many possible tests and these can place cars in different orders of merit. An appropriate choice of tests can probably only be made when there is adequate evidence from accidents to guide the choice.

(c) There is evidence from handling tests on dry surfaces that small cars are inherently more maneuverable than large cars.

5.2 Specifications Involving Basic Response Characteristics

(a) Compared with the results from the complex referred to in 5.2 the results of measurements of basic response characteristics are probably more precise and repeatable, but are also likely to be less easily correlated with accident experience.

(b) Some British cars of approximately 2,000 lb. weight have steady state yawing response characteristics which fall outside the range specified for the USA ESVs. They include at least one car whose steering characteristics have been highly praised in the UK.

6. Conclusions

There is a lack of convincing evidence on the effect of handling characteristics on safety. This means that tight specifications cannot, at present, be justified in this area.

SOME OBSERVATIONS ON ESV DEVELOPMENTS

Mr. R. D. Lister, Road Research Laboratory

In the United Kingdom we regard it as vital to keep the main objectives in mind when considering this ESV work in preventing accidents and minimising injury severity and that the success or failure of any safety feature should be measured by the extent to which these objectives are achieved. It is for this reason that we lay great stress on linking our accident and injury studies as closely as possible to design features in order to guide the progress of our own Car Safety Programme and we regard this as a most important factor in the programme. In this connection Mr. Christie has just discussed the problems of establishing handling specifications and test procedures which will be related to accident reduction and it may well be that the handling performance which results in a reduction in some types of accidents proves to be one that the driver does not like. I might add that drivers in general do not like speed limits but nevertheless they play a part in increased safety.

The same consideration applies in the choice of an injury criteria when assessing restraint systems. This point has been raised by other speakers too; we are particularly concerned that any injury criteria used should be related as far as possible with accident experience. In particular, in the case of passive seat belts we are extending an established and proven conventional belt restraint system about which we have a considerable amount of accident and injury data and there is no doubt about their value in reducing injuries in accidents. Furthermore, our dynamic testing of passive seat belt systems show that they are comparable in performance with conventional systems of the same configuration. Looking at our evidence, using the conventional 3-point seat belt, we have sufficient data to say confidently that head injuries do not occur by virtue of this type of restraint. Even when the impact is severe enough to the point at which some skeletal fracture occurs from the loading of the seat belt, we have not yet experienced any head injuries unless the head actually impacts some interior structure of the vehicle. However, the results of tests using dummies often give the Gadd Severity Index for the head as being in excess of the accepted tolerance level of 1000. Figures well in excess of 1000 are sometimes quoted. It is therefore apparent that dummy testing of belt restraint systems as carried out at the moment, and the head injury criteria used, are not consistent with accident experience. We are not questioning the validity of the 1000 Severity Index as applied to humans but quite obviously this figure is not the correct one to apply to current dummy test devices and it is unwise to exclude the seat belt type restraint systems solely on the head injury criteria.

One solution of course is to change the dummy but this would need further correlation with accident experience as the only adequate representation is by another human body. Alternatively, one could accept that seat belt restraints are giving a satisfactory performance and then run some tests with a specified dummy test device using seat belts and accept a new level of severity index for the dummy based on the results of these tests. I offer this for consideration.

SECTION 2 PART 4

THE JAPANESE TECHNICAL PRESENTATION ON THE ESV PROGRAM

GENERAL REMARKS ON THE SPECIFICATIONS FOR JAPAN ESV

Mr. Yoshiro Okami
Japan Automobile Research Institute, Inc. (JARI)

To comply with the Japanese Government's request for drawing the Specifications for a Japanese Experimental Safety Vehicle, the ESV Subcommittee was established within Japan Automobile Manufacturers Association, Inc. (JAMA) in November, 1970. The Subcommitte, comprising of technical experts from the Government, subordinate manufacturers and Japan Automobile Research Institute, Inc., started operation on the basis of the U.S. specifications for the 4,000 lb. ESV, and completed an original draft in January, 1971.

Consideration was later paid to the criticism of the U.S. National Highway Traffic Safety Administration, which had been levelled against the Japanese specifications. The Subcommittee decided on the final specifications in May, and JAMA submitted them to the Government.

Our specifications will, in general, meet the requirements, described in the U.S. specifications. However, some differences will be noted because our ESV is a smaller type and traffic regulations in Japan are not the same as those in the U.S.A.

I will explain, from the Japanese point of view, the main differences.

1. The specifications for the Japanese ESV were drawn to enable them to also meet the Safety Regulations for Vehicles for Road Transportation (JAPAN). One example is that the requirement for an outside rearview mirror was added.

2. The automobile engineers in Japan have made every possible effort towards the reduction of curb weight, and we have considered it as an indication of technical progress. However, there arose the fundamental necessity of reinvestigating the weight of vehicles. The reason is that passengers should be protected in the collision to a fixed flat barrier at the impact speed of 80 kilometers per hour, and such requirement will lead to an increase in curb weight. It is doubtful whether the increase in curb weight will be able to be compensated by a decrease in the weight of other components, but this will doubtless be proved through the achievement of subsequent technical developments. In the first stage of the programme, we consider that curb weight is one of the subjects for the research into crashworthiness.

The Graph in Figure 1 shows a conceptual diagram of the relation between curb weight and the characteristics of crashworthiness with the number of occupants as a parameter. The following two ideas can be drawn from this:

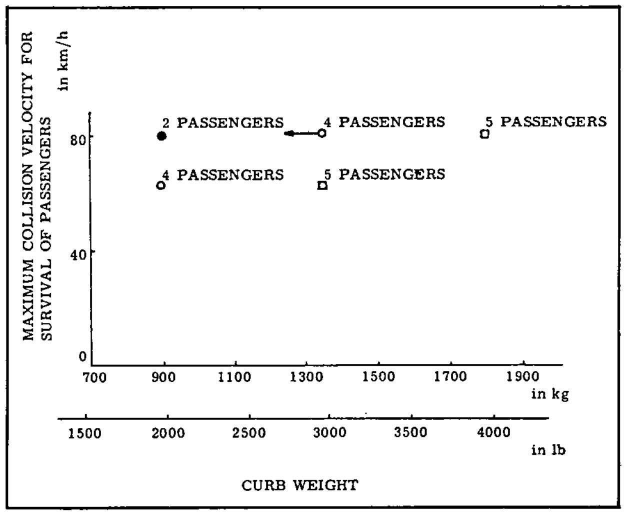


Figure 1

1. How much will the minimum weight of ESV be for four passengers?

2. Under what condition will it be possible to make a 900 kilogram-weight ESV?

We thought that in the present stage we should not conclude which type would be more pertinent to the future traffic system. We therefore adopted two specifications for the design based on the curb weight and the number of passengers (Fig. 2). The choice will be left to the participating manufacturers. Through the research into crashworthiness on the vehicles of these different

ITEM	SPECIFICATION	
NUMBER OF PASSENGERS	4 OR	2
CURB WEIGHT	1150 kg (2530 lbs)	900 kg (1980 lbs)
VEHICLE CAPACITY WEIGHT	322 kg (710 lbs)	161 kg (355 lbs)

Figure 2

types, we believe that more technical information will become available, thereby assisting the achievement of our programme.

Nissan Motor Co. Ltd. will develop an ESV for four passengers, and Toyota Motor Co. Ltd. will develop an ESV of 900 kilogram weight designed for two passengers. Furthermore Honda Motor Co. Ltd. will develop a 750 kilogram weight ESV for four passengers, which is smaller in weight than that prescribed in the specifications. The details of these vehicles will be explained in the technical presentation by the individual Japanese manufacturers.

3. Our opinions were divided as to whether intrusion should be adopted as the criterion for judging the integrity of the occupant compartment. We have not sufficient information on the relation between intrusion and human tolerance, and the injuries to the occupants will depend very much on the construction of the vehicle and on the method of the occupant restraint system. With these in mind, we are doubtful whether a uniform standard should be applied or not. We adopted a standard prescribing that "there shall be no passenger compartment intrusion greater than 125 millimeters at such places where the safety of occupants is involved."

We believe that this standard can be accepted as reasonable for a Japanese ESV, whereby the two approaches on curb weight and the number of passengers are adopted.

4. The Japanese specifications fail to describe the front bumper, which is sensitive at impact velocity. But the condition of collision is the same as that in the U.S.A. and also the requirement on occupant protection. The protection of occupants is related to such factors as vehicle configuration, body structure, occupant restraint system, interior design, etc. Therefore, in the original specifications, we decided not to specify for the front bumper, leaving room for flexibility in design. The progress of research may require further review of this problem.

5. We have tried to utilise the principles of the U.S. specifications on braking, steering and handling into a smaller type ESV, and found our results resembled the German specifications. As there is still room left for research in regard to the relation between steering and handling characteristics and the avoidance of accidents, we consider that all possible factors relating to accident avoidance should become the object of future study.

Our specifications will be increased depending on how our future research develops on these pending problems.

6. We can point out many differences in technical terms when expressed in English and also, as this programme will be extended to cover a new field of research, new terms will be introduced. Such differences could lead to confusion in the exchange of information and we earnestly hope that consideration will be given to the standardisation of technical terms.

THE TOYOTA MOTOR COMPANY

Mr. Jiro Kawano
ESV Chief Designer,
Toyota Motor Co., Ltd.

I'm a chief designer in charge of ESV project at Toyota Motor Co. in Japan.

It is indeed a great honor for me, to engage in the ESV project, which contributes to welfare of people and society of the world, and to be in cooperation with DOT in U.S.A. and many authorities in the world.

Toyota Motor just started the development of this project under the approval of Japanese Government in accordance with Japan ESV specification. This is the first time for Toyota to attend at the international conference as a member of this group, and also our project is just on the first stage.

Therefore, I would like to explain briefly the concept of our specification and programming plan, and show you a short film of our testing facilities and ESV tests by using some current vehicles on production.

Toyota decided to develop the 2,000 lb. ESV with two-seaters for the following reasons.

1. This is the opening stage in the long running term project, so to start with the simplified arrangement was thought to be the best for us.

2. We think it is very significant and fruitful to develop various kinds of ESV by many manufacturers in the world.

3. Most of Toyota's products are classified in this 2,000 lb. class, and to make the safety car within this weight range, the specification of two-seaters was thought to be the most suitable one for us.

Generally speaking, the crashworthiness mechanism with two-seaters is essentially the same with that of four-seaters except for the rear seat problems. Therefore

I believe that the result of the crashworthiness study in this experimental vehicle shall have some good fruit for the future research and development study.

As for accident avoidance performances, by making good use of characteristics of light weight on this 2,000 lb. specification, the vehicle design shall be intended to be fully analyzable of these performances.

With regard to the size of the vehicle, it will be necessary to have 4.3m overall length and 1.8m overall width, in order to satisfy the crashworthiness requirement. I would like to explain more details concerning our design, but unfortunately we can't do it now, because we are just on the first page of this program and we are under the investigation on the crash behavior of the vehicles which were locally modified from our production sedan.

As for accident avoidance, we think it is the most important item for traffic safety. We will study the technical feasibility on this subject making best use of the characteristics of the small sized car.

We have many things to do to meet the specifications – vehicle handling and steering, brake performance, visibility and so on. So we are intending to make moderate model giving careful consideration to these specifications.

With regard to the vehicle weight, we will do the best effort to reduce it down to 2,000 lbs. However, unfortunately if trade-off between the weight reduction and the safety performance may become necessary, the choice shall be made according to the principle of safety priorities, and hereby for instance the use of expensive special light alloy to reduce the vehicle weight shall be avoided as much as possible.

Next, I would like to show you the time schedule of our ESV project.

The delivery date of Japan's ESV is at the end of 1973. We have the following program to accomplish the vehicle within a term.

Up to the end of 1971, we will lay stress on the analysis of crashworthiness performance and investigation of each subsystem on the proper modified current models.

By the middle of 1972, the evaluation test of the primary prototype shall be made.

By the end of 1972, the secondary prototype shall be made considering the results of the previous model.

By the beginning of 1973, the final design and specification shall be fixed.

After various tests and improvements on the final design, the delivery of the complete vehicles shall be planned by the end of 1973.

About 100 units of test vehicles shall be prepared, that is, about 60 units of newly fabricated prototype vehicles, and about 40 units of partially modified vehicles.

Next, I would like to present a short movie film, which shows our testing facilities and various tests which we have conducted at Toyota Higashi Fuji Proving Ground.

THE NISSAN MOTOR COMPANY

Mr. Yoshio Serizawa

Mr. Teruo Maeda

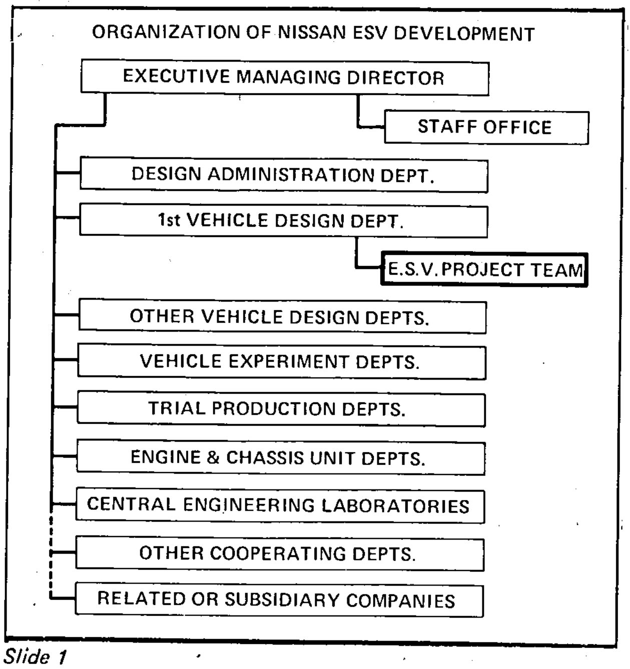
It is a great pleasure for me to present the technical efforts of Nissan Motor Company at this International Conference.

I am the deputy manager of the design administration department at Nissan, and the chairman of the Safety Committee of the Japan Automobile Manufacturers Association.

I would like to present this report with the high degree of social and technological responsibility which is Nissan's philosophy in regard to vehicle safety.

As for the ESV program, it was organized by Nissan Motor Company early this year under the general supervision of Dr. Nakagawa, Executive Managing Director who is attending today's conference, with five others from Nissan. The ESV Project team composed of 30 design engineers is headed by Mr. Teruo Maeda.

Many cooperating departments, which are engaged in various new production models, are also supporting this project team (Slide 1). For instance, a clean engine will



Slide 1

be developed and supplied from the engine department, and all experiments including ESV compliance tests are now underway in the vehicle experiment department using our various facilities.

The main specification we are working under is the same as Japanese ESV specification. We selected 4-passenger, 4-door sedan of 2,500 lbs., which is 1150 kg.

I think this specification is market-minded and applicable to future production cars. However, it is the most challenging specification in weight and size. We must accomplish almost the same specifications and characteristics as those of American vehicles of 4,000 lbs. or more, within a small and compact package. There are a few differences between U.S. and Japanese specifications, some of which are shown here (Slide 2).

NISSAN ESV SPECIFICATIONS
DIFFERENCE FROM 4000 lb E.S.V.

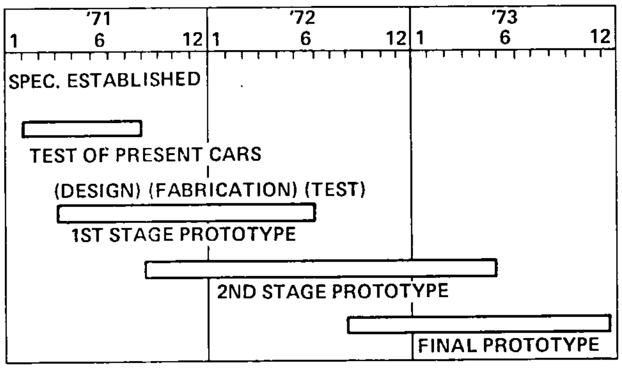
ITEM		NISSAN E.S.V.	4000 lb E.S.V.
Dimension	Size	None	max 5588x2032x1473 min
	Weight	1150 kg	1800 ± 90 kg
	Seats	4	5
Slalom	Speed	80 km/h	72 km/h
Forward Visibility	Up/Down	13°/6°	17°/8°
Crashworthiness	Intrusion	< 125 mm	< 75 mm
	Deceleration	None	Specified for Front End Structure

Slide 2

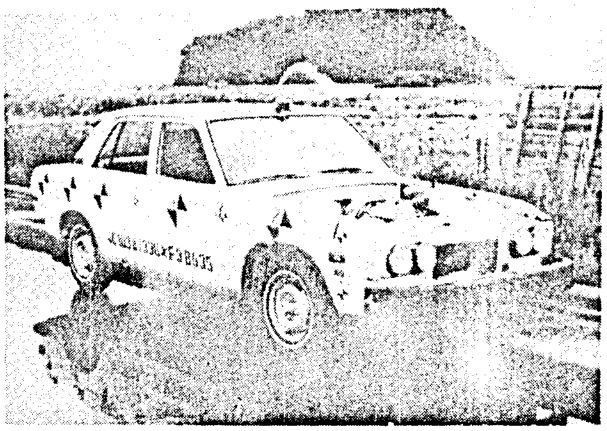
Our project team with the help of other Nissan departments is going to build about 20 final ESVs before the end of 1973. These vehicles will be tested and assured under the given specifications as far as possible in Nissan Motor Company.

For this purpose, we set up four stages of testing (Slide 3). The initial stage is that of establishing a "Bench Mark" on the status of present cars. The next one is that of testing the vehicle modified from the present cars, which we will call the 1st stage prototype. We used Datsun 510 and 610 as the basic models. The 1st stage is under way and will continue until the beginning of next year (Slide 4). The 2nd stage is that of designing and testing the 2nd prototypes. This stage has started in some fields including the development of various parts such as periscope, tires, glass, shock absorbing units and materials. This stage will be the area of maximum effort next year.

TIME SCHEDULE OF NISSAN ESV



Slide 3



Slide 4

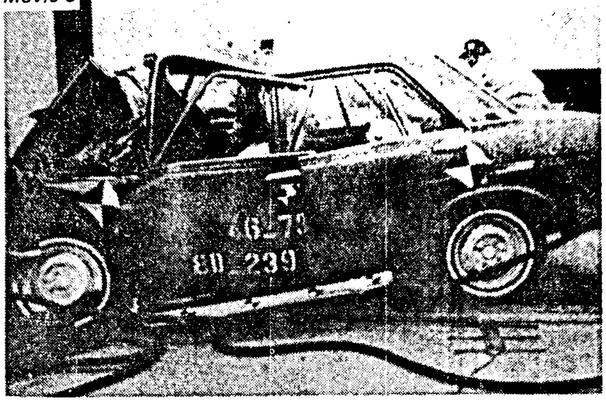
Through this experience, we will design the final ESV, and after testing and correcting again, we will accomplish the final ESV.

Now, I would like to present several testing results so far finished in Nissan by movie. Through this movie, you will see the difficulties and challenges which are encompassed in the ESV project.

(Movie)

1. Head-On Barrier Collision, 50 km/h, Datsun 510
2. Occupant Protection at Head-On Collision, 50 km/h
3. Head-On Barrier Collision, 80 km/h, Datsun 510

Movie 3



4. Head–On 45° Barrier Collision, 50 km/h, Datsun 510

5. Bench Test, Static Collapse of Front End of Datsun 510

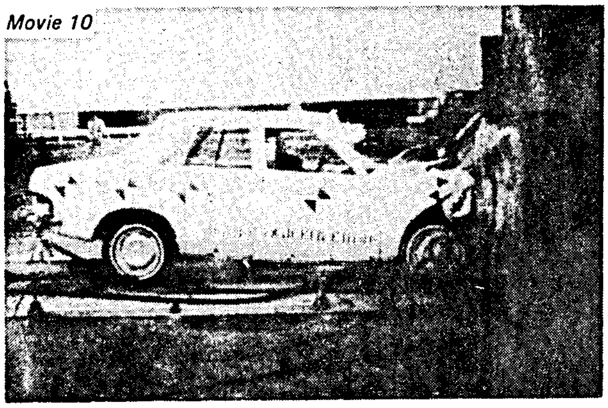
6. Bench Test, Dynamic Collapse of ½ Scale Model

7. Bench Test, Dynamic Collapse of Tire

8. Head-On Barrier Collision, 80 km/h, Datsun 510 without engine

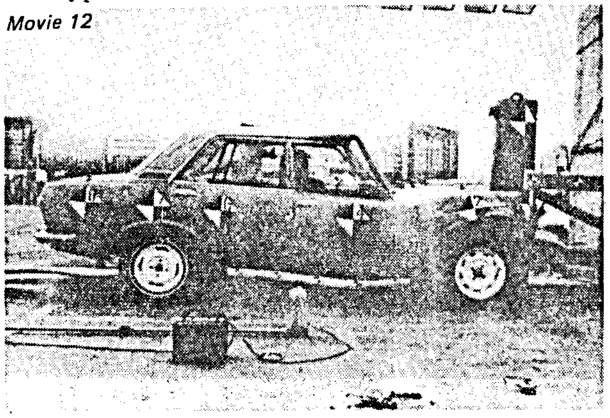
9. Head-On Barrier Collision, 15 km/h, 1st Stage Prototype

10. Head-On Barrier Collision, 80 km/h, 1st Stage Prototype



11. Head-On Pole Collision, 80 km/h, Datsun 510

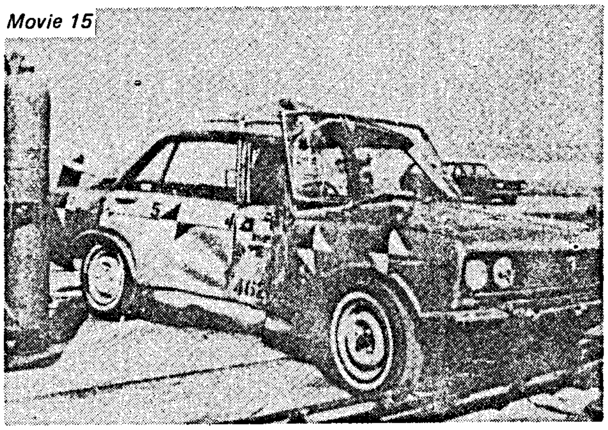
12. Head-On Pole Collision, 80 km/h, 1st Stage Prototype



13. Rear-End Collision, 70 km/h Moving Barrier, Datsun 510

14. Rear-End Barrier Collision, 64 km/h, 1st Stage Prototype

15. Occupant Protection at Side Collision, 25 km/h, Datsun 510



16. Side Pole Collision, 25 km/h, Datsun 510

17. Side Pole Collision, 25 km/h, 1st Stage Prototype

Movie 17

18. Vehicle Submergence
19. J-Turn, Datsun 510, 110 km/h
20. J-Turn, Datsun 510 – Overload on the roof, 110 km/h

(Slide) Experimental Components

5. Periscope
6. Front Bumper System
7. Front Suspension and Steering System
8. Rear Suspension System
9. Tire

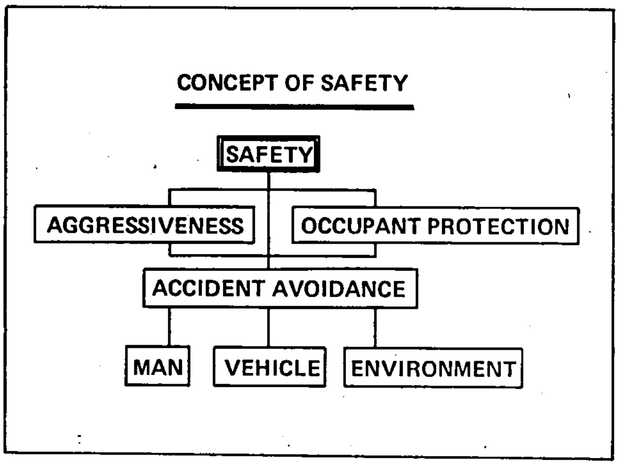
As you have seen in this presentation, we are encountering various difficulties.

For the small-sized vehicle, body crashworthiness and occupant protection are really the toughest problem. The 80 km/h head-on barrier collision is one of the most difficult requirements. We feel these problems are very challenging, and we are extending every effort to meet this requirement.

Taking the vehicle size into account, an 80 km/h rear end collision by a 4,000 lb. moving barrier is also in the same situation. The energy absorbed in the moving barrier collision is much higher than that in the actual rear-end collision. We are trying to find a more practical and suitable test condition for this purpose. We may presumably adopt a "car to car" collision between the same weighted cars or a collision with the same weighted moving barrier instead of the present specified collision.

As for the other specifications such as visibility, brakes, and vehicle handling, we do not see much difficulty in the present cars and the modified ESV.

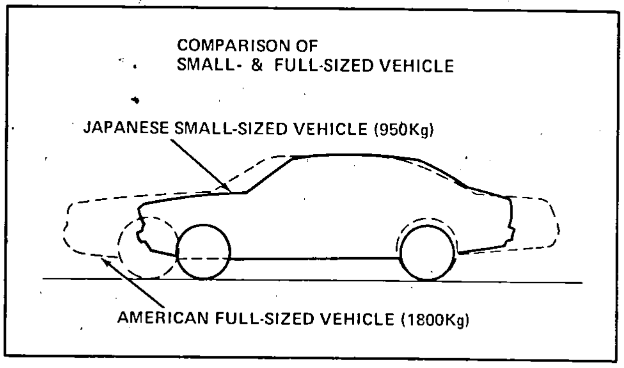
Safety itself consists of many factors (Slide 10). I would like to state our general concept of safety in ESV design. Accident avoidance is the first objective, of course. If all the accidents could be avoided, safety would be completely assured. Accident avoidance consists of three factors. One is the factor on the vehicle side such as handling, brakes, etc., which are defined to a certain extent by the ESV specifications. The other is the factor of traffic environment. The last is that of driver's conditions, such as manners, mental and physical conditions, education, enforcement, and so on. We consider the last factor to be the most important and the most emphasized by our president, Mr. Kawamata in various places.



Slide 10

Unfortunately, if accidents can not be avoided, we are faced with two kinds of damages or injuries. These are damages to the offender, and damages to the sufferer. We should never forget the safety on the sufferer's side. The offender's problem is how to reduce the sufferer's damage caused by the offender's vehicle. This characteristic may be called "aggressiveness." Sometimes this will be much more important if we think of the driver's responsibility to society.

We, Nissan Motor Company, do not intend to increase the weight, nor the size of our ESV to satisfy the requirements (Slide 11). These increments will bring an increase of aggressiveness. Naturally, small-sized vehicles have less aggressiveness and easier handling. We will not sacrifice this superiority even if we face very strict crashworthiness problems.



Slide 11

I would like to say that we at Nissan are doing our best to design the safest vehicle considering overall safety factors.

We will spend 1.7 billion yen, that is, more than five million dollars for the ESV project. We will use more than 200 man-years. These burdens are quite heavy on our company. But for the high objective of ESV, we will promote this project intensively. It is said, in the Olympic Games, participation itself is worthwhile. Through this challenging participation, we hope we can demonstrate to the world that Nissan Motor Company is a reliable, dedicated and socially conscious manufacturer of excellent motor vehicles.

THE HONDA MOTOR COMPANY

Mr. Hiroshi Hayano
Chief Engineer, ESV Project

Introduction

Today we would like to explain our view on the small lightweight ESV which Honda is taking up as a project, because we have a different point of view in our approach to this project than that of the large ESV represented by U.S. 4,000 lb. vehicle.

I. Needs Of Small Lightweight Vehicles

There is no doubt that a prime objective of ESV is to seek the technical feasibility of vehicle safety. In considering the uniqueness of Japan's city structure and road conditions and noting that demand for small cars is gradually increasing in the recent market trend, it is clearly foreseeable that a continuous demand for cars in the small category will remain at a significant level for years to come.

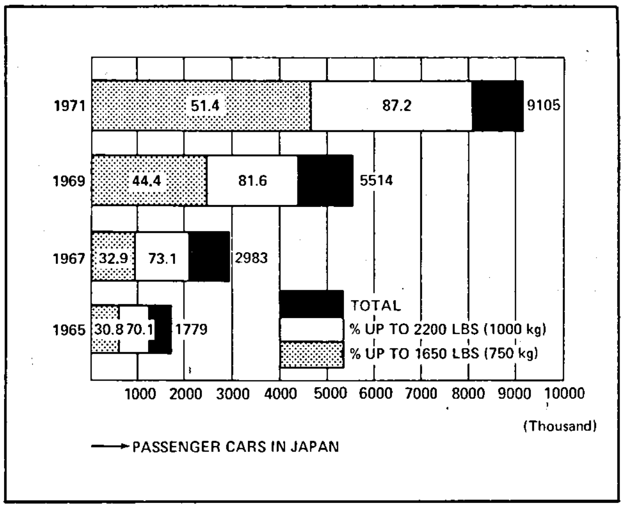
Therefore there could be small lightweight ESV to suit the social needs and its manner of use in Japan.

Considering also their usage, small cars should be capable of sustained 100 km/h cruising while being economical and easy to operate when driving at medium and lower speeds.

With this background in mind, we have decided to challenge this ESV project by developing a small ESV not only smaller than U.S. 4,000 lbs. ESV, but also the 2,000 lbs. ESV of Japan.

Because of technical hardships due only to the smallness and lightness of our ESV, the completion may take a year longer than other Japan ESVs. This is the reason why we are participating in the capacity of semiparticipant.

We shall provide JARI with the Honda ESV free of charge instead of seeking the government funds in exchange.



II. Basic Requirement Of Honda ESV

The basic requirement for a small ESV then would be as follows. The main objectives in developing such a small ESV would naturally be different from that for 4,000 lbs. vehicle.

1. Accident Avoidance
   (a) Ensure perfect controllability
   (b) Prevent erroneous and excessive operation
2. Man-Machine Communication
   (a) Automatic checking system for pre-start inspection
   (b) Monitoring system to ensure safe running
   (c) Warning system to prevent driver negligence
   (d) Improvement of visibility and identification
3. Crashworthiness
   Aimed at the specification established for Japan ESV

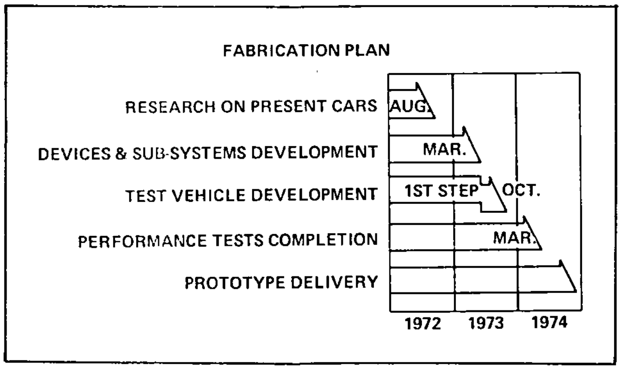
III. Particular Emphasis On The Specifications

Curb Weight	750 kg (1650 lbs.)
Passengers	4
Type	Family Sedan
Expected Car Dimensions	
Length	3500 mm (138 in.)
Width	1500 mm (59 in.)
Maximum Horsepower	55 bhp

As to the crashworthiness, we are anticipating a number of technical difficulties because of the size of this car.

IV. Fabrication Plan

Because of the circumstances within our company and expected technical difficulties, the delivery of the Honda ESV prototype will be one year later than those of formally participating companies in Japan.



THE JAPANESE AUTOMOBILE RESEARCH INSTITUTE

Prof. Dr. Masaichi Kondo
Director

We can see often the lovely scenes in which even the children less than one and a half years old wish earnestly to ride in motor vehicles. According to my feeling, this seems to mean that human beings innately love motor vehicles and like to have and ride in them, though verification for it is not enough by the above fact alone. Needless to say, the motor vehicle is very convenient, useful, economical and productive; and in addition, it affords us pleasure and enjoyment. The motor vehicle is truly the prime mover for development of economy and civilization of societies and nations.

While we are using very many machineries of various kinds in present days, we have none so social as the motor vehicle, which comes into the midst of our society, being used by almost all people and maneuvered very freely in compliance to the individual's will every day and everywhere. I would like to claim the motor vehicle has semi-human character and hence I call the motor vehicle "semi-human machine" or "semi-mechanical man."

Very regrettably, however, present motor vehicles have large demerits: they pollute the atmosphere by emissions and cause traffic accidents, etc. Considering the large merits and special characteristics of the motor vehicles above stated, we have to improve, with all and utmost endeavors, the motor vehicle into a safe and non-pollutant one. Realization of a safe and non-pollutant vehicle is eagerly requested by all Japanese people as well as by all mankind of the world.

With the background of these social situations and requisitions, Japan Automobile Research Institute, Inc. (abbreviated as JARI) was inaugurated in April, 1969, by the sponsorship of all Japanese automobile manufacturers and related industries with the cooperation of the Japanese Government. The Institute was established basing upon the establishment named Automobile High Speed Proving Ground, Inc., which had been established in 1960 at Yatabe-cho, Tsukuba-gun, Ibaraki (about 60 km north of Tokyo) with the site about 2.5 square kilometers and had already a test circuit of 5.5 km length as well as other large scale test grounds. The site is located in the neighborhood of Satellite Town for Research and Educational Institutes (Tsukuba Kenkyu-Gakuen Toshi) which was planned afterwards by Government, and is now under construction. Thus, our Institute is the recipient of the predecessor's large scale proving ground and therefore we could begin research activities comparatively earlier by adding new buildings and research equipments.

Though saying easily in words, realization of safe and non-pollutant vehicles is very difficult. From safety's point of view, following are requested: crashworthy devices which protect occupants even when collision occurs at high speeds, cushioning designs of the vehicle's front part which guard the pedestrian from injuries when the vehicle hits him, and immunity of overturning against all rough steering and braking so long as running on smooth horizontal roads, and so on. As for non-pollutant vehicles, situation is more severe and it requires: redesign and reconstruction of engines improving combustion in the cylinder, reburning and purification of the exhaust gas by means of reactors and catalizers, etc., and development of new types such as electric vehicles and vapor engine vehicles, and so on.

In our Institute, we are making allout efforts considering it the primary target to solve various problems relating to realization of safe and non-pollutant vehicles. At the same time, we are making fundamental and futuristic researches also. These research works are being conducted in harmony with the ones which are made in Japanese automobile manufactures and related industries.

Adding to the test ground including other auxiliaries already mentioned, several research laboratories with new equipments were recently completed, and the dormitories for research staff are now partly constructed. Total number of research staff and supporting members is about 165 on April 1, 1971.

As above stated, in our Institute, we are making, under the direction of Mr. K. Kawamata, President of our Institute, all endeavors day and night for the urgent target of completing safe and non-pollutant vehicles with earnest wishes to answer the requests of all Japanese people as well as of all mankind of the world. Concluding the address, I ask sincerely understanding and cooperation of the people relating to automobiles in the Governmental, academic and industrial circles as well as all the public.

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	Tsutomu Nomiyama – Managing Director, Japan Automobile Manufacturers Association, Inc.
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Osamu Hirao	Professor, Dr. Eng., University of Tokyo
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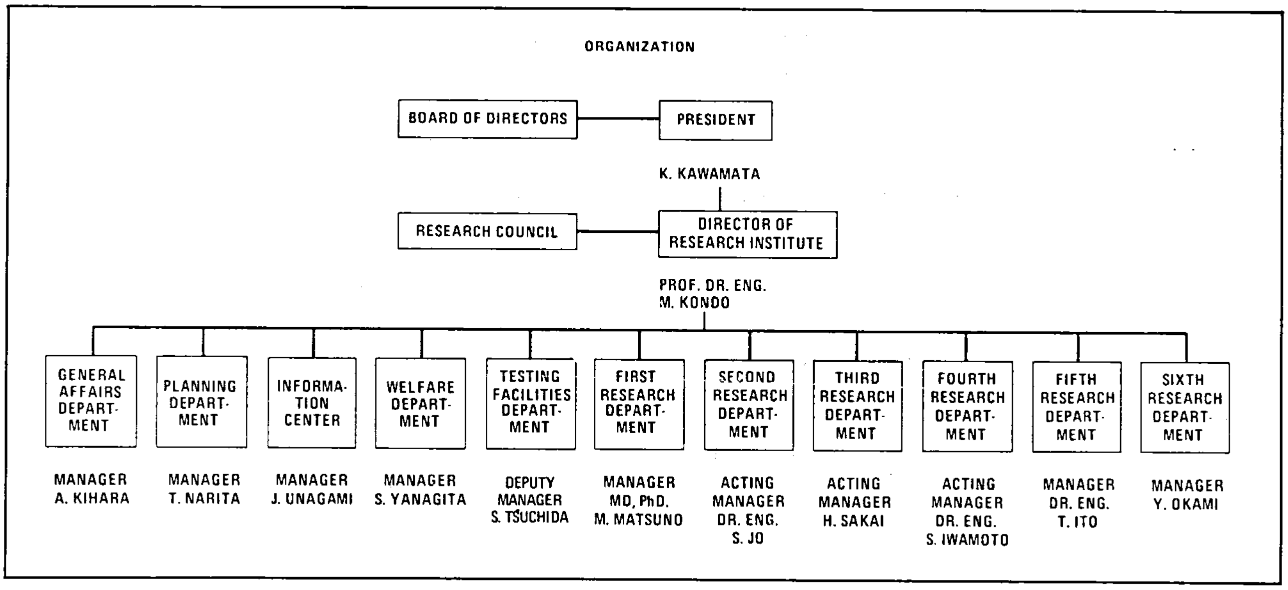
Tomoo Ishihara	Professor, Dr. Eng., University of Tokyo
Hiroshi Takahashi	Director, Nissan Motor Co., Ltd.
Masao Shomura	Manager of Technical Administration Dept., Mitsubishi Motors Corp.
Tozo Yabuta	Director, Toyota Motor Co., Ltd.
Yoshio Kono	Managing Director, Toyo Kogyo Co., Ltd.
Yozo Shimizu	Managing Director, Isuzu Motors Limited
Kiyoshi Yamoto	Executive Managing Director, Hino Motors, Ltd.
Ichiro Niitsuma	Engineer, Honda Motor Co., Ltd.

RESEARCH ACTIVITY

Research activities of the Institute are divided into two fields: one is conducted in each Research Department and the other is carried out by various Research Committees. Those researches are made up each other and constitute the consistent projects. Most of research



theme are based on those desired by Japan Automobile Manufacturers Association, Inc. through the deliberation made by various Committees.

It goes without saying that at present we are focused on urgent theme, that is on environmental protection and safety problems.

Although substantial research areas of each Research Department is as stated below, it is necessary systematic and mobile cooperation among research departments to promote research project, and the management of the Institute takes serious consideration on systematization and mobility.

First Research Department: Principally researches based on Human Factors
Second Research Department: Research on Power Plant
Third Research Department: Principally researches based on Vehicle Dynamics
Fourth Research Department: Principally researches based on Vehicle Mechanics
Fifth Research Department: Principally researches based on Hydrodynamics and Control Engineering

RESEARCH THEME

I. Anti-Pollutions

1. Researches on Automobile Exhaust Emission Control
   - Trial Manufacture of Perfect Emission Control System
   - Study of the Catalyst for Emission Control
   - Study of the Improvement of Fuel Supply and Combustion in Automobile Engine
   - Study of the Influence of Lead Free Fuel on the Engine Performance and Exhaust Emission
   - Study of the Influence of Fuel Composition on Diesel Exhaust Composition and Smoke
   - Smoke Suppressive Additives, NOx Suppressive Method, etc.
   - Establishment of Correct Measurement Method of Exhaust Gas
   - Study of the Exhaust Particulate and Its Removal
   - Development and Operation of Smog Chamber Vehicle and Pollution Analysis Vehicle
   - Research on Forecasting System of Air Pollution in Big City
   - Investigation of Actual State of Ozon and Oxidant Concentration in Tokyo
   - Basic Research on Oxidant and Pollution
   - Biological Study on the Exhaust Catalyzer Substance
   - Experimental and Analytical Research of Diffusion and Dilution of Exhaust Gas in the Automobile Tunnel (with Natural Ventilation) (Charge: 2nd Res. Dept., 1st Res. Dept., 5th Res. Dept., Combustion and Exhaust Emission Committee, Fuel and Lubricant Committee, Lead Free Fuel and Engine Performance Committee, Air Pollution Analysis Research Committee)
2. Researches on Low Emission Engines
   - Basic Study of the Development of Vapor Engine Car
   - Investigation of Engineering Feasibility in Gas Turbine, Stirling Engine and Electric Powered Automobile (Charge: 2nd Res. Dept., Vapor Engine Car Committee)
3. Research on Noise Reduction
   - Analysis and Experiment to Grasp the Present

Condition of Travelling Noise (Especially about Tire Noise and Engine Noise) of Trucks and Buses
Research on Tire Noise, Engine Noise and Other Related Problems as Elastic Vibration and Wind Vibration
(Charge: 4th Res. Dept., Research Committee on Vehicle Noise)

4. Research on Prevention of Radio Frequency Interference
   - Investigation of Actual Situation of Radio Frequency Noise Generated from Domestic Vehicles,
   - Investigation of Preventive Effect of Current R. F. Noise Suppressors and Various Experimental Products, and Comparative Study of JRTC Standard and CISPR Standard
   (Charge: Research Committee on Prevention of Automobile Radio Frequency Interference)

II. Safety

1. Study of Occupant Protection
   - Development of Anthropomorphic Test Device
   - Study on Work Space and Control Dynamics
   - New Standardization on the Automobile Seat
   - Researches on Restraint System including Airbag, Helmet, Seatharness, etc.
   - Biological Study of Deceleration Effects
   (Charge: 1st Res. Dept., Human Engineering Committee, Windshield Committee)

2. Research on Absorption of Crash Energy (. . . of Energy Due to Impact of Collision of Automobile)
   - Research on the Body and Its Components which Augment the Energy Absorbing Capability in Collision of Automobile
   - Development of Accelerometer or Speedometer of Simple Construction to Measure the Impact Velocity or Acceleration in Collision of Automobile

3. Researches on Vehicle's Stability and Control
   - Dynamics of Vehicle's Overturning and Test Procedures for the Limit of Maneuverability
   - Research of Handling Characteristics of Multiple Vehicle Combinations
   - Arrangement and Unification of the Methods of Test and Appraisal of the Stability in High Speed Research of the Relation between the Vehicle Shape and Running Stability at High Speed, Based on Statical and Dynamical Aerodynamics
   - Research of Movement of Automobile under Side Winds
   - Study on the Friction of Test Courses by Means of Skid Resistance Tester
   - Research on Tire Mechanics Covering Hydroplaning, Braking Characteristics, Mechanism of Tread Wear and so on
   - Development of No-puncture Safety Tire
   - Systematization of Feeling Test of Vehicles
   - Research on Methods for Measurement of Fundamental Vehicle Characteristics
   (Charge: 3rd Res. Dept., 4th Res. Dept., Stability and Control Committee, Aerodynamic Performance Committee, High Speed Stability Appraisal Committee)

4. Study on For-Pedestrian Safety Vehicle
   - Systematic Researches on Padding Material, Vehicle's Front Form, and Methods of Increasing Shock Absorbing Ability and so on, with the Object of Trial Production of For-Pedestrain Safety Vehicle
   - Study on the Motion of a Pedestrian Just before He Collides or Contacts with a Vehicle
   - Trial Production of V. T. R. (Video Tape Recorder) for Recording On-the-spot Auto Accident Scene
   (Charge: 3rd Res. Dept., For-Pedestrain Safety Vehicle Committee)

5. Studies on Lighting and Visibility of Automobile
   - Improvement of Brake Light, Turn Signal, Tail Light, etc. for Rear Collision Prevention
   - Researches on Visibility of Automobile
   (Charge: 1st Res. Dept.)

III. Experimental Safety Vehicle (ESV)

- Study on Evaluating Test of ESV
- Study of Testing Facilities for ESV

IV. Future Traffic Systems

- Research of Guided Automobile
- Research of the Simplified Control Equipments of Automobile to Control the Vehicle along the Guide Way and Further to Systematize the Traffic Research of the Electronic Guidance on the Guideway
- Research of Linked Automobile
(Charge: 6th Res. Dept.)

V. Fundamental Researches

1. Research on Elastic Vibration of Structure
   (4th Res. Dept.)
2. Fundamental Research of Aerodynamical Problems of Vehicle
   (5th Res. Dept.)
3. Research of Oil Pressure Control Apparatus
   (5th Res. Dept.)
4. Research of Dynamics of the Bearing
   (5th Res. Dept.)
5. Studies on Reduction of Body Weight and Application of Plastics to Body
   (6th Res. Dept.)

PROGRESS TOWARD VEHICLES DESIGNED FOR PEDESTRIAN SAFETY

Prof. Dr. Masaichi Kondo
Director, Japan Automobile
Research Institute, Inc. (JARI)

1. Introduction

The author explains first that statistics indicate high percentage of pedestrian accidents in Japan and Japanese experts are eager to research for-pedestrian safety vehicle. He contends ideal safety vehicle is the combination of for-occupant safety vehicle plus for-pedestrian safety vehicle. He wishes survey tests made recently by JARI would be a one-step advance for the realization of for-pedestrian safety vehicle.

2. Vehicle-Pedestrian (Dummy) Collision Tests To See The Effect Of Front Body Form

2.1. Method Of Test

Method of test used recently in JARI is as follows. A driver-less and power-off test vehicle, being guided by two rails, is pushed forward by a powerful accelerating vehicle from the rear. The test vehicle is equipped with an automatic brake pedal actuator operated by wireless signal. The pedestrian (dummy) is hung vertically facing to the test vehicle by a supporter and is let free just before collision. Thus central and symmetrical collision is achieved with prescribed impact velocity and with prescribed deceleration of the test vehicle.

2.2 Test Plan

Test vehicles are three, all belonging to 1,000kg class passenger car. Vehicle A has a long front body with a bonnet of curved contour in side view. Vehicle B has a low grill and the bonnet is composed of two planes with inclinations toward the front window. Vehicle C has a high grill and the bonnet is nearly horizontal. With each test vehicle, collision tests were made at impact velocities 10, 20, 30 and 40 km/h under the vehicle's deceleration of about 0.5g.

2.3 Some Test Results

Some of test results are explained by history curves of accelerations of various parts of the dummy, deceleration history of the test vehicle and consecutive postures of the dummy relative to the collided vehicle. High-speed cinefilms taken from right side, from front and from above are also used to show the phenomena. Test vehicles deformed by collision are shown by photographs.

2.4 Some Observations

The front body with high grill pushes, at low velocity impact, the pedestrian (dummy) forward and let the dummy fall with its backside and head hitting the ground. The front body with long nose and low bumper gives, at high velocity impact, the dummy a large rotational angular velocity and let the legs lift high, and the dummy lands with the head hitting the ground. The author thinks the desirable front body form would be such that which may let the pedestrian (dummy) fall to the ground with the legs hitting first or with flat posture, within the impact velocity range as wide as possible.

3. Collision Tests To See The Effect Of Covering Front Body With Shock Absorbing Material

3.1 Characteristics of Shock Absorbing Material

As the material for this purpose, the author adopted the following multi-layer grid structure composed of polystyrene foam: Section of the component member: 10 mm (wide) x 30mm (high); no. of layers: 5; spacing of the member: 20mm; combination: 90° crossing and 10mm staggered; total height: 150mm.

3.2 Collision Tests With A Test Vehicle Covered With The Above

With another test vehicle D, the effect of covering the front body with the above material was tested. The effectiveness was made clear.

4. Collision Tests To See The Effect of Equipping With Shock Absorbing Device

As shock absorbing device, the author adopted wire ropes arranged transversally or wire rope net set above the bonnet, both with solid friction type shock absorbing device at the side. These devices were beforehand examined by falling ball test, etc. and then tested by collision tests with the test vehicle D. The effectiveness of these devices is prospective.

5. A Trial To Use Scoop Net For Protecting The Pedestrian Against The Second Impact

The idea of receiving the thrown down pedestrian (dummy) to protect him from hitting the ground is not new. The author had tried a scoop net type about three years ago and the trial was successful. The scoop net is supported by two telescopic horizontal poles and is storaged ordinarily underneath the body. If a pedestrian (dummy) collides with the vehicle, the supporting poles and consequently the scoop net extend forward and receive the thrown down pedestrian (dummy).

6. Theoretical Investigation On Pedestrian (Dummy) Movement In Collision With A Vehicle

Our group is now making theoretical investigation, by using fundamental equations of motion of nine-degree freedoms, assuming the dummy as a jointed combination of seven rigid bodies. Investigations of the same kind are made by other organizations and some results obtained by Isuzu Motors Limited are introduced here.

7. Concluding Remarks and Future Research Plan

After reviewing the whole survey tests presented in this paper, the author introduces future research plan such as followings:

1. Researches based upon present day vehicles
2. Systematic research
3. Theoretical investigation
4. Non-central or non-symmetrical collision
5. Development of dummies more similar to real human bodies and determination of human tolerance limits
   (With regard to the last item, our Institute is only capable to take part in very limited area.)

aimed. The test program is not yet over and, hence, the information on the three models is not equally ample.

It should be emphasised that, basically, the various requirements in terms of passive safety for the occupants can be whittled down to two as follows:

1. survival space should remain after impact
2. occupant impact, against the car interior, should be as soft as possible.

Our experimental approach was that of arriving at satisfactory results primarily in terms of the first above requirement, which poses considerable problems on small-volume, low-weight cars.

Frontal Impact

Concerning the 1,200 lb. car, in the current production version results are satisfactory for front-end impact against barrier (Fig. 1) at speeds of 30 mph. It may be seen how intrusion is limited to the front trunk and how the passenger compartment has remained practically unaltered.

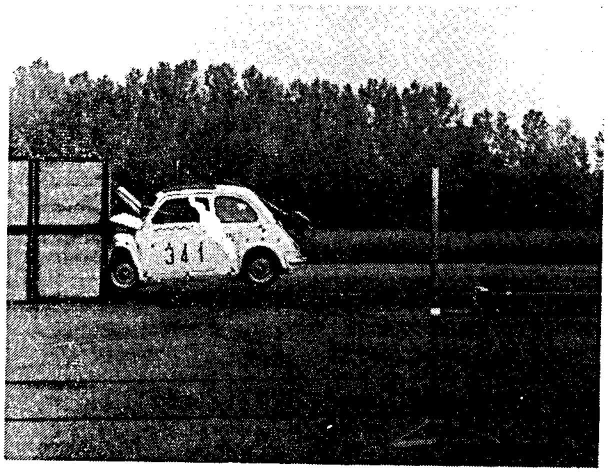


Figure 1

The current version, after substantial modifications and reinforcements was retested at 40 mph (Fig. 2), further reinforced and tested again at 50 mph (Fig. 3). The outcome is that the appearance of the reinforced car, impacted at 50 mph, is similar to that of the current car, as impacted at 30 mph; that is to say that reinforcement (Fig. 4) has almost trebled the energy-absorbing capability of the front end. This fact is clearly evidenced by the static forebody crushing test (Fig. 5) for current version and (Fig. 6) for the reinforced version the results of which have been used to plot the load/car crushing chart (Fig. 7).

In this connection attention should be drawn to the different maximim load figures reached in the two curves plotted on the chart. This means that in the course of impact the reinforced car undergoes maximum deceleration values higher than those incurred by the normal car. Therefore, we should like to emphasise that in our opinion it would be desirable to review the principle of fixing limits to the deceleration on the

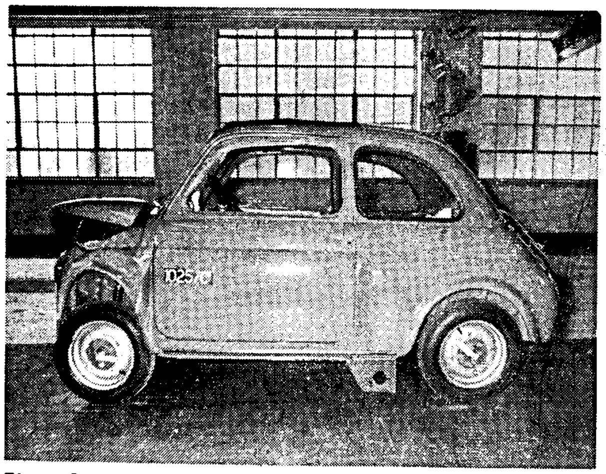


Figure 2

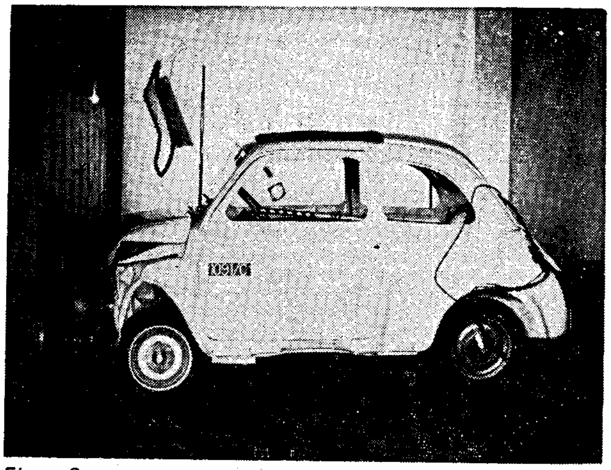


Figure 3

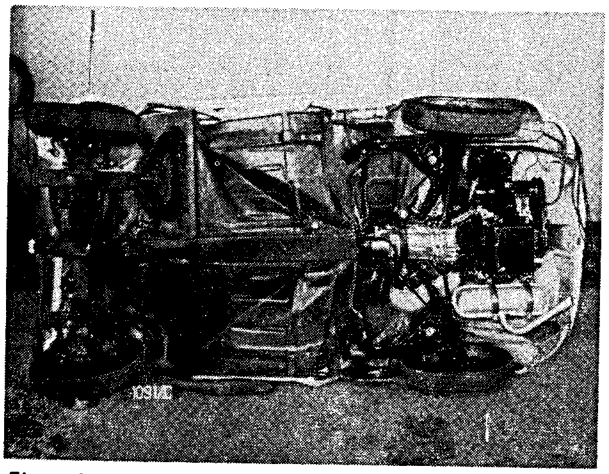


Figure 4

SECTION 2

PART 5 THE ITALIAN TECHNICAL PRESENTATION ON THE ESV PROGRAM

FIAT RESEARCH PROGRAM ON MOTOR VEHICLE SAFETY

Dr. Ing. Vittorio Montanari

In the Spring of 1971 Fiat has begun to work on a wide research program regarding "vehicle safety," co-ordinated with the European intergovernmental program.

The work was started before knowing if, how and when the Italian Government would have contributed to finance the program.

The official program concerns the study of five subjects which Fiat undertook to develop within the Italian national program.

1st – Vehicle behaviour in collision
2nd – Vehicle behaviour in rollover
3rd – Braking improvements
4th – Occupant restraint systems
5th – Fire hazards

The studies cover two classes of cars, namely: the class "1200 Lbs all rear" and the class "1800 Lbs all forward."

The actual Fiat program instead includes, in addition to the official one listed above, also the study of all the subjects considered in the European program which are the basic safety problems:

6th – Vehicle handling
7th – Improved lighting and signalling systems
8th – Driving in fog
9th – Interior vehicle design to reduce occupant injuries
10th – Design of bumpers to reduce damage in low speed impacts
11th – Exterior vehicle design to reduce injuries to pedestrians
12th – Improved visibility conditions
13th – Improved ergonomics control
14th – Tires
15th – Driver aids

In the actual program, research and testing are extended to three classes of vehicles:

1200 Lbs all rear
1800 Lbs all forward
2200 Lbs with front engine and rear wheel drive

The work was started on current production cars, typical of the three classes.

The first stage of the program, concerning the "study and development of the themes," will span over two years and end in the Spring of 1973 with the definition of the design of new experimental cars.

For this first stage, approximately 1,200,000 working hours are required, corresponding to a continuous activity by about 280 highly qualified technicians, and an expense of $16,000,000 is anticipated, including the investments for special testing equipment.

As regards investments, a few months ago our new Safety Laboratory started its activity: practically, it was opened by Mr. Toms in June during his visit to Turin.

This Laboratory covers a surface of approximately 6,000 sq. meters and is equipped for making indoor almost all the safety tests and, in particular, crash testing of vehicles up to 4,000 lbs at 50 mph.

The Laboratory is now considered already inadequate to meet the test requirements envisaged for the near future and we are therefore urgently trying to define the design of a new Laboratory with facilities about three times bigger than the present one. The expected cost is $8,000,000.

CRASHWORTHINESS IMPROVEMENT— TESTS AND RESULTS

Mr. Enzo Franchini, Fiat

In the ESV as well as in the European programs, the requirement is to pass front, rear and side impact and rollover tests. The following information concerns the tests performed and the results obtained using the three types of cars towards which our investigations have been

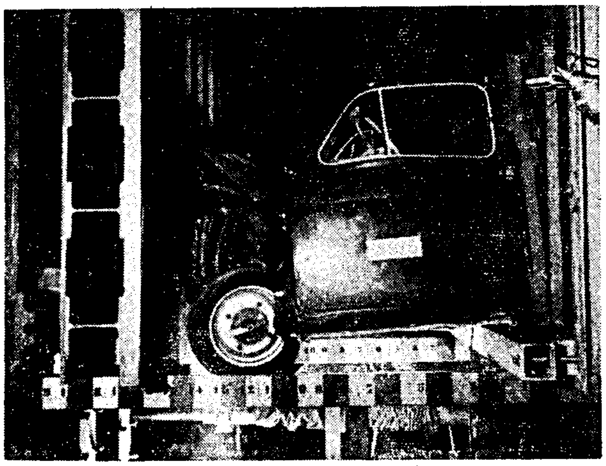


Figure 5

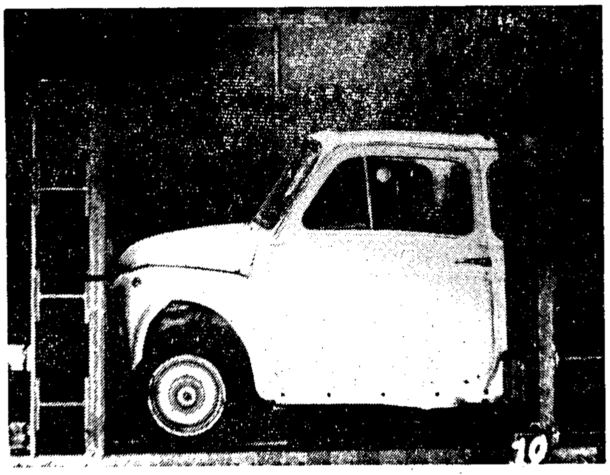


Figure 6

structure, as this would involve a considerable extension of the car front-end which, in turn, would entirely change the nature of the small size car concept. As regards the 2,200 lb. car, the chart (Fig. 8) evidences how less important localised reinforcements have brought about a considerable increase in crushing value without affecting the initial slope. As in the case of the normal version impacted at 30 mph (Fig. 9), thanks to this increase the passenger compartment has remained unaffected, also in the reinforced version impacted at 40 mph (Fig. 10), and in the further reinforced version impacted at 50 mph (Fig. 11).

Impact From Rear

The stationary 1,200 lb. car (Fig. 12) has been impacted at 30 mph from the rear by a moving barrier, of size and mass as specified in SAE J972, installed on board a radio-controlled car. The behaviour of the normal version is satisfactory (Fig. 13). The reinforced

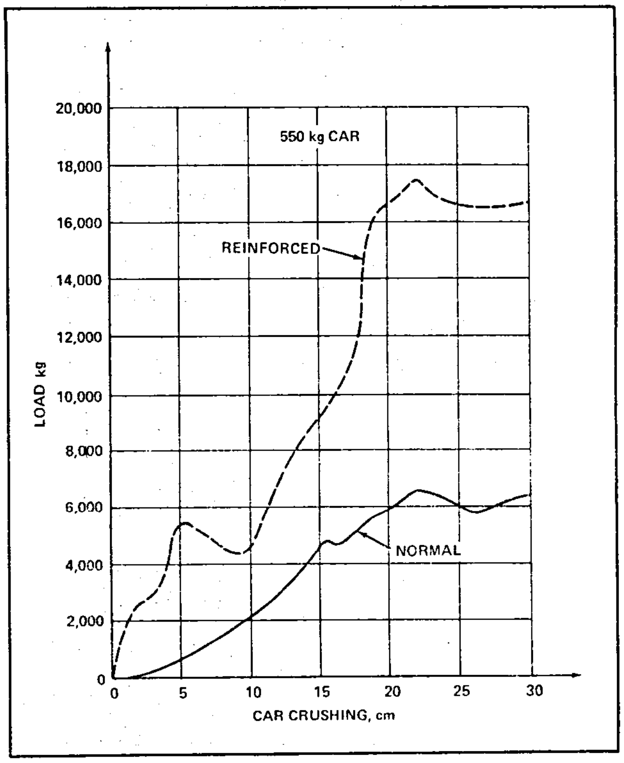
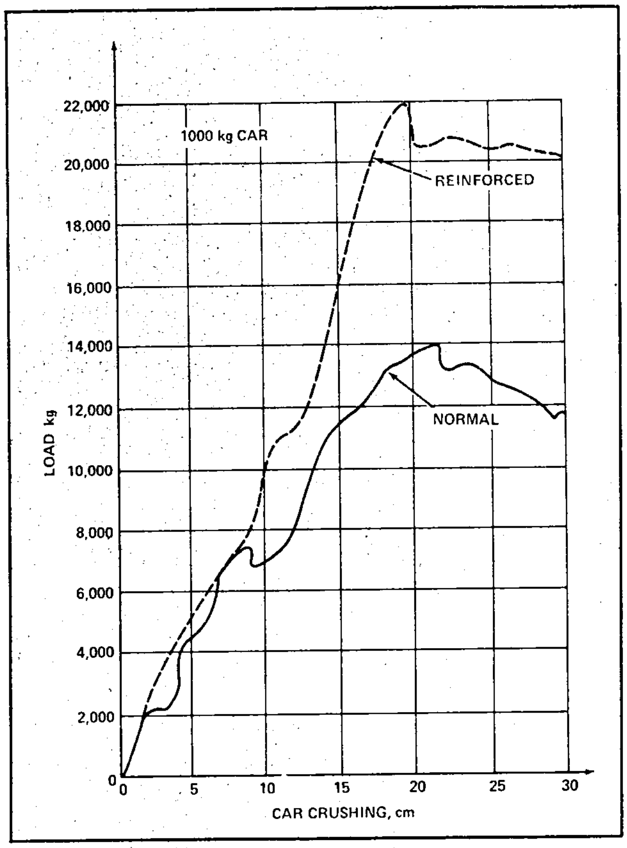


Figure 7



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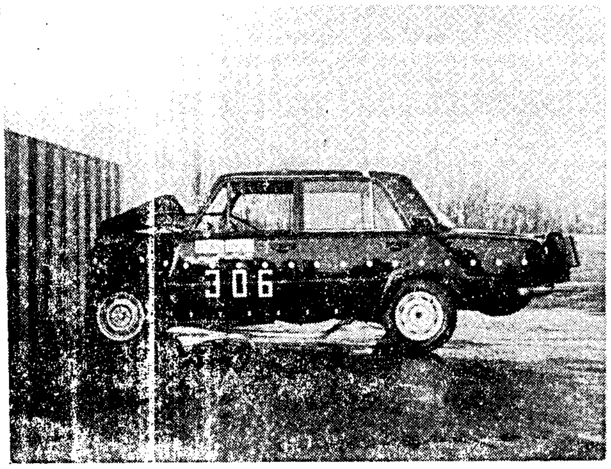

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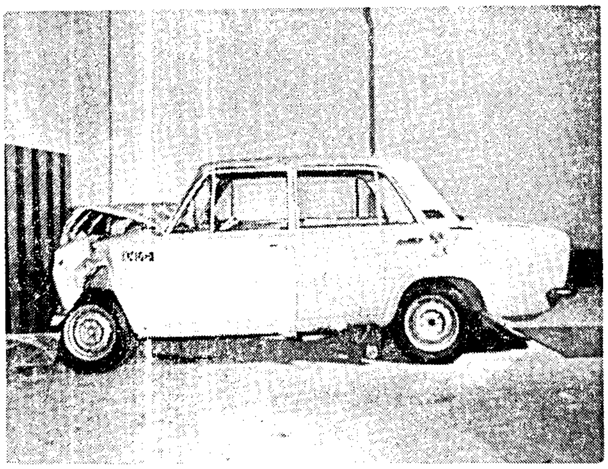


Figure 10

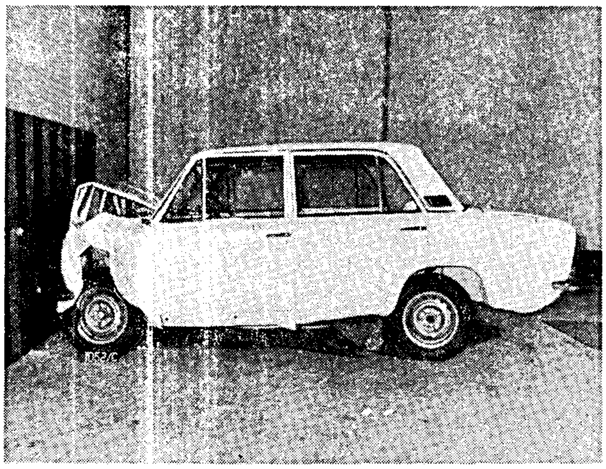


Figure11

Figure 12

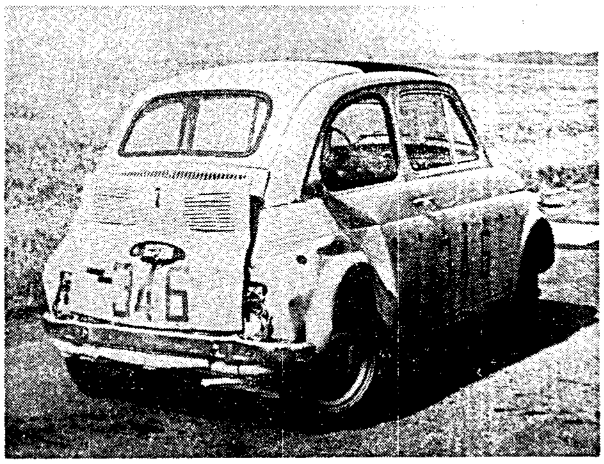


Figure 13

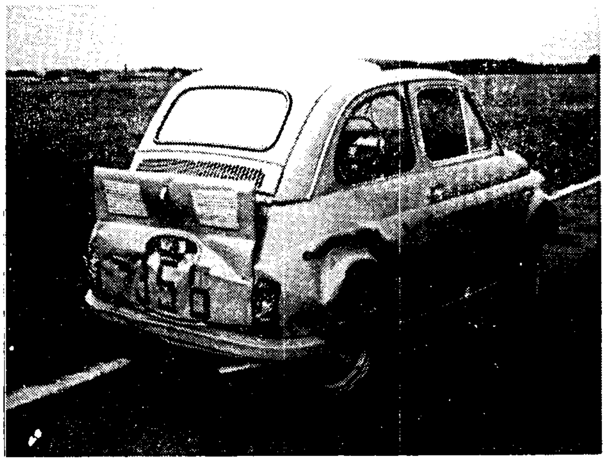


Figure 14

version has been impacted at 40 mph (Fig. 14) and, after further reinforcement, at 50 mph (Fig. 15), with consequent crushing almost equal to that incurred by the normal version impacted at 30 mph.

It is interesting to note that, from the viewpoint of test methodology, similar crushing values have been obtained not only during static testing with a press (Fig. 16), but also in the course of dynamic tests with a pendulum (Fig. 17), that we use currently in particular for side impact testing. The different degrees of deformation for the various cars are merely due to the different energy levels obtained in the cases in question.

Figure 15

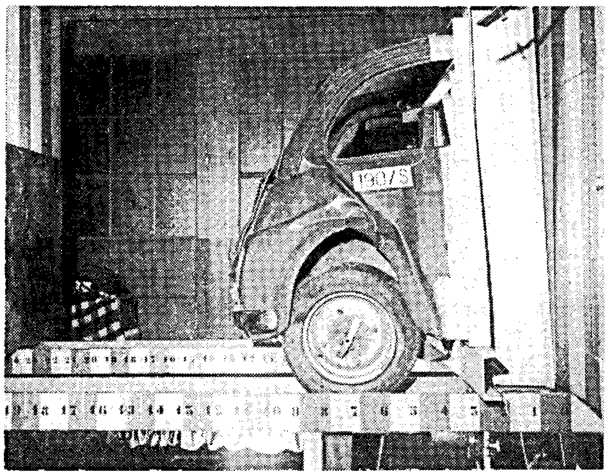


Figure 16

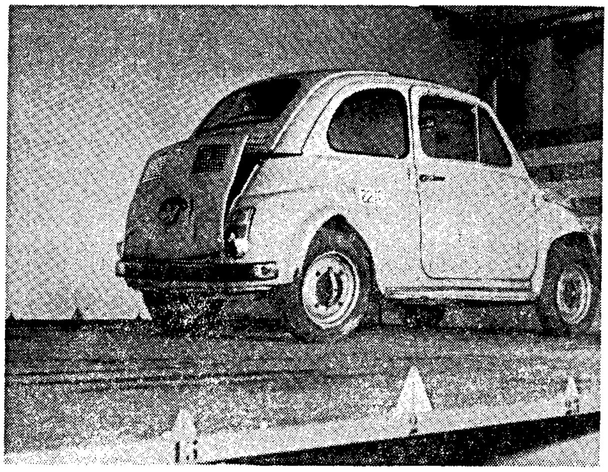


Figure 17

Side Impact

The normal version 2,200 lb. car, stationary and in a crosswise position (Fig. 18) has been side impacted at right angle by a car of the same type radio-controlled at 20 mph. The resulting side intrusion (Fig. 19) has been reproduced (Fig. 20) with an extra-long arm pendulum test (Fig. 21), featuring mass (Fig. 22), frontal size and speed equal to those of the impacting car. Compared with the outdoor test, this indoor procedure not only obviates to the inconveniences caused by adverse weather conditions, but also requires simpler equipment, involves easily computable energy and yeilds highly reproducible results.

Figure 18

Figure 19

The normal version 1,200 lb. car was catapulted against a pole at 15 mph (Fig. 23), the results of which are here illustrated (Fig. 24). The addition of localised reinforcements, in order not to alter the architecture and, therefore, the max bodyshell cross section, has not brought significant advantages. It would seem that this type of test is excessively severe.

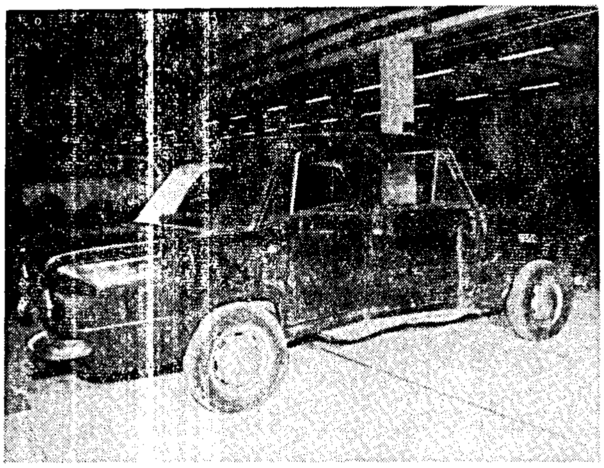


Figure 20

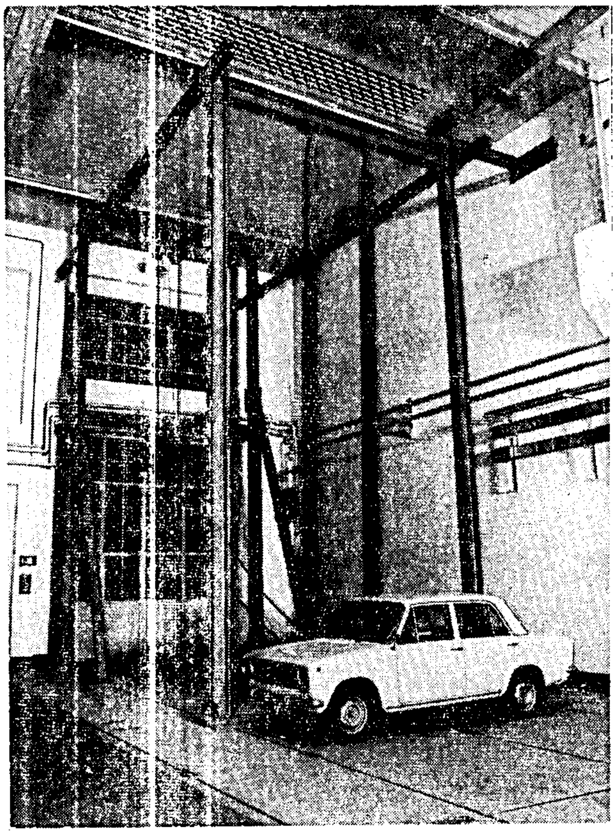


Figure 21

Rollover

The poor reproducibility of rollover tests whether by the ramps or abrupt off-steer method on radio-controlled cars, is a well known fact. In a simplified simulation of the rollover test, the pendulum may well be used.

An example is a roof panel impact test (Fig. 25) on a car secured with one side down and struck by a pendulum having a wider area than the roof (Figs. 26 and 27). A similar test may also be conducted under static conditions (Fig. 28) and in this test, again as before, the load may be applied perpendicularly (Fig. 29) or at an angle (Figs. 30 and 31) to the roof panel.

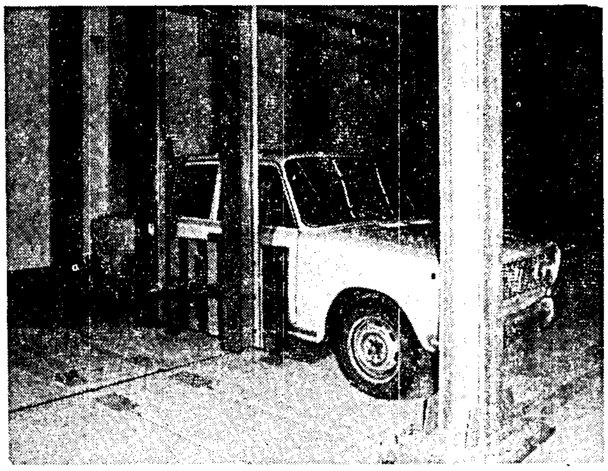
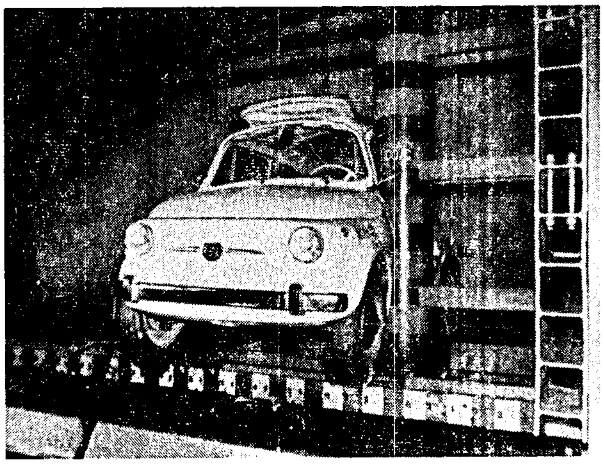


Figure 22



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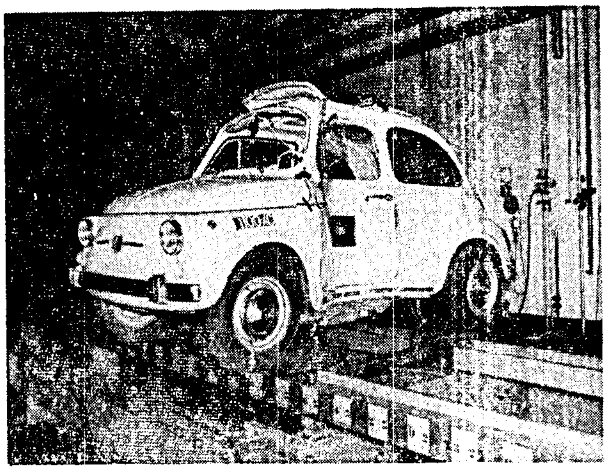

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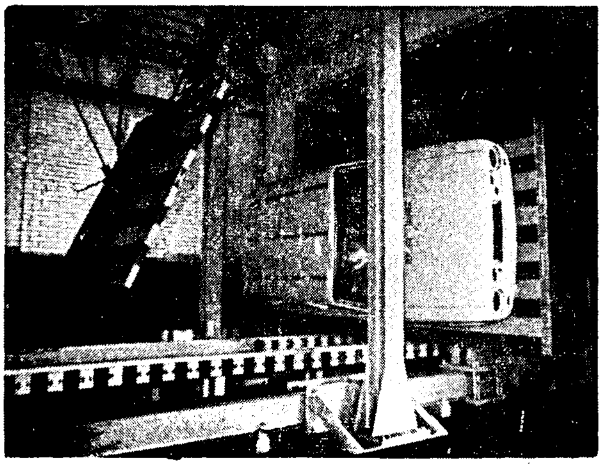

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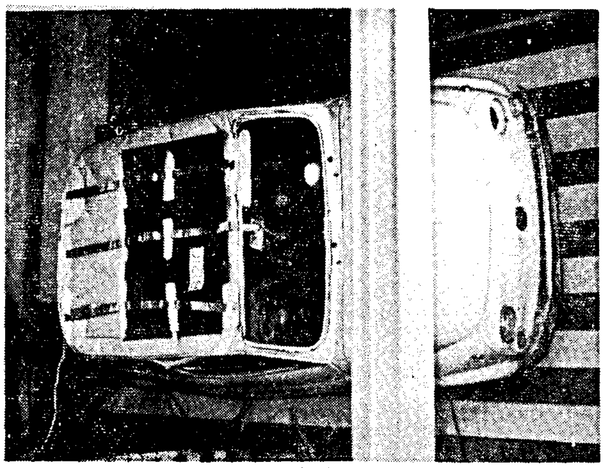

Figure 27

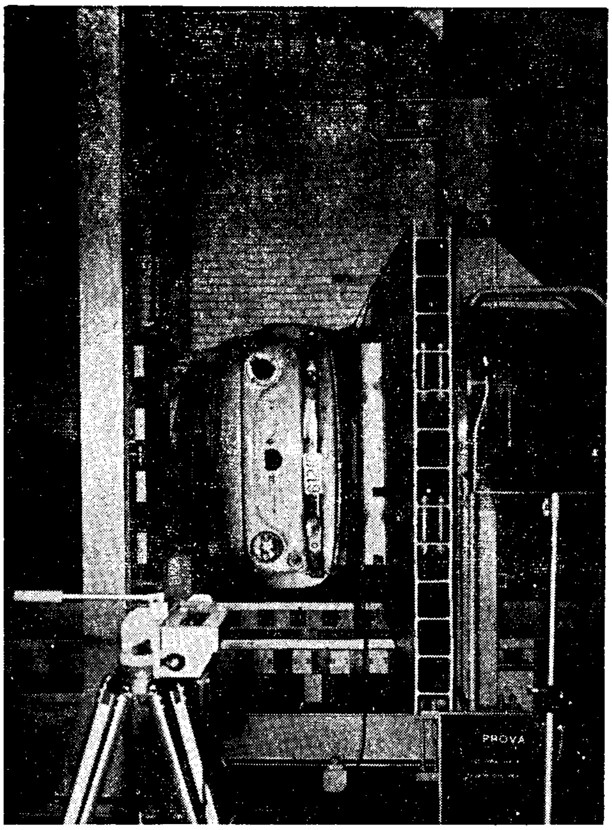

Figure 26

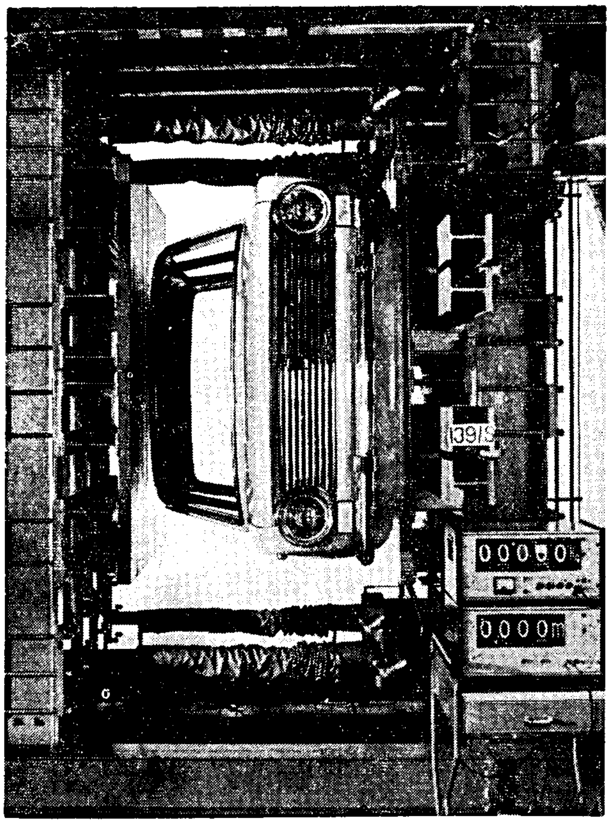

Figure 28

Such testing methods are both simple and reproducible. We are adding some information obtained during the development of the research program on *bumpers*.

The ESV is required to withstand impacts of up to 10 mph without body damage. Front-end barrier collision tests were run on the 1,800 lb. car, with standard bumpers, at increasingly higher speeds of 3 mph (Fig. 32), 6 mph (Fig. 33), and 10 mph (Fig. 34). While at 3 mph the body damage is practically nil, as impact velocity is increased they become evident on forebody front-end, even though all the lighting and signalling devices are still intact.

Experiments were made with a pneumatic bumper (Fig. 35) – on which a separate report will be made by Mr. Sapper – consisting of an air cushion inflated to 4 atm with compressed air, and provided with inertial device which, upon reaching a pre-set deceleration of 5g, triggers the opening of exhausts for the compressed air.

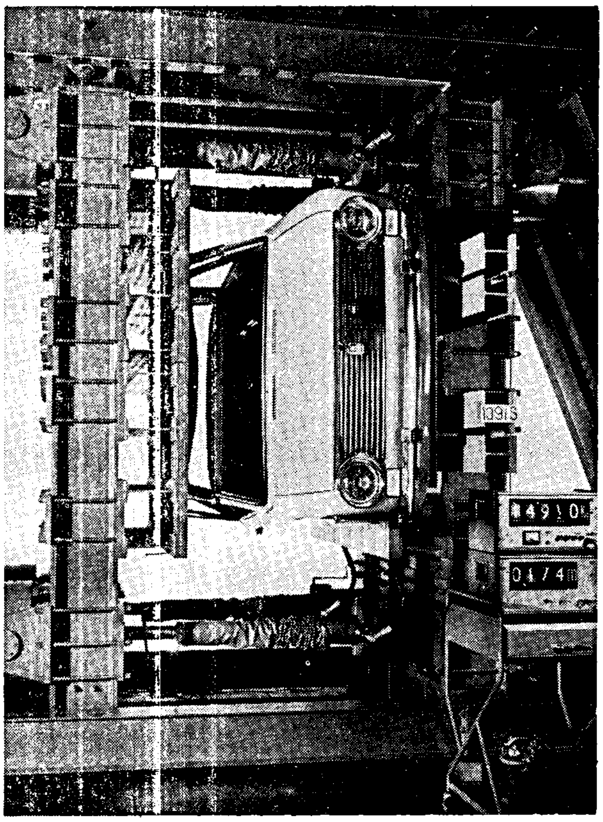

Figure 29

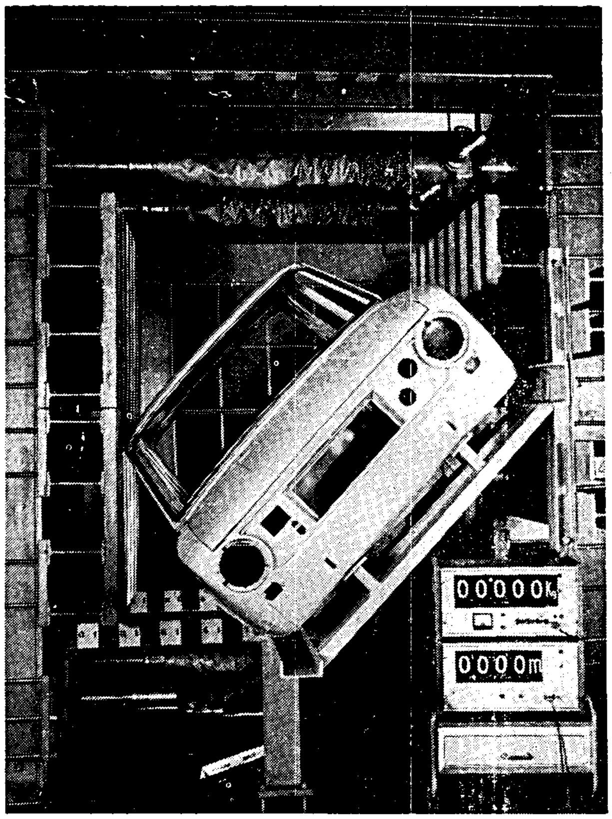

Figure 30

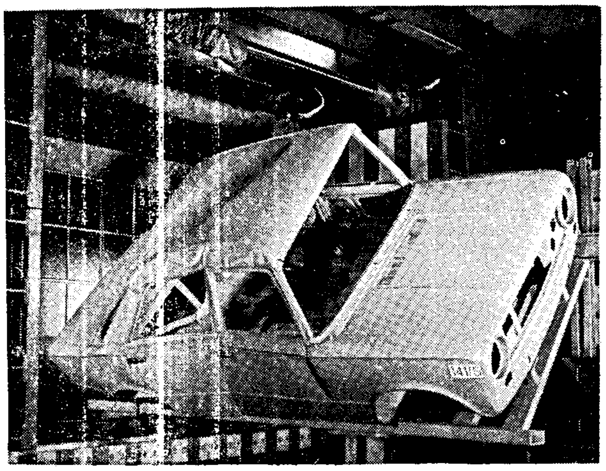

Figure 31

Figure 32

Earlier tests against barrier were repeated and (Fig. 36) no damage to body was found up to 10 mph.

Another series of tests was conducted with pole impact; with the standard bumper car (Fig. 37), again the body damage increased (Fig. 38) as impact speed was increased (Fig. 39), while with the pneumatic bumper car (Fig. 40) no damage was found (Fig. 41) up to 10 mph (Figs. 42 and 43). Tests are in course, using different inflation pressures and inertial device settings.

As regards the bumper problem we are against the proposed imposition of deceleration values to be measured on the structure not only because of the reasons mentioned earlier but also for the fact that it prompts the adoption of bumpers protruding noticeably from the front-end, thus making the car highly aggressive for pedestrians.

In fact, note (Fig. 44) how first contact between the front-end of a normal car and the dummy, simulating a

Figure 33

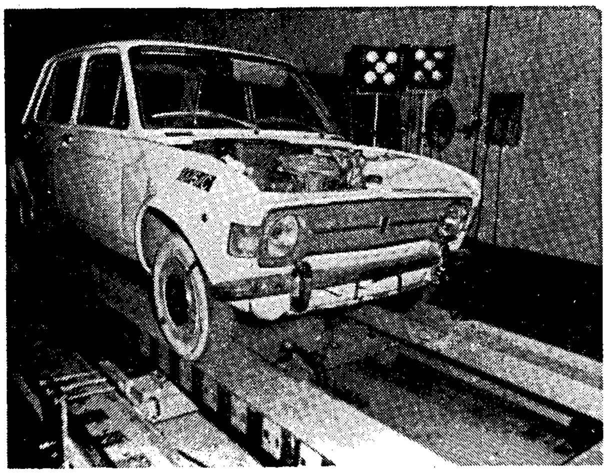

Figure 34

Figure 35

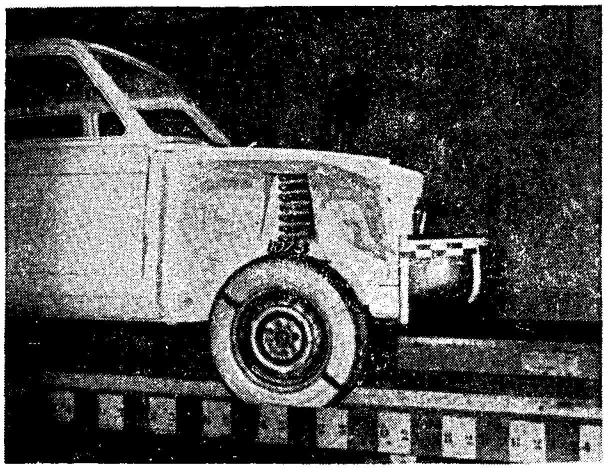

Figure 36

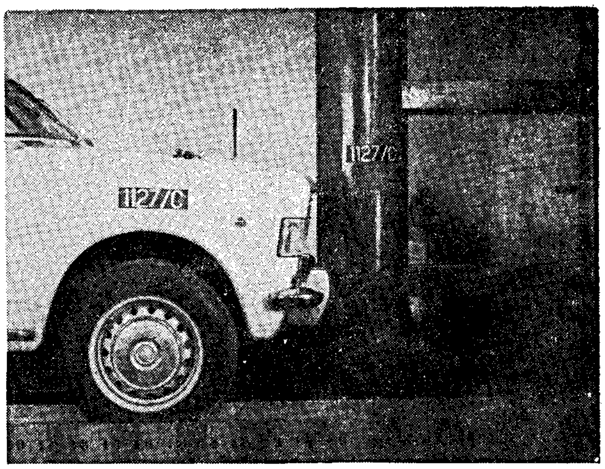

Figure 37

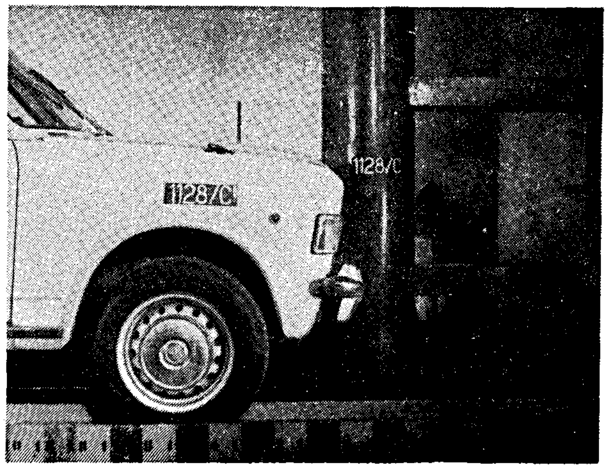

Figure 38

Figure 39

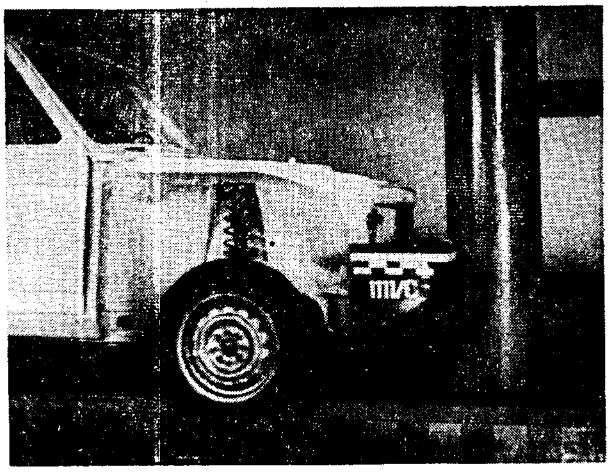

Figure 40

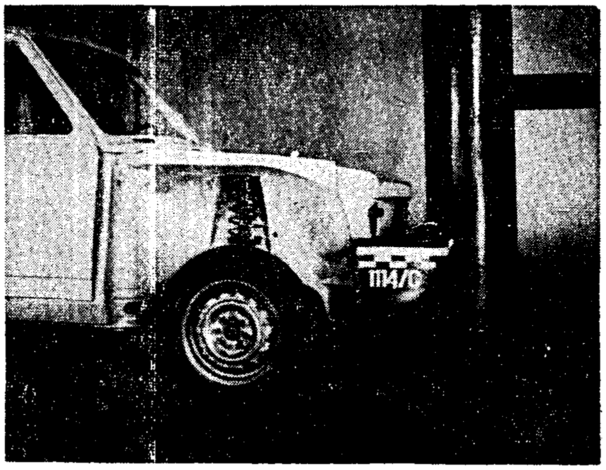

Figure 41

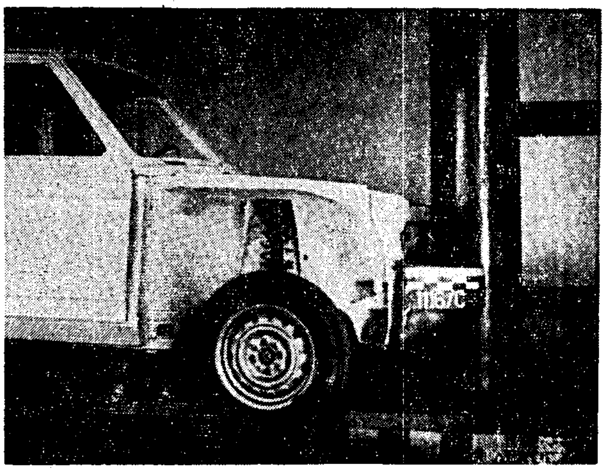

Figure 42

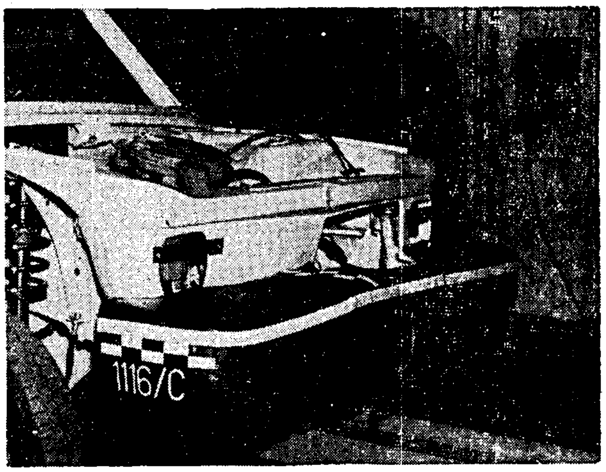

Figure 43

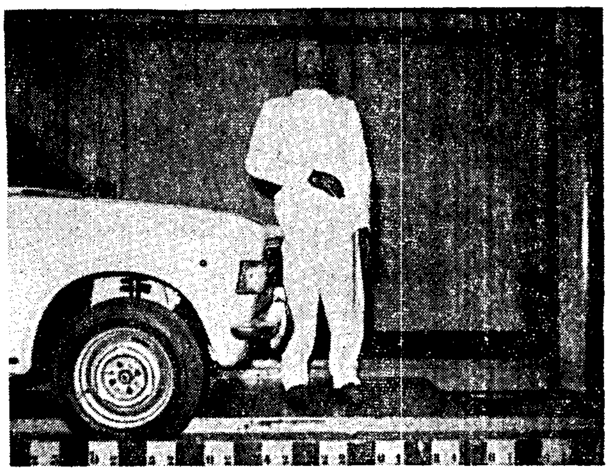

Figure 44

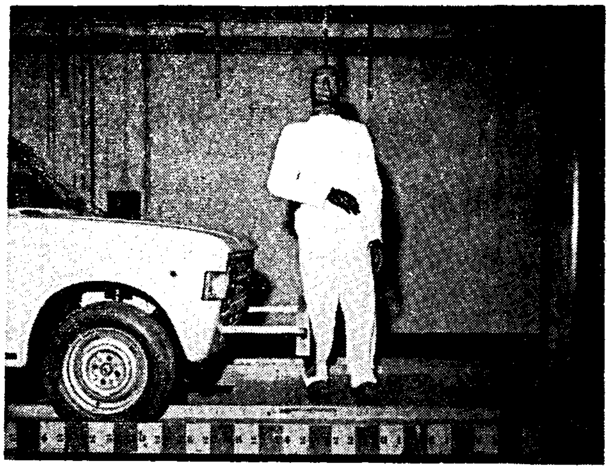

Figure 45

pedestrian, occurs at two different heights above ground – bumper and hood edge – that is, with loads distributed in two areas of the leg. The standard 215 already requires that the bumper must protrude so that no contact whatsoever shall take place with the pendulum top block, which means that the body fore-section must be located noticeably backward in relation to the bumper. The ESV requirements impose an even more marked protrusion of the bumper and in this case (Fig. 45) the first contact with the dummy occurs at bumper level only, hence, with load concentrated on only one spot of the leg. It seems to us that a higher safety level for car occupants should not be achieved at the expense of the pedestrian being run over by a "safe" car.

CONSEQUENCES ON THE DESIGN OF AN ECONOMY CAR

Dr. Ing. G. Puleo, Fiat

The results you have been shown, recorded from the tests run by our Safety Laboratory on a series of suitably modified cars, seem to support a rather optimistic view on the actual possibilities of solving one of the basic problems arising particularly in the design of a safe car belonging to the weight class of about 1,200 pounds. Namely, the problem of providing the vehicle structure with those features which are essential to ensure, through suitable restraining devices, the survival of occupants in the different types of collisions likely to occur on the road.

However, before drawing hasty conclusions, it would be well to proceed with a critical analysis not so much of the results but, rather, of the means used to obtain the results and in the light of the assumptions and aims of the investigation in question.

The fundamental objective which Fiat purports to reach on completion of the specific research and test program on collision behavior is the acquirement of all the informative elements needed to provide positive answers to the following questions:

1. What is the highest safety level thought to be reasonably attainable for a car having the characteristics typical of those in the class considered here?
2. What technical provisions are necessary to reach said maximum safety level and lower levels.
3. What cost increases are involved by each of the different safety levels considered.
4. What is the limit beyond which the joint safety and cost levels become practically incompatible with the class of car considered?

As is readily apparent, the search for possible solutions to the numerous safety problems is in our case not a matter of purely theoretical approaches, but is conducted with the specific aim of ascertaining the real limits of the improvements obtainable. The possible provisions and means intended for vehicle safety improvements cannot in fact be conceived without due consideration of the basic technical, economical and commercial requirements of mass production at industrial levels.

For this reason, after having concluded the first stage of our research work with extremely positive results – from a strictly technical angle – it seems we have now come to the point where the first economical facts must be faced. That is to say, in line with the aims of our program, we wish to proceed with a preliminary verification of the true validity of the technical solutions tested and try to convert into cost terms the direct and indirect consequences of the possible adoption of said solutions in the realisation of a hypothetical car as a future substitute for the present model being investigated. In drawing this preliminary cost account we shall limit our considerations to the influence on car cost exerted only by the provisions aimed at ensuring the passive safety primary requisite, namely, the "occupants' survival space."

The comparative table in Figure 1 shows, for the vehicle outfits relevant to the different front- and rear-end impact velocity levels, the weight increases ascribable to the new elements fitted additionally onto the original structure. Also given in the same table are the presumable weight increases resulting from the satisfaction of the side and rollover impact safety requirements, these being types of collisions on which a research and test program is now in course at our plant. Taking into account the latter requirements, and with reference to the outfit prepared for the 50 mph impact

GROUP	WEIGHT INCREASE		COST INCREASE	
	kg	lb	lire	$
BODYWORK	110	242	115'000	188
ENGINE	5	11		
POWER TRAIN	7	15,4		
SUSPENSION	9	19,8	65'000	107
STEERING	3	6,6		
TYRES AND WHEELS	10	22		
BRAKES	6	13,2		
TOTAL	150	330	180'000	295

CAR OF THE NOMINAL CLASS OF 550 KG (1,200 LB) - EXPECTED WEIGHT AND COST INCREASE TO MEET SAFETY REQUIREMENTS FOR SURVIVAL SPACE

Figure 1

velocity tests, the total weight increase estimated for body structural reinforcements alone amounts to about 240 pounds which raises the 1150 lb. curb weight of the present car to about 1390 lbs. and the gross weight from 1860 to 2100 lbs. Now, it is all too evident that a weight increase of this order – that is, approximately 21% and 13% over the curb and gross weights, respectively – cannot but deeply modify the delicate conditions of balance existing between the different technical, economical and commercial features of the original car, especially when the attainment of said balance, as is the case of the model being considered, has called for the solution of exceptional design difficulties.

Let's examine in detail the practical consequences that said weight increase would originate in the new project, starting firstly with the modifications that would have to be introduced in the mechanics of the car.

- Increased engine displacement, from present 500 cc to about 650 cc, and power, from 18 to about 23 HP (DIN), to retain the same performance of the original car (top speed, pick up and gradeability).
- Re-design of power train components (clutch, transmission, final drive bevel gear and differential, axle shafts and joints) to cope with increased engine torque and load on ground.
- Stronger suspension components (swinging arms, springs, shock absorbers, wheel hubs and bearings) as a result of increased axle loading.
- Stronger steering gear components because of increased load on front axle.
- Higher tire and rim loading capacity, with consequent larger size, 125-12 to 135-13 and 3½-12 to 4-13, respectively.
- More effective braking power, by adequately increased size of brakes on wheels, as a result of higher vehicle gross weight.

But the consequences of the practical introduction of the foregoing structural improvements would not be confined to vehicle mechanics alone. In fact, the obtainment of truly acceptable results as regards passenger compartment protection would inevitably involve the introduction of the new structural elements we have tested in a body outline having larger dimensions than the body of the original car. Figure 2 compares the

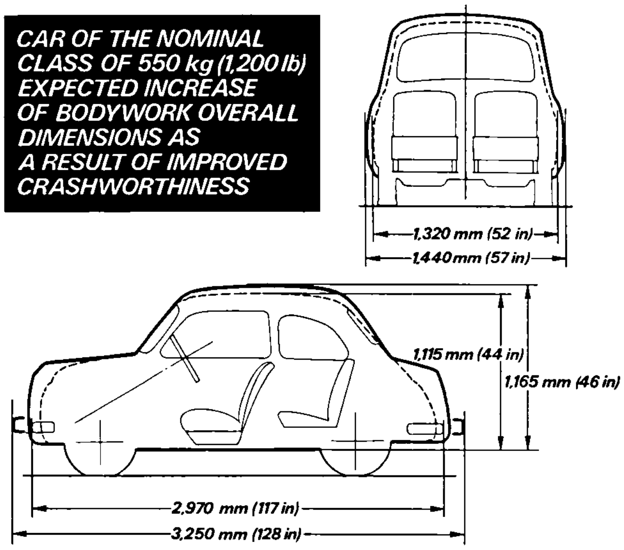

Figure 2

probable dimensional configuration of this hypothetical new car with the current 500 Sedan configuration.

The summary table in Figure 3, instead, gives for each one of the modifications examined the corresponding weight and cost increases, the latter being already converted into customer costs.

The final outcome of the entire operation would eventually be:

- About 20% larger car bulk surface area.
- About 330 lbs. added weight, i.e., 29% of curb weight.
- About $295 sales price increase, i.e., 31% of the initial price.

But the item in the red which is not considered above and which to us seems more important than the indicated items, is the fact that in reality the car so redesigned would no longer offer any of the features consistent with the class to which it is supposed to belong.

In other words, no valid reasons would be left to justify its existence, unless it is subjected to a more

TYPE OF COLLISION	SPEED		WEIGHT	
	kph	mph	kg	lb
HEAD-ON COLLISION	48 64 80	30 40 50	- 20 45	- 44 99
REAR COLLISION	48 64 80	30 40 50	- 15 30	- 33 66
SIDE COLLISION	24	15	20	44
ROLL-OVER	96	60	15	33

CAR OF THE NOMINAL CLASS OF 550 KG (1,200 LB) EXPECTED WEIGHT INCREASE TO IMPROVE CRASHWORTHINESS

Figure 3

radical upgrading revision so that it may more properly belong to the next higher class into which it has inevitably trespassed.

The above percentage increases in overall bulk, weight and cost estimated for this hypothetical new car still represent, in our view, the maximum limit beyond which it would not seem logical to go for the sake of offering occupants the only benefit of "survival space."

Much severer consequences on car design – body length in particular – would have to be expected, however, in case the "survival space" requirement were to be met in the respect of possible restrictive conditions for passenger compartment decelerations at different impact velocities. This is a problem that was ignored during the first stage of our research work as it will be the theme of a future test cycle.

From the foregoing, the conclusions that can be drawn are extremely pessimistic with regard to the possibility of building in the future a safe car having such features as to remain within the economy class so far considered.

One thing is certan: if some day the small economy car were sacrificed, millions of potential motorists belonging to the low-income bracket would be unjustly deprived of the possibility of using a means of transportation which, perhaps more than any other, has contributed to improve the living standard of mankind. And this multitude of disappointed would-be motorists would then have no other choice but go back to other less costly means of transportation, whose presence on the roads would inevitably lead to a revival of the safety problem and, what is worse, in even more dramatic terms than at present.

Even though the mass production of cars capable of meeting the safety requirements laid down for the ESVs at present appears to be far from forthcoming, our research work is continued with sincerity of purpose and with confidence in the fact that the work done will soon yield its first fruits. The cars we will produce in coming years will surely already benefit from the partial findings that will be accomplished from time to time and that the state-of-the-art will allow to transform into industrially feasible constructional provisions.

We are aware that the road to safety is long and rough; it will certainly not be possible to come to its end in just one non-stop lap and at every fork on the way it will not be easy to choose the right direction.

One thing is sure: come what may, we shall go all the way to destination.

ANALYSIS OF STATISTICAL DATA ON ROAD ACCIDENTS IN ITALY 1969-1970

Mr. Alfredo Margara, Fiat

From the report made previously by Mr. Puleo we have seen that safety may affect the weight, size and costs of a small car to such an extent as to change its nature.

It is a serious problem which, if not suitably solved, would create a series of new problems; social and economic in particular.

It is therefore right that the study of any solution be conducted on the grounds of an accurate analysis of the motor vehicle safety situation in the complex framework of road traffic.

In the course of the "Multidisciplinary Road Accident Investigation Conference" held by NATO-CCMS on July 1-2, 1971 in Turin, Fiat had submitted an investigation on the degree of dangerousness of cars during road accidents in Italy. The conclusions were quite surprising as it was found that, during an accident, the dangerousness of a small car was not greater than for a larger class car.

We are going back to those investigations to let you know some data which we think worth considering.

The data was obtained from the official statistical information published by the Italian State Central Institute of Statistics.

To this end we have plotted a series of histograms showing the death figures provided by the Central Institute of Statistics for the various classes of cars involved in accidents on the Italian roads.

The death figures are related both to the cars on the road and to the kilometers covered.

Figure 1 shows, for the years 1969 and 1970:

- The total number of deaths in road accidents.
- The number of deaths in accidents involving at least one motor vehicle.
- The number of deaths in accidents involving at least one car.

		1969	1970
	TOTALS	NO. 9891	NO. 10208
DEATHS IN ACCIDENTS INVOLVING AT LEAST ONE MOTOR VEHICLE		NO. 8809	NO. 9137
DEATHS IN ACCIDENTS INVOLVING AT LEAST ONE PASSENGER CAR		NO. 7422	NO. 7771

Figure 1

In Figure 2 is illustrated how the Central Institute of Statistics has split up the total cars on the Italian roads. There are five classes – A, B, C, D, and E – each referring to a given engine displacement group.

CLASS	DISPLACEMENT cm^3
A	< 750
B	750 ⟶ 1000
C	1000 ⟶ 1300
D	1300 ⟶ 1500
E	>1500

Figure 2

Histogram in Figure 3 shows the total cars on the road in 1969 and 1970, and the relevant subdivision into the five classes illustrated in Figure 2. For 1970, also the percentages of cars in the various classes have been indicated.

The division in engine displacement classes nearly corresponds to the weight and size class split-up.

In the following histograms we have indicated the number of deaths – recorded in the accidents involving at least one car – divided according to car class. For a detailed investigation we have again divided the number of deaths in two separate histograms:

- Number of deaths inside cars, namely occupants in the cars of that class, involved in the accidents.
- Number of deaths outside cars (third parties), i.e., occupants of other vehicles involved in the accident, pedestrians, cyclists, motorcyclists or any other road user.

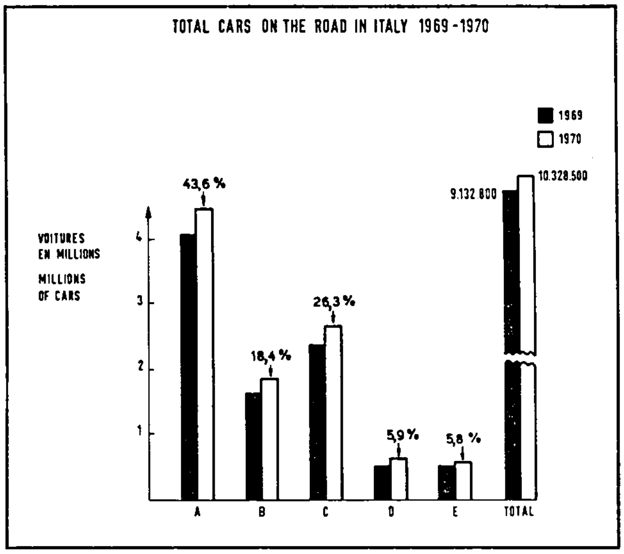

Figure 3

In the next three histograms of Figure 4, the number of deaths is related to the number of cars on the road and is referred to 1,000 cars of each class on the road.

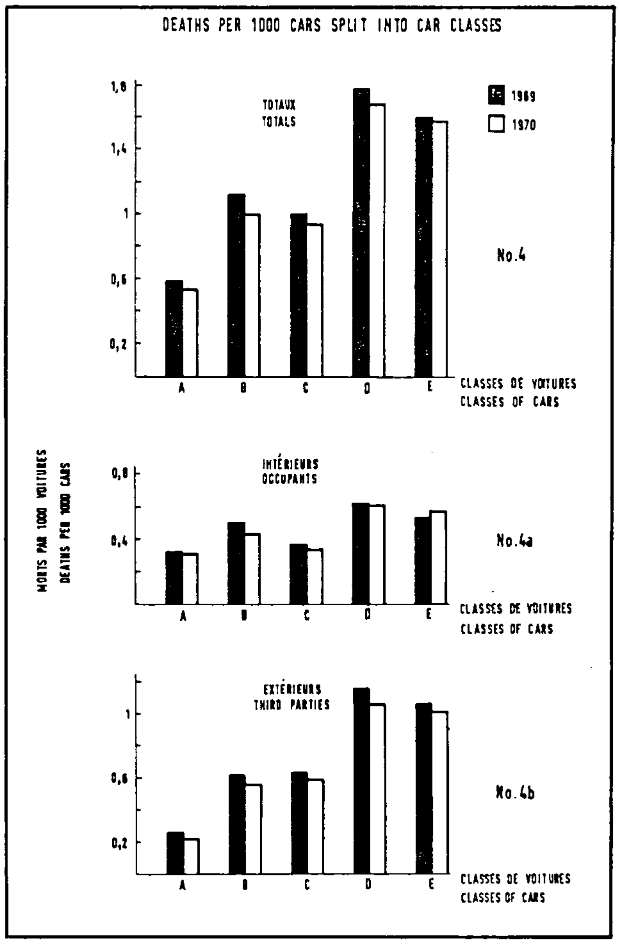

Figure 4

Histogram 4a covers deaths of car occupants.

The histogram shows the trend to a lower number of deaths in small cars.

Finally histogram 4b gives the number of deaths outside cars (third parties).

The trend towards a lower number of deaths in small cars, for this type of selection, is very strong.

Figure 4 does not, alone, give a clear picture of the situation in that kilometers covered are not kept into account. We have therefore thought it more significant to relate the number of deaths to the kilometers covered yearly by the cars in each class rather than to the total number of the cars on the road.

Figure 5 gives the average of the kilometers covered. These figures have not been provided by the Italian Central Institute of Statistics but are the result of Fiat investigations.

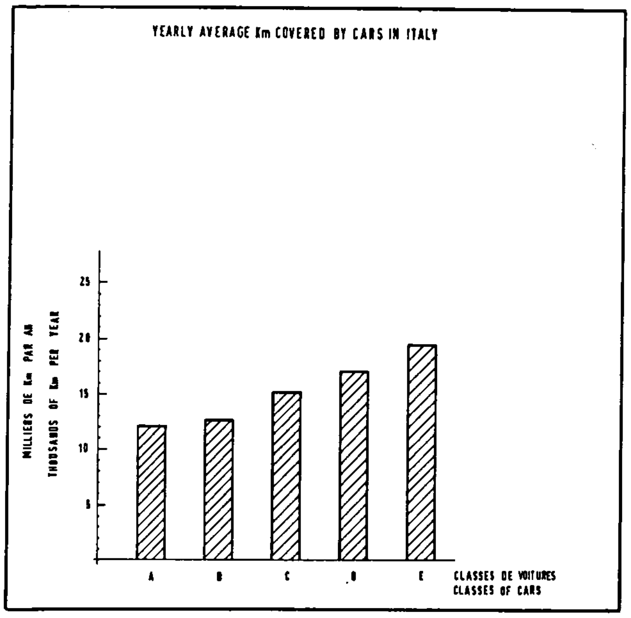

Figure 5

In Figure 6 histogram 6 indicates the distribution of deaths in each class versus the number of kilometers run. In this and in the following histograms is shown the number of deaths per 100 million kilometers covered.

Histogram 6a gives the number of car occupant deaths.

The sub-division of deaths outside cars are shown in histogram 6b.

Histograms in Figure 6 also show an average increase in car casualties as engine displacement increases.

In particular, histogram 6b on third party deaths shows that small class A cars cause less deaths than any other class of cars.

At this point it may be of interest to analyze third party deaths caused by cars in the various classes,

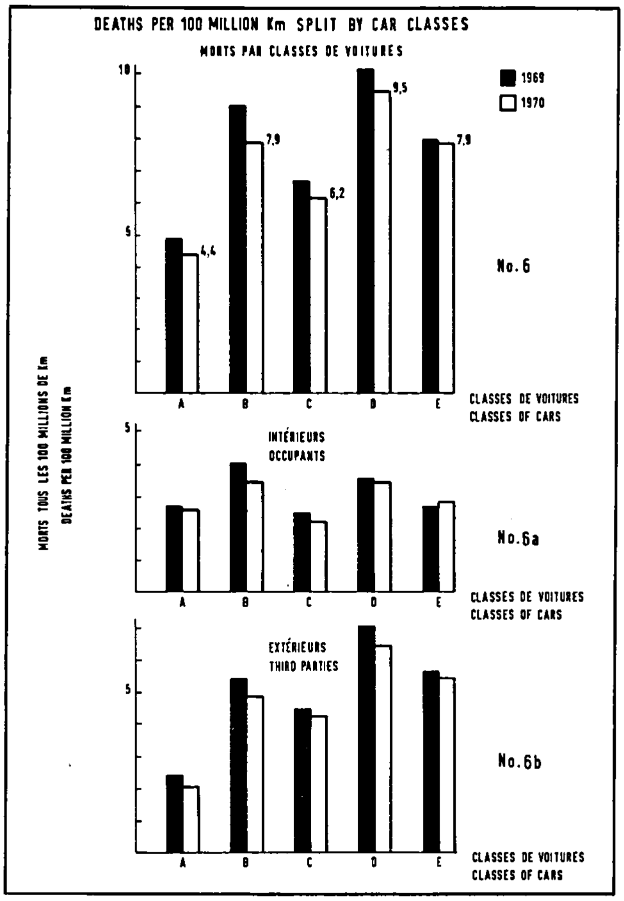

Figure 6

divided as follows: pedestrians, riders of motorcycles, mopeds, bicycles, wagons and other users, among whom are included also the occupants of other cars involved in the accident.

Figure 7 illustrates the deathly consequences for third parties in accidents against cars in the various classes. Class A cars are less dangerous than cars in the higher class to pedestrians, cyclists and motorcyclists and cause very few casualties in the cars against which they crash.

One objection to this could be that the cars with larger engine displacements are responsible for a proportionally higher number of deaths because they usually travel at higher speeds.

Let's then analyze the urban area traffic factor and examine the case history of casualties occurring in traffic conditions at a speed as uniform as possible; in Italian cities the maximum speed limit is 50 km/h.

The investigation method relating the number of deaths to every 100 million km covered by cars in the different classes cannot however be applied to distances travelled in town where, evidently, the distances totalled do not increase proportionally to the class of cars.

We have therefore prepared histogram 8 where, neglecting the average distances covered, the number of

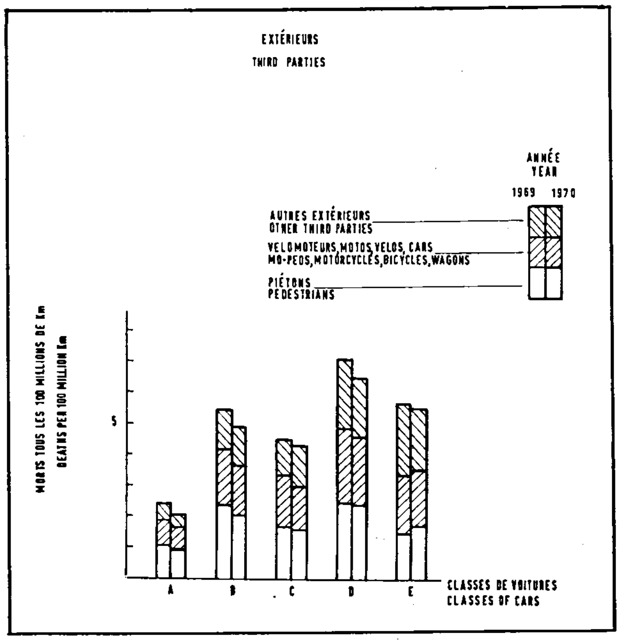

Figure 7

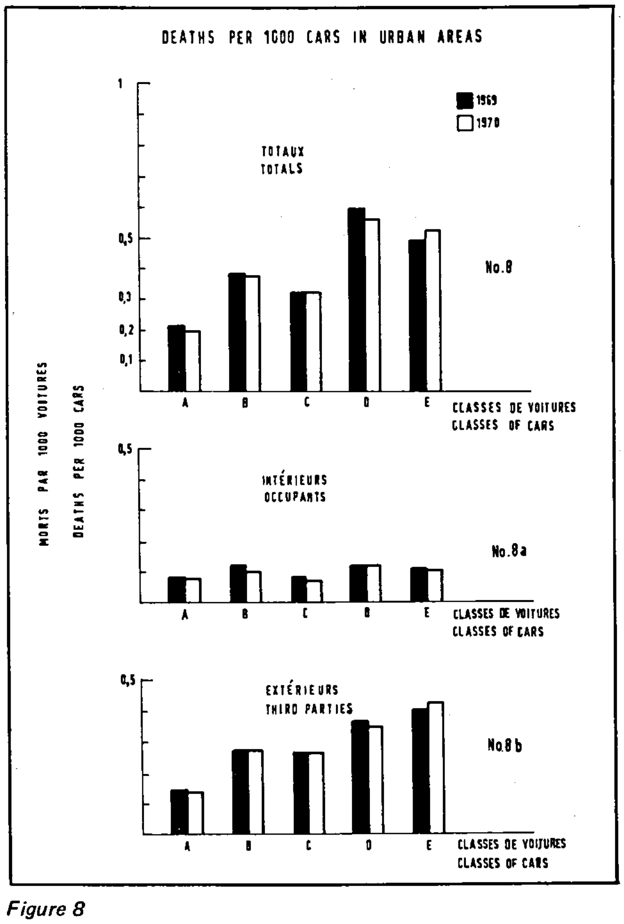

Figure 8

deaths is related to the number of cars on the road. Here again, statistical data is dealt with separately: the number of car occupant deaths in 8a shows an almost level pattern and the number of third party deaths in 8b once more evidences the low dangerousness of the small class A cars.

This chart clearly proves that the large size cars are responsible for a larger number of deaths though it is quite right to presume that in town they circulate less than the smaller cars.

However, data of Figure 9 provide the most convincing evidence. For each 1,000 cars of class A on the road, the number of casualties in accidents in urban areas and on open roads, involving small cars of this class, corresponds to the deaths caused by large cars (classes D and E) in urban areas alone.

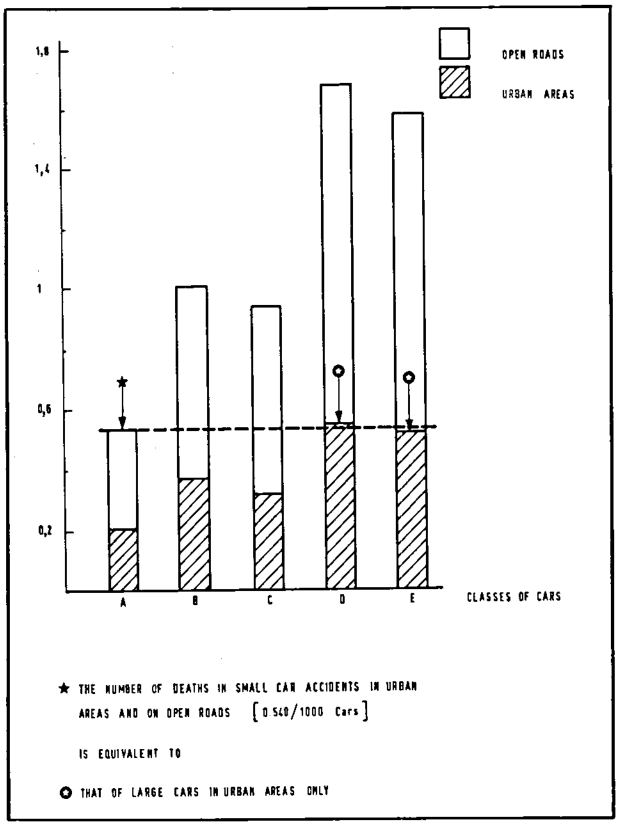

Figure 9

All the histograms we have so far examined prove that the mass of the car – which supposedly is the fundamental factor in passive safety – does not play a determinant role even when the case history of car occupant deaths is taken into consideration. It is then inevitable to admit that there must be other factors, belonging evidently to active safety, that exert a much more incisive influence also on the picture of car occupant deaths.

Our feeling is that it is hardly possible to deny that the ease-of-handling and limited bulk of small cars represent a determinant factor in accident avoidance and, consequently, that their influence on active safety is much stronger than the influence which a large mass may have on passive safety.

All these factors contribute to give small cars a low death rate and cannot be transferred to large cars.

We wish to end with some considerations. Total deaths in accidents on the Italian roads in 1970 were 10,208. Of these, as many as 1,071 were due to accidents in which motor vehicles were not involved.

It is clear that no ESV or subsystem safety improvement would have contributed a pennyworth in the avoidance of these 1,071 casualties which account for 10% of the road victims total.

One more piece of information. Of 7,771 deaths in accidents involving cars, as many as 3,802 deaths, namely 50% of the total, were represented by pedestrians, motorcyclists, cyclists or other road users less protected than the occupants of a car. Passive safety as a whole will in no way lower this high percentage.

On the contrary, there is the risk that by making a driver feel safer in his "armour" he may be led, perhaps unconsciously, to be more reckless, with the sad, but not unlikely, result of an increase in the already heavy 50% toll which will hardly be compensated for by the reduction of deaths inside the car afforded by passive safety.

We can conclude by admitting that it may be true that the small car is more dangerous once it crashes, but undeniable data show that even in a highly diversified traffic such as in Italy, it is less dangerous than any other car.

Shall small cars therefore be banished?

Do we really want to increase the 50% death rate of the less protected third parties?

It is better to think it over.

PNEUMATIC BUMPER PROTECTION SYSTEM FOR PASSENGER CARS

Dr. Richard Sapper, Fiat-Pirelli Consultant

This project, conducted as a joint effort with Pirelli and Fiat, aims at the reduction of the consequences of low speed collisions.

Among the new utilizable systems of energy-absorbing bumpers we examined the features of the following:

1. Elastic metal elements
2. Hydraulic systems
3. Water bumpers
4. Foam structures
5. Pneumatic elements

We have concentrated on the latter system as long earlier we had been working on a similar element surrounding the whole car to limit bodywork damage following minor impacts or swiping.

We had noticed that pneumatic elements could provide considerable car protection with negligible penalty on weight and, besides, they could be manufactured so as to ensure good abrasion resistance.

Some pilot solutions were realized and tested during the last four years and were used to study a new type of bumper – to be fitted at car front and rear – which was capable of performances similar to those required by the ESV program low speed collision specifications.

It consists essentially of three parts (see Fig. 1):

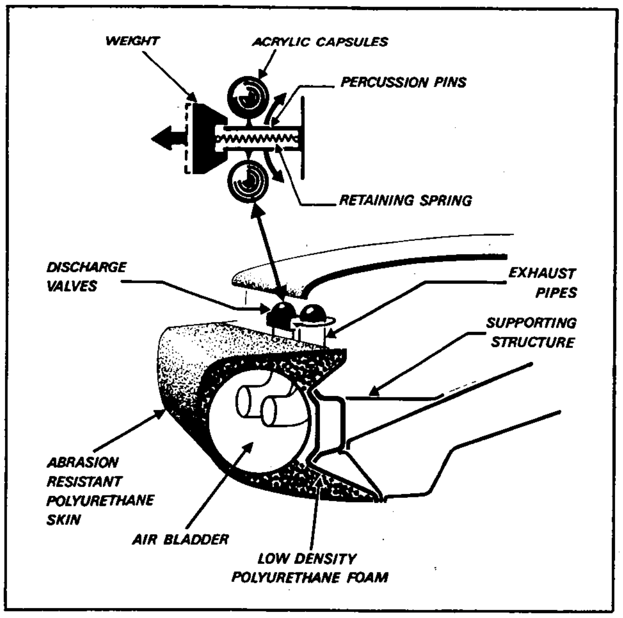

Figure 1

- A cylindrical rubber air cushion diagonally and longitudinally reinforced to make its surface inextensible. The two ends are hemispherical and provided with exhaust tubes.
- A polyurethane foam protection, lined with an abrasion resistant skin – enveloping the air cushion.
- Two exhaust tubes whose ends are connected to inertial decelerometer actuated valves. They consist of two thin diaphragms blanking the exhaust tube ends and of two percussion pins, held at a distance from the diaphragms by a hook connected to the decelerometer mass. When deceleration exceeds a pre-fixed limit, the diaphragms are perforated by the pins and air escapes from the cushions.

Design and dimensions of the elements were determined by the following specifications:

- Vehicle weight: 800 kg
- Type of collision: head on against vertical barrier

- Impact speed: 15 km/h
- Maximum tolerable deceleration: 10g
- Maximum diameter of the cushion: 200 mm

The optimum values for diameter, initial pressure, exhaust section and critical deceleration for valve opening were calculated making the following hypotheses:

- The discharge of the gas was considered without losses of any kind; whereas two different equations were used depending on the pressure ratios being higher or lower than the critical state.
- The cylindrical cushion was considered inextensible and infinitely flexible. The influence of the hemispherical ends on the behaviour of the cushion was neglected; it was considered as a cylinder with a horizontal, straight axis whereas in reality its axis is slightly curved with about 25 mm camber.
- The structure of the car was considered non-deformable during collision and deceleration was supposed to result exclusively from the pneumatic element applied forces.
- The opening of the valves and the discharge of the gas was considered instantaneous as soon as an established deceleration value was reached.

Based on these considerations, the equations simulating the vehicle motion during collision against barrier were introduced into Pirelli IBM 360/44 computer and the optimum dimensions investigated by the trial and error method.

Some results of these calculations can be seen on the following diagrams.

They show clearly how the discharge of gas through the exhaust valves lowers considerably the maximum deceleration as compared to an element without valves.

In Diagram A, which shows a collision at 15 km/h, with opening of the valves at a deceleration of 6.3 g, maximum deceleration is lowered from 23 to 9 g.

Diagram B shows the progression of deceleration during the collision versus time, with and without opening of the discharge valves.

Diagram C shows the maximal values of deceleration in function of impact speed, with and without gas discharge.

In all these diagrams, the comparison between the behaviour of the two types of pneumatic elements, with or without valves, has been made not only with equal quantities of energy, but also with the same amount of deflection of the pneumatic element; for this purpose it was necessary to establish different initial pressures: in the case of the element with valves, this initial pressure is considerably higher.

The calculations resulted in the following optimum dimensions:

- Cushion diameter: 200 mm

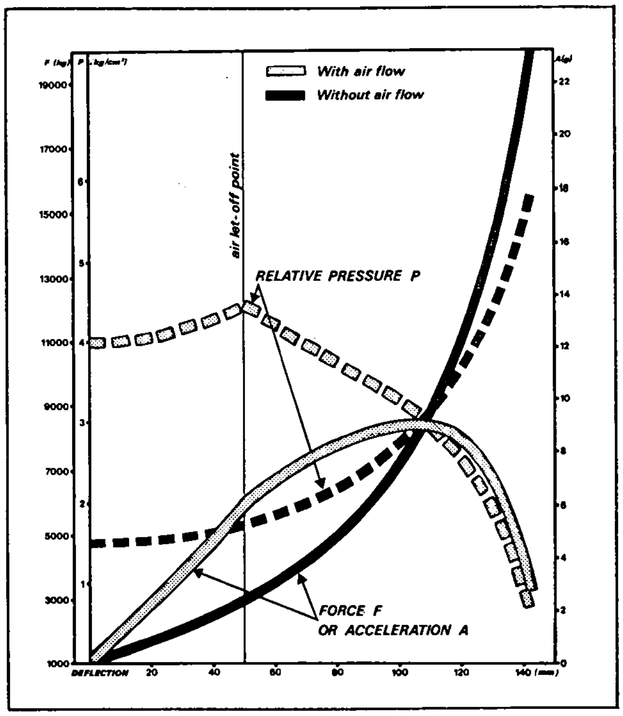

Diagram A

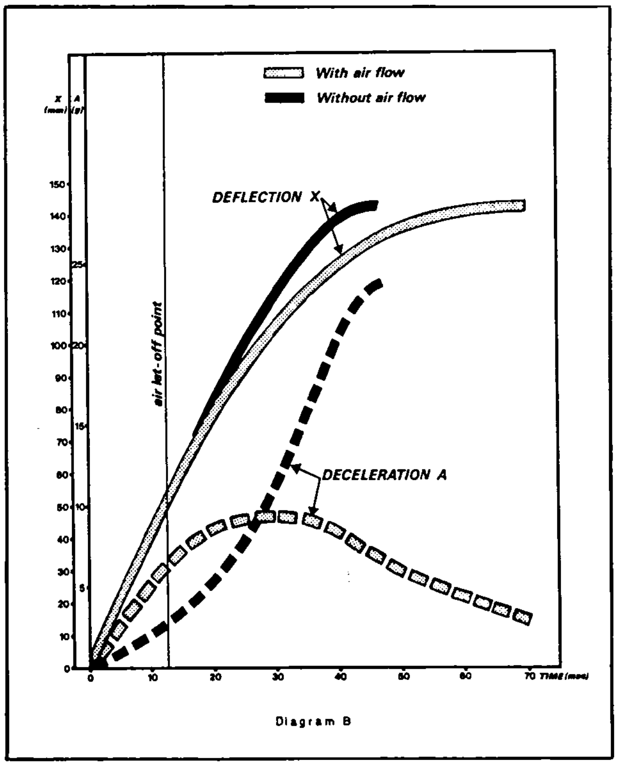

Diagram B

- Initial pressure: 4 atmopheres (gauge)
- Discharge section: 0.0048 sgm
- Critical deflection for valve opening: 50 mm – corresponding to 6.3 g

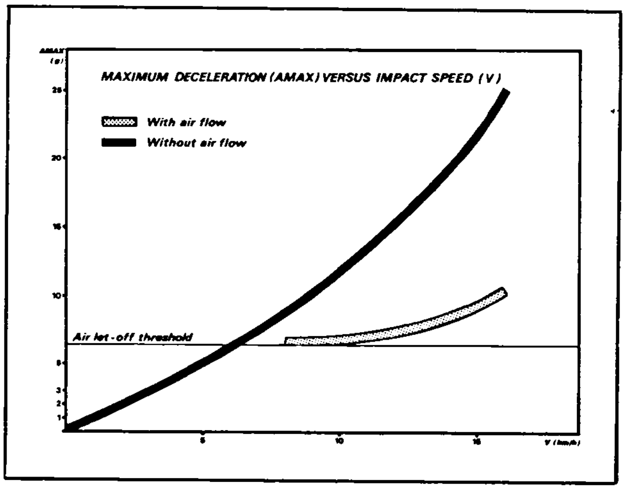

Diagram C

As a next step, a series of prototype bumpers was built and fitted to modified Fiat 128 bodies. This pneumatic bumper protection system, the test results of which have been illustrated in Mr. Franchini's report, represents the present state of the project. We are now analyzing these test results in order to go on with the development.

NOTES ON VEHICLE STABILITY PARAMETERS WITH RESPECT TO ACTIVE SAFETY

Mr. Angelo Schiepatti, Alfa-Romeo

1. Introduction.

It is well known that the optimisation of the single parameters which determine vehicle handling and stability is a difficult problem, not only because the physical laws controlling vehicle motion sometimes give difficultly foreseen results, but also (and especially) because these parameters interact in rather a complex way with each other.

However, there is no doubt that the greatest obstacle in defining a safe vehicle is the present uncertainty which surrounds the essential characteristics of such a vehicle. In turn, this is due to the fact that the dynamic behaviour of a vehicle is strongly influenced by its driver's behaviour which is still, in our opinion, not sufficiently known.

For our purposes, then, a classical definition of vehicle stability will not suffice, but what is needed is a deeper understanding of the driver-vehicle system, and of handling itself. To overcome these difficulties, Alfa Romeo has started a research program, on both the theoretical and experimental aspects of the driver-vehicle system behaviour, with the aim of satisfactorily defining the essential response characteristics of a normal driver, and hence establish the limits of acceptability of the dynamic characteristics of the vehicle.

It is then our opinion that only when the definition of these limits has been achieved, through the study of the above mentioned driver-vehicle system, we will be able to establish an objective definition of active safety tests.

2. Driver-Vehicle System Research.*

The research is carried out on a track, with vehicles having different and well-defined dynamic characteristics, and with drivers of varying ability.

The processing of the first experimental results has allowed us to prepare a mathematical model of the driver-vehicle system. This model, rather complex but undoubtedly effective, represents the vehicle in the now traditional scheme, with 3 or more degrees of freedom, according to the type of problem to be solved. More particularly, the non-linear representation takes into account the actual behaviour of tires, of aerodynamic effects, of tractive and braking actions, etc. The driver's reaction, manifesting itself mainly as a steering input, is based on a continuous comparison between a predetermined trajectory and that extrapolated starting from the position at each particular instant (i.e.: a step by step process). The extrapolation gap is linked with the vehicle time constants, and the driver's reaction time. The comparison between the 2 trajectories obviously involves an error, the probability distribution of which is assumed to follow Gauss's law. The driver's steering action, in his effort to bring the vehicle back on the pre-determined path, is affected by the above named error distribution in such a way that it will undergo an attenuation (with respect to the ideal condition) which will increase with the mean square difference of the distribution. This difference is linked with the extrapolation step, the path curvature, and to a parameter pertaining to the driver's ability.

Moreover, the steering action is conditioned by the presence of curbs and possible obstacles, in a similar way to that used for the pre-determined path.

To sum up, this scheme has the advantage of taking into account the driver's characteristics in quite a realistic manner, using only two parameters:

a) the driver's reaction time

b) the accuracy of the extrapolation estimate.

It may however become necessary, in the course of the present work for the improvement of this model, to accept further complication. The following are some of the results obtained with the above method.

2.1. Behaviour Of A Vehicle Travelling On A Bend At Various Speeds

The vehicle travels on the centreline of a 90° bend joining two straight roads (Fig. 1). This centreline is the reference trajectory we will use. The vehicle considered here is one having average dynamic parameters and neutral behaviour. Figs. 2, 3, 4, 5 show the trajectories,

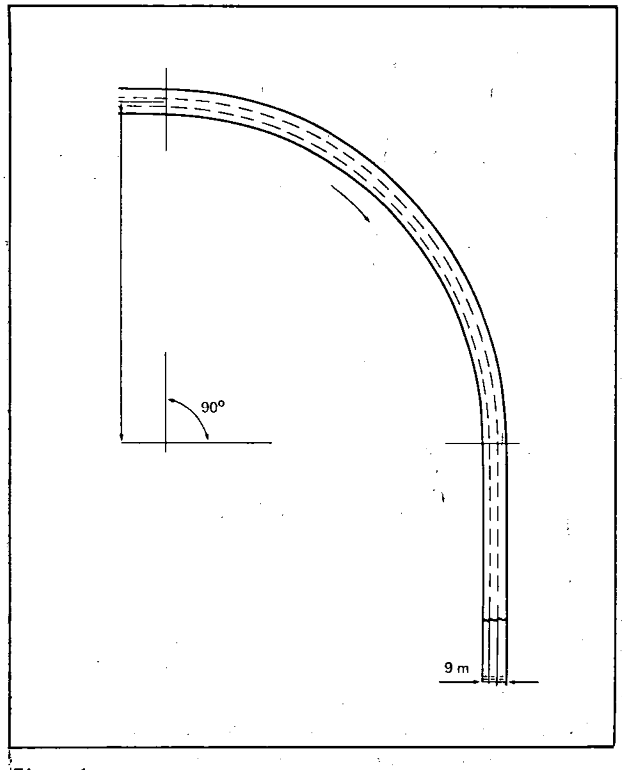

Figure 1

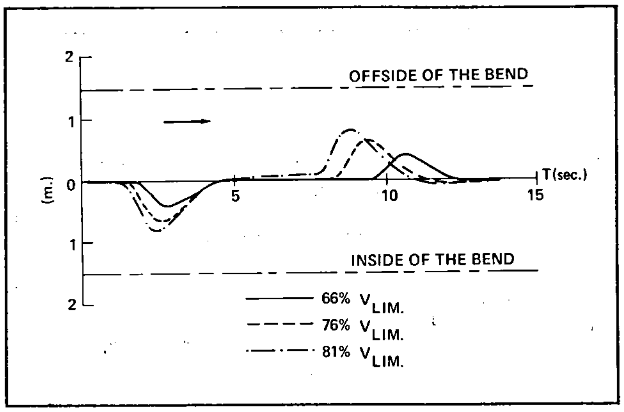

Figure 2

the lateral accelerations and the steering angles at the wheels for three different speeds, and for two driver reaction times.

For each of these reaction times, as the speed increases, so does driving difficulty; at the maximum

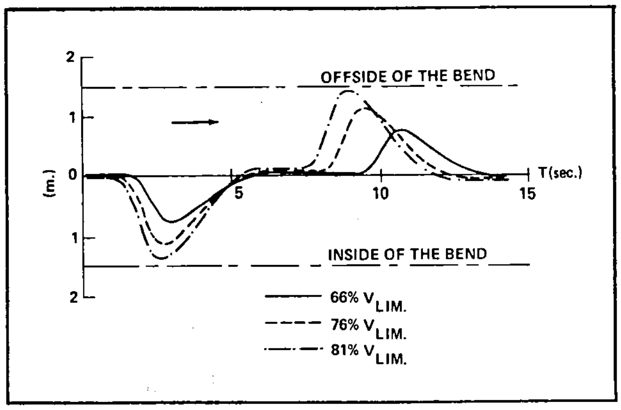

Figure 3

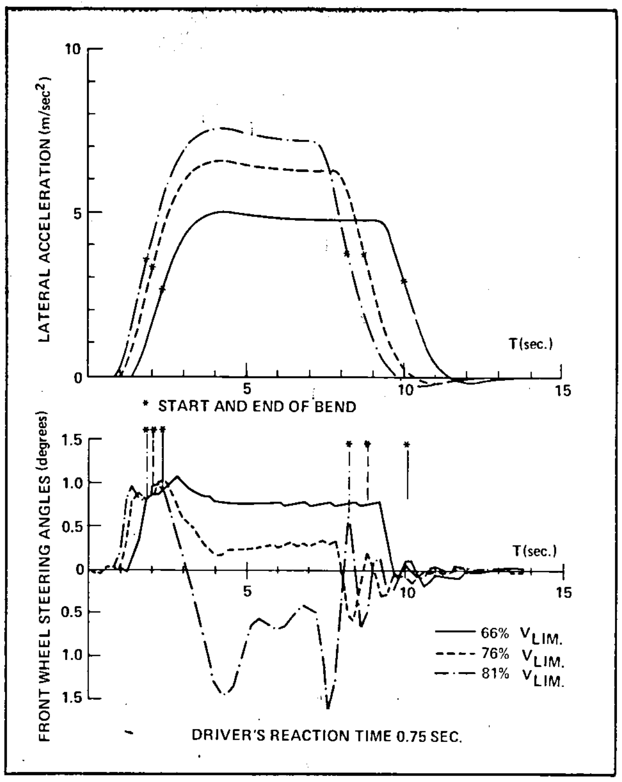

Figure 4

velocity considered, substantial "opposite lock" was necessary.

As the reaction times increase, the deviations from the reference trajectory become greater; when at the maximum velocity considered, with a 1.25 second reaction time, at the end of the bend the vehicle leaves its lane and enters the overtaking lane.

2.2. Lane Changing Maneuver On A Straight Road.

This maneuver (per se interesting in the study of the driver-vehicle system dynamic behaviour) can also be identified with the first part of an overtaking maneuver.

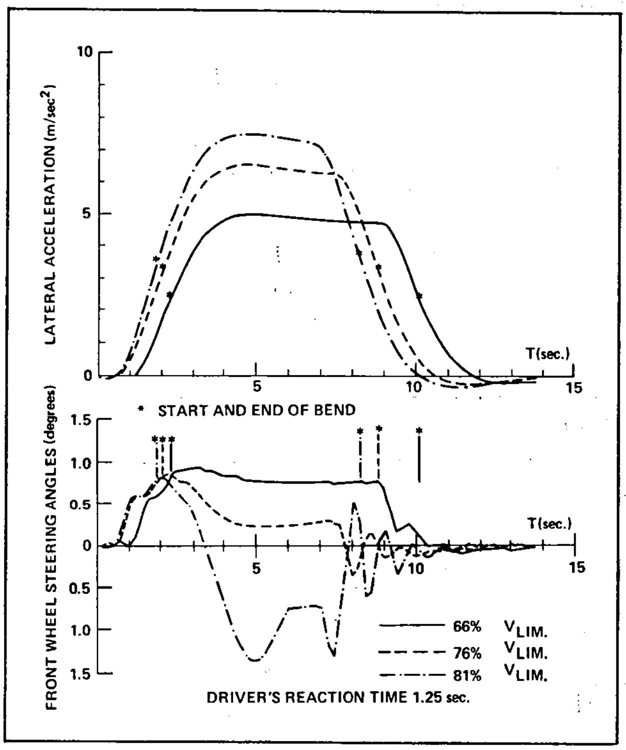

Figure 5

The vehicle, travelling at 40 m/sec., has characteristic dynamic parameters as in the previous case. The driver's reaction time is 1 second.

Under the test conditions used, roll oversteer made the vehicle obviously unstable. The effect of understeering, instead, is strongly stabilizing (Fig. 6).

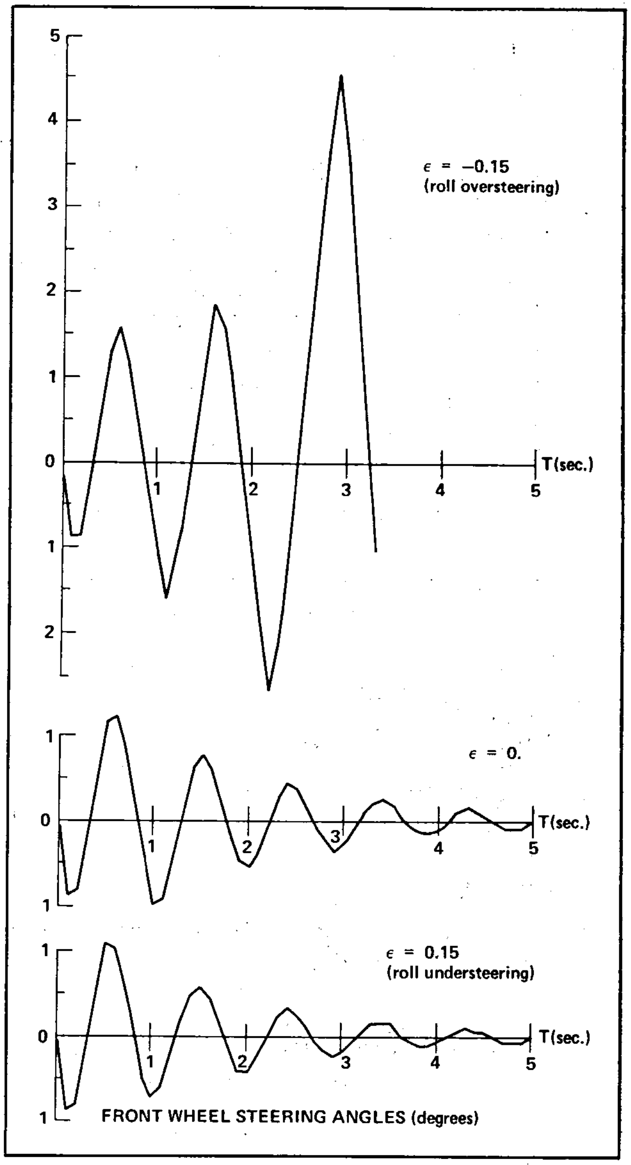

Figure 6

3. Active Safety Tests

These must satisfy the following requirements:

1. Be safe in their actuation
2. Emphasize those dynamic characteristics shown by driver-vehicle system analysis to be the most important for safety
3. Have a sufficient degree of repeatibility
4. Be, if possible, easy to perform.

The requirements mentioned in 3 and 4 can be met with tests using an actual driver, who will perform simple and previously well defined maneuvers, as long as point 1 is conformed to. We note that the proposed American ESV requirements generally satisfy the four points mentioned above.

As far as we are concerned, we are utilizing the results of the above described theoretical and experimental research to define a series of tests to be incorporated in the classification of Fig. 7. The blank squares may be occupied by further definitions.

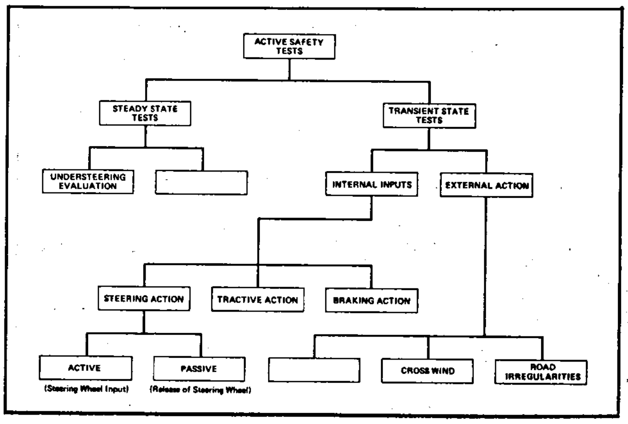

Figure 7

In what follows we will illustrate the simulations of some of these tests comparing them, whenever possible, with the active safety requirements contained in the American proposal. The simulations were based on the configuration of an average European car with good road-holding and varying, when necessary, the most significant parameters.

It may be interesting to show the data which more closely characterizes the vehicle under consideration:

Total mass = 113 kg. sec^2/m
Sprung mass = 101 kg.sec^2/m
Principal moment of inertia of the total mass with respect to the yaw axis = 160 kg. sec^2 m
Distance of the center of gravity from the front axle = 1.05 m
Distance of the centre of gravity from the rear axle = 1.40 m
Height of the centre of gravity = 0.47 m
Height of the front roll centre = 0.106 m
Height of the rear roll centre = 0.23 m
Front track = 1.38 m
Rear track = 1.35 m
The tires have non-linear characteristics, of the average European type.

3.1. Steady State Tests

3.1.1. Evaluation Of The Degree Of Understeering

The behaviour of the basic vehicle was compared with the American proposal limits, concerning the relationship between steady state yaw velocity and steering angle at the front wheels, with a lateral acceleration of 0.4 g. The test speeds specified are 40, 80 and 112 km/h.

The results obtained are shown in Fig. 8: this diagram is derived from the original American proposal, with the difference that the ordinate was multiplied by the vehicle wheel base, to extend the application of this diagram to vehicles having different dimensions.

The diagram was completed with curves for fixed degrees of understeering, defined by the following expressions:

$$\frac{\omega L}{\delta} = \frac{V}{1 + K V^2}$$

$$K = \frac{\Delta}{A_m g L}$$

$$\Delta = \frac{A_p - A_a}{A_m}$$

where

ω = steady state yaw velocity
L = Wheel base
δ = front wheels steering angle
A_m = average dimensionless cornering stiffness of the vehicle = $\sqrt{A_a / A_p}$
A_a = front dimensionless cornering stiffness
A_p = rear dimensionless cornering stiffness
g = gravitational acceleration

The curves were traced for a value $A_m g L$ = 240 m^2/sec^2, which may be considered valid for an average vehicle with generous tire equipment undergoing 0.4 g. lateral acceleration.

The vehicle examined, as shown in Fig. 8, falls outside the imposed limits, even if it is characterized by substantial understeering and considered having a good road-holding standard.

We are of the opinion that the USA proposal expects rather strong understeering characteristics.

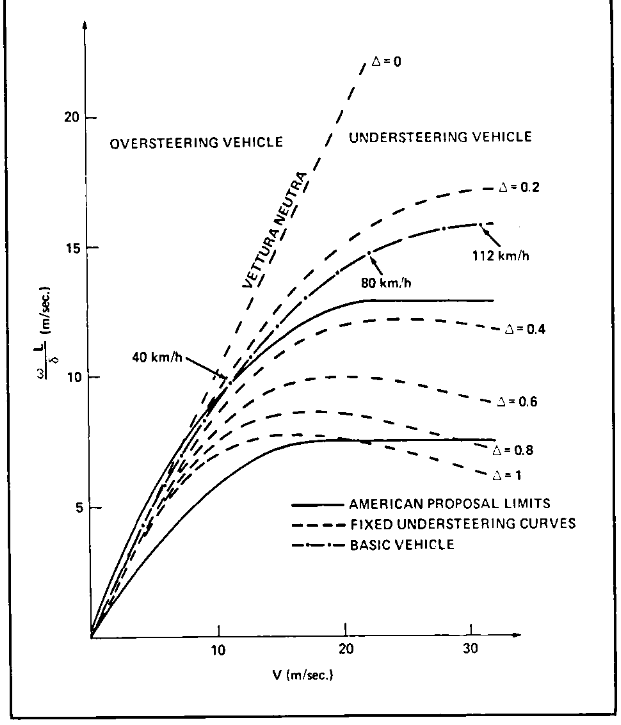

Figure 8

3.2. Transient State Tests

3.2.1. Active Internal Steering Action – Step Function Steering Input

It is assumed that, when the vehicle travels at constant velocity in a straight line, an instantaneous steering input is applied, so as to achieve a fixed value of steady state lateral acceleration.

In actual practice, the time taken to rotate the steering must be negligible with respect to the lowest of the time constants related to this phenomenon, for the particular vehicle. This requirement is due to the aim of making the test result independent of maneuvering speed.

For comparison, we will show the simulations results on the basic vehicle in accordance with the American proposal on this maneuver.

The test conditions are as follows:

velocity of rotation of the steering wheel: V500°/sec.
test speed: 40-11 = km/h
steady state lateral acceleration: 0.4 g.

The curves of yaw velocity against time must be contained within the limits shown in Figs. 9 and 10; in these diagrams appear also the transient state curves for the same vehicle and various degrees of understeer, as defined in the previous case.

The same considerations as the ones in paragraph 3.1.1. can be made by examining Fig. 10, concerning the high speed test.

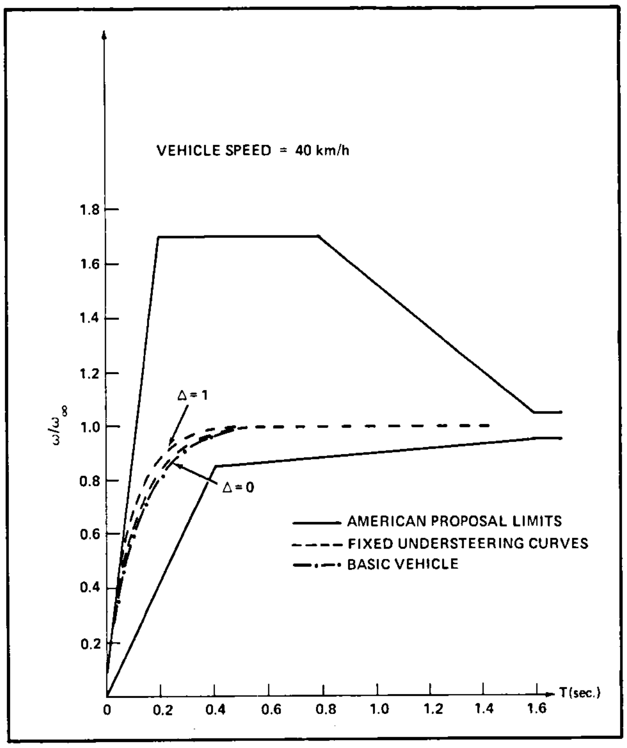

Figure 9

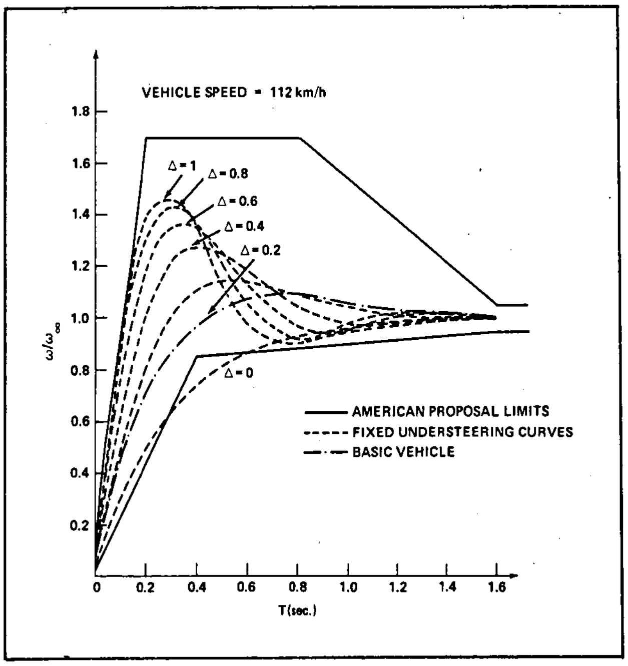

Figure 10

3.2.2. Passive Internal Steering Action – Influence Of Steering Dynamics On Vehicle Control And Stability

The treatment of the present problem is referred to a vehicle with three degrees of freedom (lateral displacement, yaw angle and roll angle) and to a steering system with two degrees of freedom (front wheels steering angle and steering wheel angle). As far as the steering system is concerned, not only its inertial characteristics are taken into account, but also its damping (assumed to follow Coulomb's law), roll understeer and characteristic wheel angles.

The vehicle starts the bend with a pre-determined forward speed and lateral acceleration. The steering wheel is suddenly released at a point on the trajectory which then becomes the initial reference point.

The test conditions suggested by the American proposal are analogous to the ones described above, but are characterized by the requirement of running the vehicle on circular trajectories of such radii that the lateral acceleration achieved is 0.4 g, for both 40 km/h and 80 km/h.

The principal reason for this test is to evaluate steering returnability and damping. Hence, after releasing the steering wheel, yaw angles (referred to the initial angular position of the vehicle) and yaw velocities are measured as a function of time.

With reference to the American proposal, the yaw angles response curves for 40 km/h and 80 km/h must be within the limits shown in Fig. 11. In addition, two seconds after the start of the test, the yaw velocities must be within the following limits (Fig. 12):

$\geqslant 4°$/sec. at 80 km/h
0°/sec. at 40 km/h

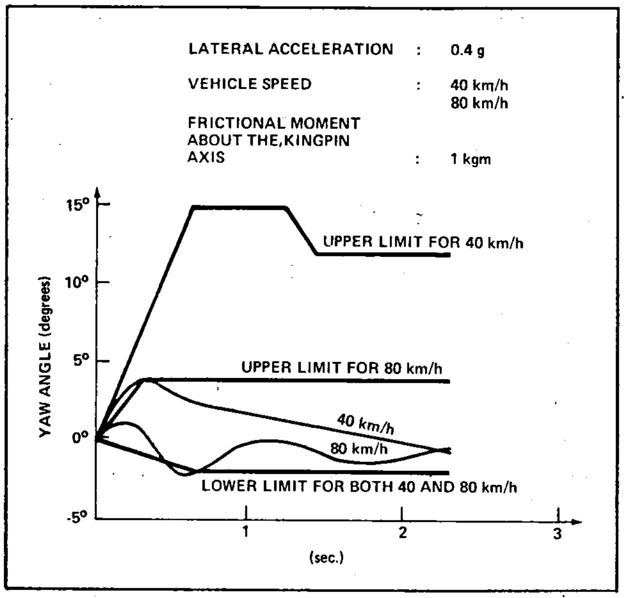

Figure 11

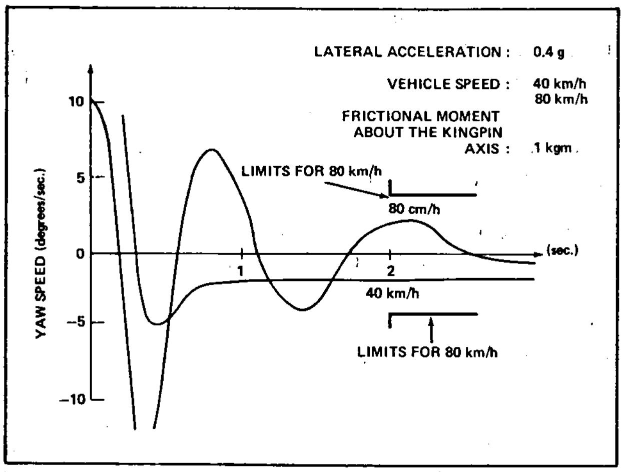

Figure 12

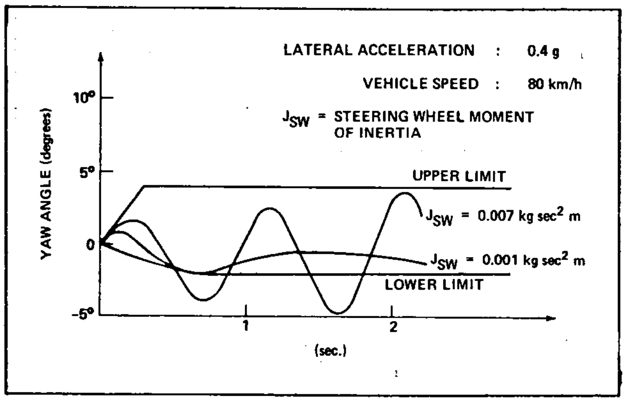

Figure 13

It can be seen from Figure 11 that the curve pertaining to the speed of 40 km/h is wholly inside the ESV limits, while the one drawn for 80 km/h is substantially outside those limits for a small time interval.

The curves shown in Figure 13 are deduced from the basic conditions, increasing the steering wheel moment of inertia from 0.00297 kg.sec^2.m to 0.007 kg.sec^2.m, then decreasing it to 0.01 kg.sec^2.m. It can be noted that an increase in the steering wheel moment of inertia emphasizes the amplitudes of oscillations of yaw angles. Similar effects are caused varying the steering ratio from 18 to 24 to 15 (Fig. 14).

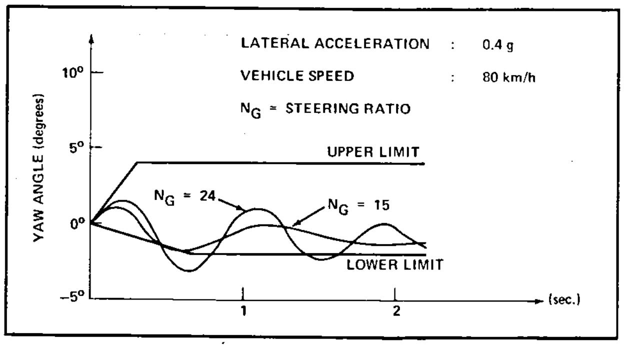

Figure 14

3.2.3. External Inputs – Wind – Vehicle Cross Wind Sensitivity

For uniformity with the American proposals, the vehicle was assumed subjected to a sudden cross wind having a velocity of 80 km/h. The total course deviation, for a wind exposure of 6.1 m, must be less than the values specified in Figure 15, when measured two

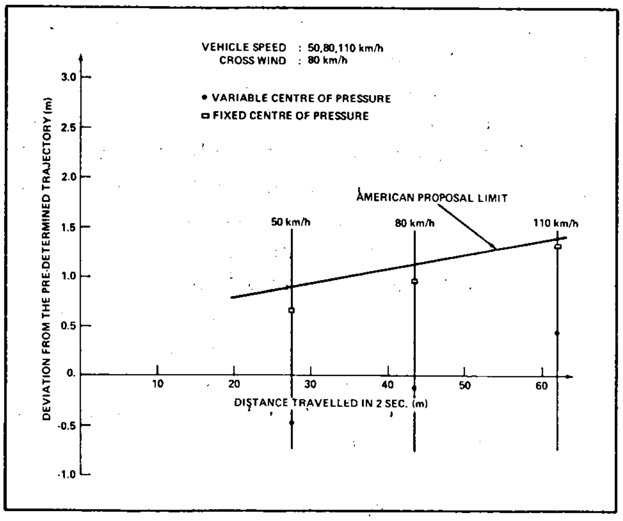

Figure 15

seconds after the start of this test. Vehicle speeds considered are 50, 80 and 110 km/h; the steering wheel is assumed locked in position.

Figure 15 shows the results for two different aerodynamic considerations: one with a fixed centre of pressure, located at a distance, from the front axle centre, equal to one quarter of the wheel base, and another with a variable centre of pressure (Fig. 16).

In this case the variable centre of pressure solution shows advantages over the other type. However, for small relative wind incidence angles, like the ones obtained, for instance, with high vehicle speeds and relatively low wind velocities, the fixed centre of pressure vehicle becomes more desirable.

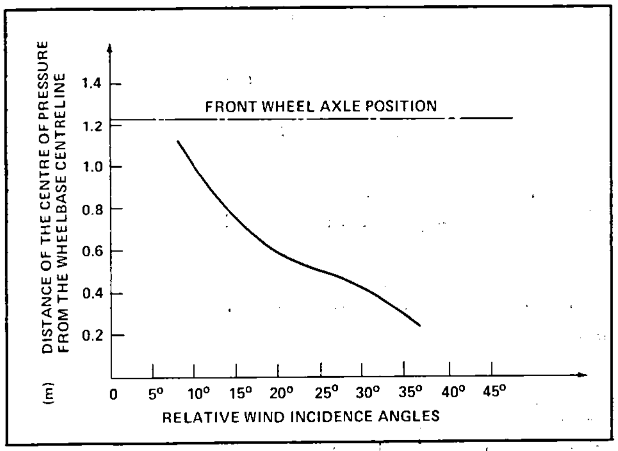

Figure 16

3.2.3. External Inputs – Road Irregularities – Roll Understeer Influence On Vehicle Stability

The vehicle is assumed to travel along a predetermined trajectory (e.g., rectilinear) with the steering wheel locked in position.

It is further assumed that the steering wheel and the front wheels are rigidly connected.

The investigation consists, for different speeds, in following the behaviour of the vehicle having various degrees of roll steering, and affected by an external input due, for example, to some road irregularity.

In this case the input is assumed to be applied at the centre of gravity of the basic vehicle (having neutral characteristics). Defining ϵ (the roll steering value) as the relationship between steering angle and roll angle (when ϵ is positive, it causes understeering), the effects of the following values of ϵ were considered:

0.15 (understeering)
0.03 (understeering)
-0.15 (oversteering)

Figure 17 gives the variations of lateral accelerations and lateral course deviation from the original path,

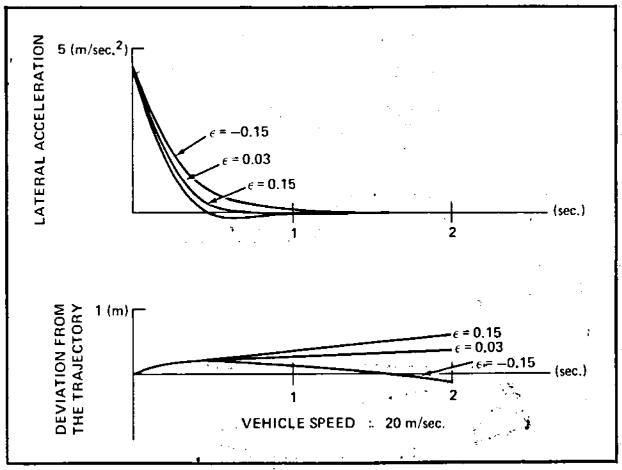

Figure 17

relative to the time from the start of the test. The vehicle speed is 20 m/sec. The examination of Figure 17 shows that, at this speed, vehicle stability is not appreciably affected by roll steering. Figure 18 shows similar diagrams to the ones in Figure 17, but for a 50 m/sec. vehicle speed. In this case it can easily be observed that roll oversteering (-0.15) is such that it renders the vehicle unstable.

The example above shows the importance for active safety of perfecting a test to analyze, with the steering wheel locked in position, high speed vehicle stability, the lack of which creates the dangerous and well known phenomenon of high speed snaking.

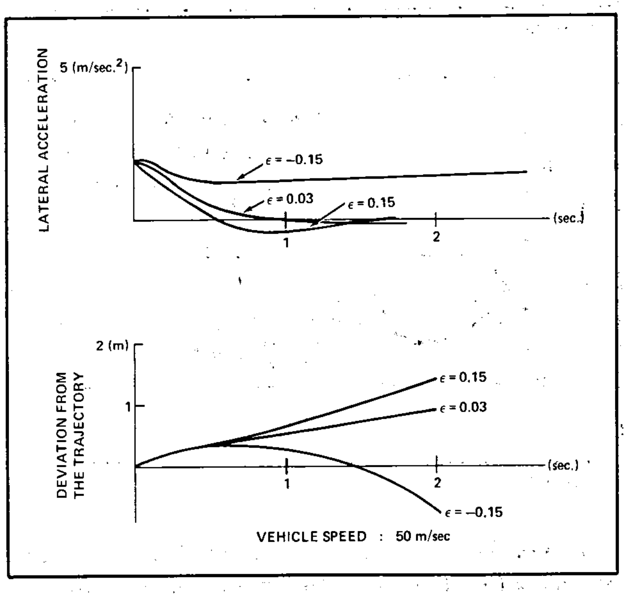

Figure 18

Conclusions

During our research we have compared, whenever possible, our results with the ones obtained using the American proposal: this suggests an undoubtedly interesting series of tests for the definition of the handling and road-holding characteristics of vehicles.

In our opinion it is probable that further tests will have to be introduced, that some parameters need to be more specifically defined and some limits reviewed, with the aim also of extending the applicability of such work to European type vehicles. We further believe that this analysis and problem penetration, to which we dedicate considerable efforts, can only advance through a study of the driver-vehicle system. Then we will obtain that knowledge of vehicle dynamics which, in the future will allow us to build safer vehicles.

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SUMMARY OF DEVELOPMENT WORK ON AUTOMOTIVE OPTICAL REAR VIEW DEVICES

Prof. Vasco Ronchi, Fiat Consultant

The problem of improving driver side and rear view has now been the object of investigations for some five years. In the course of these studies the complexity of the problem has come to full light, and to facilitate its solution, the relevant subject matter has been divided into three sectors as follows:

1. *Optical problems*, with a view to developing devices which afford a wide field of view, both in the horizontal and in the vertical planes, with clear and luminous and suitably magnified images.
2. *Mechanical problems*, involving installation on the vehicle so as to promote rapid, clear vision, at the same time meeting aesthetical requirements.
3. *Economic problems*, which drastically curtail the chances of using high-quality materials and semi-finished products and dictate the adoption of very simple devices.

In the programming of the work, optical problems have been given top priority.

The general approach and work schedule can best be summarised as follows:

a. It has been decided not to adopt separate devices for side and rear fields of view. Although flat or convex mirrors can be used for such devices, previous experience has shown that they are inadequate.

b. Accordingly, efforts have been channelled towards the development of a wide-field optical device capable of giving the driver simultaneous view of the rear and both sides.

The first approach in the development of a rear view device affording such features was to design a unit giving virtual images of 1/3 magnification. The original device (see Fig. 1a and 1b) comprised a negative lens on the

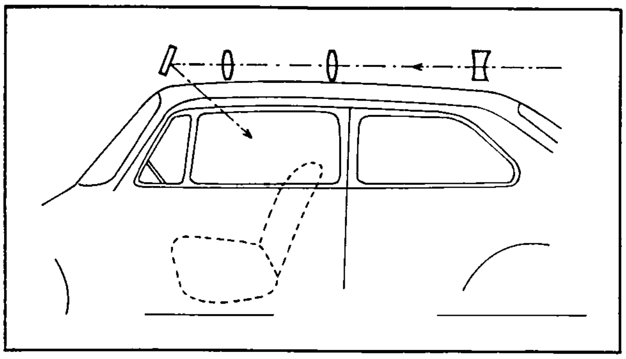


Figure 1A

rear of the car, followed by a system of lenses ending with a mirror similar to the currently used rear view mirror. A 160° external horizontal field contracted within a 60° apparent field, was visible all at once to the driver. The negative lens was approximately 20 centimetres wide.

When fitted on a car, the prototype gave encouraging results. A second prototype of different design but based on the same principle (see Figs. 2a and 2b), which was fitted on top of a fully closed van, again yielded

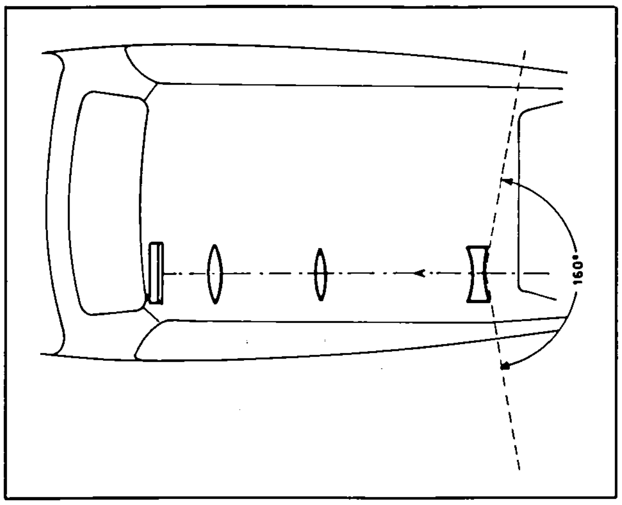


Figure 1B

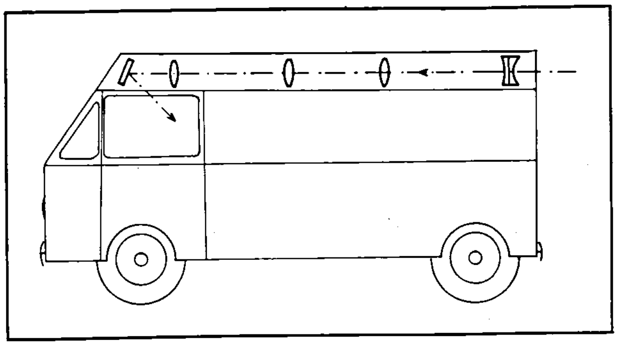


Figure 2A

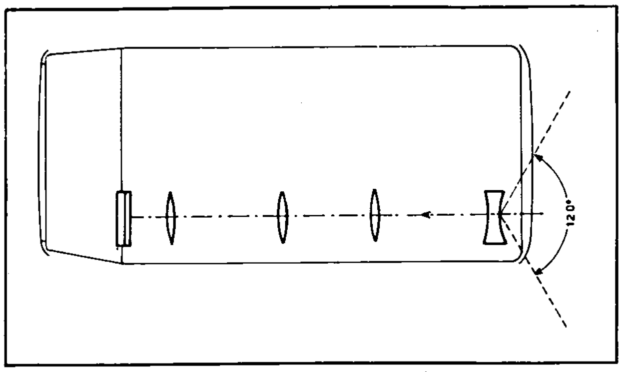


Figure 2B

interesting results. A third and more advanced prototype (see Figs. 3a and 3b), fitted to an 11 metre long urban bus confirmed that by following this approach it was possible to arrive at promising solutions.

Though offering the big advantage of a wide field viewed all at once, the adoption of an approximately 1/3 magnification gave a false impression as to the actual distance of the objects reflected as small images. This distance was reckoned three times as great. Initially, it

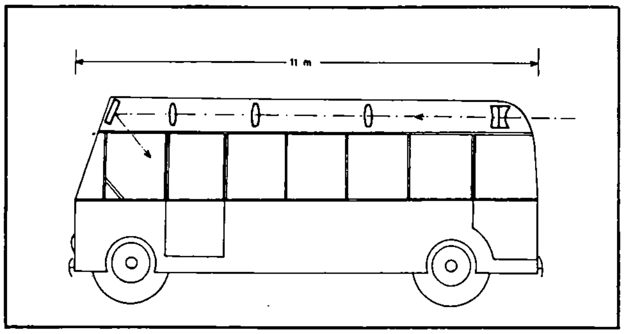


Figure 3A

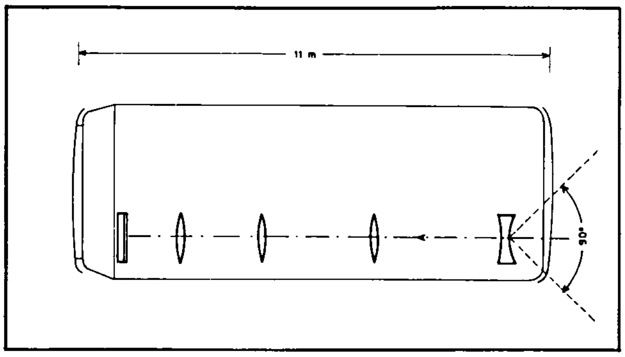


Figure 3B

was thought that the balance between the advantage of having a full view of the rear and sides including those areas which at present cannot be seen, and the drawback of a false judgment of the distance could turn out to be favourable and justified the investment in extensive trials to obtain confirmation. However, when the American proposed rule making irrevocably laid down that rear view magnification would not be permitted to differ from unity, the approach followed up to that time was dropped.

c. Thus the research effort was switched to wide-field unit-magnification rear-view devices. This meant foregoing the full-field vision feature, which it was decided to offset by allowing a limited sidewise head movement as contemplated in the American Standards.

The first car-mounted prototype featured a field of view of 90° in the horizontal and 30° in the vertical plane (see Figs. 4a and 4b), which is even greater than required by the American proposed rule making for the 1973 model year. This fairly uncomplicated device was housed in a 60 cm long, 30 cm wide and 15 cm high casing placed lengthwise on the roof of the car on the left-hand side above the driver's head, so that to look backwards from the straight-ahead posture, the driver only had to raise his eyes by approximately 30°.

However, investigations were continued with the aim of improving performance and further simplifying the device. In turn, this brought about a change in the concept of the optical system.

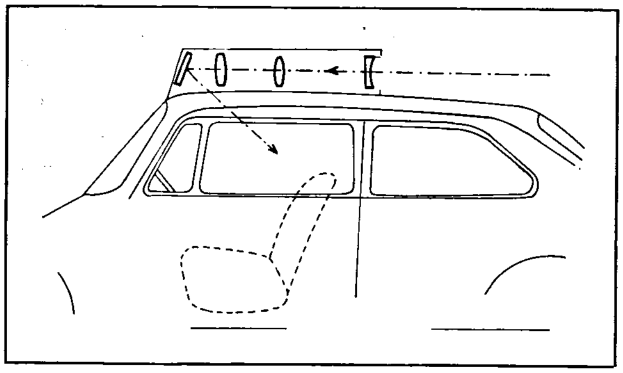


Figure 4A

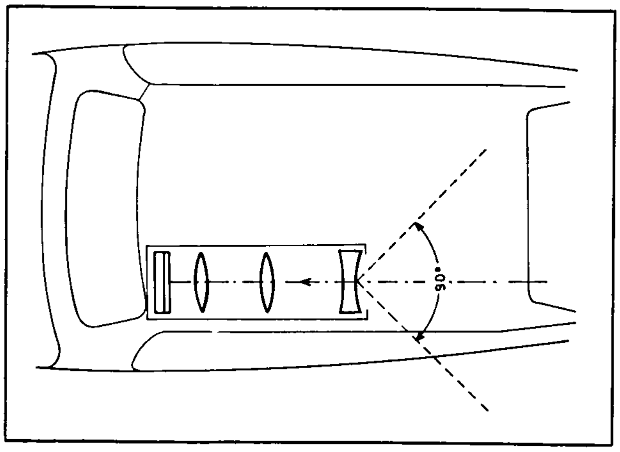


Figure 4B

In the latest type of device (see Figs. 5a and 5b) the wide range of divergent optical system and the magnification of the convergent systems was enhanced. The device simply consists of a divergent system (specular or dioptric) giving reduced size images but over a very wide field. These images are observed through a convergent optical system which acts as a magnifying lens and returns the magnification of the combination to the desired value giving suitable power ratings to the two systems. In particular, the degree of magnification of the system can be brought to unity with incredibly wide fields.

The description is rather vague, as this type of combination affords many degrees of freedom which have yet to be fully investigated. For example, one combination (see Fig. 6) is composed of only one convex mirror and a converging lens, both 30 cm wide, 8 cm high and 15 to 20 cm thick, and permits the observation of a horizontal 140° (approximately) field with a magnification of 1 and binocular vision over almost all the field; the images are optically well corrected and bright.

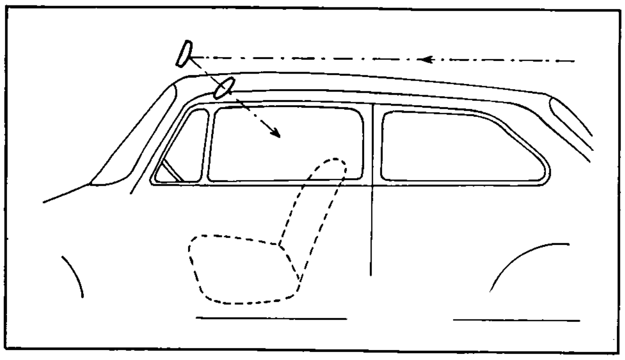


Figure 5A

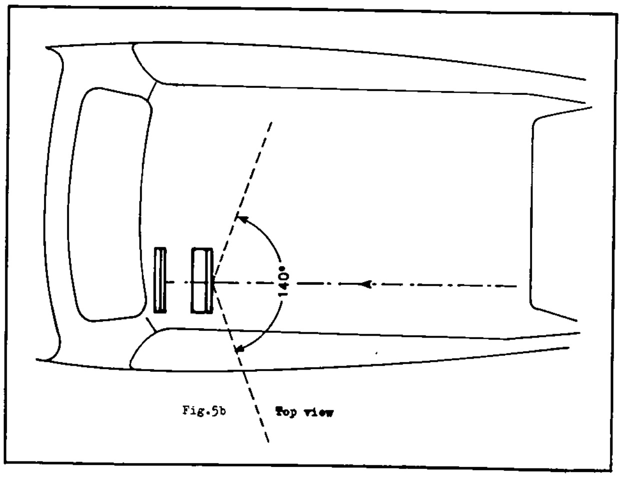


Figure 5B

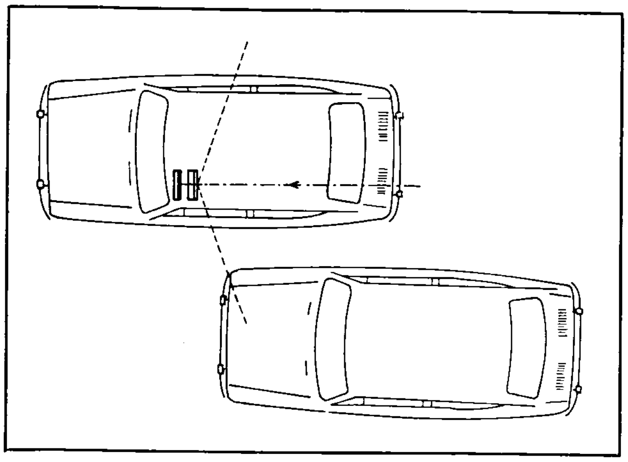


Figure 6

However, to observe the field boundary areas the head must be moved slightly to the right or to the left. However, the fact is that by moving his head and looking slightly upwards he can see an overtaking car coming up beside him at the same instant when he can also see it (by turning his head) through the front window.

The best compromise is now being sought between the various optical characteristics (by experimentally devising the optimum geometry of the device and its associated parts) and mechanical, as well as aesthetical features. Unfortunately, this sort of compromise looks highly complex and extremely difficult to achieve.

The economic problems can only be solved after this compromise has been found. However, it is anticipated that, owing to the extreme simplicity of the device, the associated economic problems will not present undue difficulty.

It is also anticipated that different types of vehicles will require different, and in some cases very different, solution. But the flexibility of the device as conceived is such that it is possible to look with an optimistic eye to the possibility of arriving at acceptable, if not complete, solutions to so difficult a problem.

SECTION 2

PART 6 THE FRENCH TECHNICAL PRESENTATION ON THE ESV PROGRAM

DISTRIBUTION AND GRAVITY OF COLLISIONS AS A FUNCTION OF THE DAMAGED PART OF THE VEHICLE AND THE OBSTACLE HIT

M. Claude Berlioz, O.N.S.E.R.

1. Object and Area of Study

The improvement of automobile crash qualities can involve many methods, not only by the nature of the planned technical improvements, but also by the type of collision where we try to minimize the consequences for the occupants. It is therefore important to define the priorities in these different situations in order to get the maximum improvement at the same cost. This choice calls for at least two criteria: the frequency and the gravity of different types of collisions. This study proposes to provide some comments on these ideas.

The study involves about 1/10th of the property damage accidents, involving at least one touring car, that occurred in France in 1968 (17,916) and not involving pedestrians, bicycles, nor a third vehicle (7,087).

2. Method

The facts were collected by police through their certified reports of accidents. On the form filled out for each accident, the officer indicates, for each vehicle, the damaged part by checking with the drawing on his form and reproduced here as Figure 1 (the angles shown on the form drawing). No other special instructions on this subject were given to the police. We must assume that in cases of multiple collisions, the damaged area indicated would represent the major crash.

However, it is interesting that a non-negligible number of officers had indicated the direction of the crash instead of the damaged part. The boundaries between the designated areas are most likely not interpreted in the same way by all the officers, but we can assume

TABLE 1
Using the Card Index of 1/10 of Accidents in 1968
Distribution of the Hit Part of Cars and Vans in Terms of
The Type of Obstacle or Vehicle Hit

(7,087 Accidents)

	Front	Rear	Left Front	Left Center	Left Rear	Right Front	Right Center	Right Rear	No Answer	TOTAL
Post	45.9% 200 5.8%	0.7% 3 0.6%	13.1% 57 2.1%	4.1% 18 2.6%	1.6% 7 2.0%	16.1% 70 4.4%	5.0% 22 4.2%	1.8% 8 3.4%	11.7% 51 13.7%	100% 436 4.2%
Tree	40.8% 227 6.5%	1.3% 7 1.5%	14.4% 80 2.9%	6.8% 38 5.5%	2.1% 12 3.5%	14.0% 78 4.9%	10.0% 56 10.8%	1.4% 8 3.4%	9.2% 51 13.7%	100% 557 5.3%
Wall	39.2% 231 6.7%	0.8% 5 1.0%	16.3% 96 3.5%	3.6% 21 3.0%	1.0% 6 1.7%	18.3% 108 6.8%	5.1% 30 5.8%	1.0% 6 2.6%	14.7% 87 23.4%	100% 590 5.7%
Other Obstacles	39.0% 293 8.5%	0.7% 5 1.0%	11.8% 89 3.2%	8.5% 64 9.3%	1.5% 11 3.2%	14.9% 112 7.0%	7.0% 53 10.2%	2.1% 16 6.8%	14.5% 109 29.3%	100% 752 7.2%
Touring Car	29.9% 2011 58.1%	5.8% 388 80.8%	30.5% 2058 74.6%	6.7% 450 64.9%	4.0% 267 76.9%	15.3% 1032 64.7%	4.4% 299 57.6%	2.4% 166 70.9%	1.0% 65 17.5%	100% 6736 64.4%
Truck	35.5% 445 12.9%	5.2% 65 13.6%	28.4% 356 12.9%	7.2% 91 13.1%	3.3% 42 12.1%	13.6% 170 10.7%	4.3% 54 10.4%	1.9% 24 10.3%	0.6% 8 2.1%	100% 1255 12.0%
Other Vehicles	40.3% 52 1.5%	5.4% 7 1.5%	16.3% 21 0.8%	8.5% 11 1.6%	1.5% 2 0.6%	18.6% 24 1.5%	3.9% 5 1.0%	4.7% 6 2.6%	0.8% 1 0.3%	100% 129 1.2%
TOTAL	33.1% 3459 100%	4.6% 480 100%	26.4% 2757 100%	6.6% 693 100%	3.3% 347 100%	15.2% 1594 100%	5.0% 519 100%	2.2% 234 100%	3.6% 372 100%	100% 10455 100%

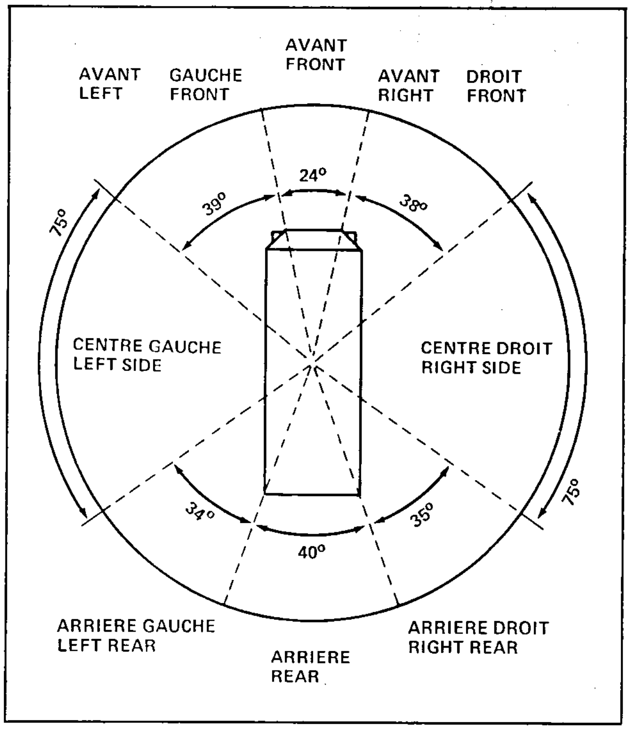


Figure 1

that on the average they correspond to the vertical joining of the fenders in the structure.

The obstacles hit as defined on the form are:

1. street lamp, post, milestone
2. tree
3. level crossing barrier
4. edge of a street island
5. safety guide-block (window guide)
6. animal, alone or many
7. wall, construction, various material

In view of the number of various objects, we have regrouped numbers 3-6 under the heading "other obstacles." For the sake of simplification, we will call the first heading "post" and the last one "wall" in the following text.

In the accidents involving only one vehicle, there is generally no question as to the obstacle hit (except in the exceptional case where many objects may have been hit but the form only allows for one case).

In accidents involving two vehicles, in about 4% of the cases an obstacle is hit, but we do not know if the main crash was against the other vehicle or against the obstacle. We will suppose, at least at first, that the main crash was against the other vehicle. For "other vehicle" we consider:

- touring car or van
- truck
- other vehicle with the exception of two wheelers

We generally include a distinction between the different trucks according to their total loaded weight for more detailed studies, but this distinction was not used here.

These facts are actually available for all property damage accidents in France, but we figured that one-tenth of the accidents would offer a precise enough measure, at least for the first step.

TABLE 2

Using Card Index of 1/10 of Accidents in 1968
State of Drivers of Touring Cars or Vans in Crashes Against An Obstacle or Another Vehicle According to the Hit Part

(7,087 Accidents)

	Front	Rear	Left Front	Left Center	Left Rear	Right Front	Right Center	Right Rear	No Answer	TOTAL
Killed	35.2% 114 3.3%	0.6% 2 0.4%	22.8% 74 2.7%	10.8% 35 5.1%	1.5% 5 1.4%	12.4% 40 2.5%	5.9% 19 3.7%	1.9% 6 2.6%	8.9% 29 7.8%	100% 324 3.1%
Serious Injuries	38.9% 648 18.7%	1.9% 32 6.7%	25.4% 422 15.3%	7.6% 127 18.3%	1.8% 30 8.7%	13.0% 217 13.6%	5.1% 85 16.4%	1.1% 18 7.6%	5.2% 86 23.1%	100% 1665 15.9%
Light Injuries	35.2% 1456 42.1%	3.8% 157 32.7%	26.7% 1105 40.1%	7.3% 300 43.3%	3.7% 152 43.8%	13.5% 558 35.0%	5.1% 209 40.3%	1.5% 63 26.9%	3.2% 135 36.3%	100% 4135 39.6%
Total Victims	36.2% 2218 64.1%	3.1% 191 39.8%	26.1% 1601 58.1%	7.5% 462 66.7%	3.1% 187 53.9%	13.3% 815 51.1%	5.1% 313 60.4%	1.4% 87 37.1%	4.2% 250 67.2%	100% 6124 58.6%
No Injuries	28.8% 1235 35.7%	6.4% 274 57.1%	26.9% 1151 41.7%	5.3% 228 32.9%	3.6% 154 44.4%	18.0% 771 48.4%	4.8% 205 39.5%	3.4% 145 62.0%	2.8% 120 32.3%	100% 4283 40.9%
No Response	12.5% 6 0.2%	31.3% 15 3.1%	10.4% 5 0.2%	6.3% 3 0.4%	12.5% 6 1.7%	16.7% 8 0.5%	2.1% 1 0.1%	4.2% 2 0.9%	4.0% 2 0.5%	100% 48 0.5%
TOTAL	33;1% 3459 100%	4.6% 480 100%	26.4% 2757 100%	6.6% 693 100%	3.3% 347 100%	15.3% 694 100%	5.0% 519 100%	2.2% 234 100%	3.5% 372 100%	100% 10455 100%

Only the state of driver and front seat passenger were studied, the number of rear seat passengers was much less. We first studied them as a function of the damaged part of the vehicle, as they were distributed among the four following situations:

- killed in the crash or dead within a week
- seriously injured, still in the hospital six days after the crash
- slightly injured—medical treatment or hospitalization for less than or equal to six days
- uninjured

We have analyzed the possible heterogeneity of these distributions by means of tests of X^2.

The same was done for the obstacle or vehicle hit, instead of the hit part of the first car.

We finally studied the distribution of the damaged part in terms of the obstacle or vehicle hit, in order to see if possible differences of gravity observed in the two first phases of the study could be explained by a non-independence of the damaged part and the damaged obstacle.

3. Chief results

a. Damaged part (Tables 2 and 4)

The most frequently damaged parts are, in order:

- the front: 33% of crashes and 35% of fatalities
- the left front: 26% of crashes and 20% of fatalities
- right front: 15% of crashes and 15% of fatalities

The distribution of occupants involved in fatalities, serious and slight injuries, and those unhurt differ significantly according to the damaged part, for the driver as well as the front seat passenger. We can make note of the seriousness of these types of crashes with the help of two indicators.

- the rate of mortality, ratio of the number killed to the number involved in crashes (3.1% for drivers and 2.8% for the front seat passenger)
- the rate of seriousness, ratio of the total killed and seriously injured to the number involved (19% for drivers and 22% for front seat passengers)

For the driver, the most serious crash corresponds to the left center crash for the two rates of 5% and 23%. Then come the right center and the front; the order depends on the indicator chosen. Rear collisions are the least serious.

For the front passenger the most serious crash is the center right side, for the two rates of 7% and 32%. Then come the right front and the front; the order depends on the indicator chosen. The rear crashes are the least serious.

TABLE 3
Using Card Index of 1/10 of Accidents in 1968
State of Drivers of Touring Cars or Vans as a Function of the Type of Obstacle or Vehicle Hit
(7,087 Accidents)

	Post	Tree	Wall	Other Obstacles	Touring Car	Truck	Other Vehicles	TOTAL
Killed	8.0% 26 6.0%	21.9% 71 12.7%	12.0% 39 6.6%	11.7% 38 5.1%	23.5% 76 1.1%	21.0% 68 5.4%	1.9% 6 4.8%	100% 324 3.1%
Serious Injuries	8.1% 135 31.0%	12.4% 207 37.2%	10.5% 175 29.7%	10.4% 174 23.1%	40.4% 673 10.0%	16.5% 274 21.8%	1.7% 27 20.9%	100% 1665 15.9%
Light Injuries	4.6% 190 43.5%	4.8% 200 36.0%	6.3% 259 43.9%	8.5% 350 46.5%	59.0% 2440 36.2%	15.2% 629 50.1%	1.6% 67 51.9%	100% 4135 39.5%
Total Victims	5.7% 351 80.5%	7.8% 478 85.8%	7.7% 473 80.2%	9.2% 562 74.7%	52.1% 3189 47.3%	15.9% 971 77.3%	1.6% 100 77.6%	100% 6124 58.5%
No Injuries	2.0% 85 19.5%	1.8% 79 14.2%	2.7% 117 19.8%	4.4% 190 25.3%	81.8% 3504 52.1%	6.5% 279 22.3%	0.8% 29 22.4%	100% 4283 41.0%
No Response	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	89.6% 43 0.6%	10.4% 5 0.4%	0 % 0 0 %	100% 48 0.5%
TOTAL	4.2% 436 100%	5.3% 557 100%	5.6% 590 100%	7.2% 752 100%	64.4% 6736 100%	12.0% 1255 100%	1.3% 129 100%	100% 10455 100%

The left collisions are significantly more serious for the driver than for the front passenger, no matter what indicator is used, and the roles are revised for right collisions.

But the results are not symmetrical.

- for the collisions on the side of the occupied seat, the front passenger is more seriously hurt than the driver, in a significant way, for both indicators (the difference is greater with the rate of seriousness)
- for collisions on the opposite place, the driver is more seriously hurt than the front passenger in terms of mortality rate, but not in terms of the rate of seriousness)

For the front seat passenger, the collision on the side of his seat is significantly more serious than the collision on the opposite side, for both indicators, while that is not true for the driver.

b. Obstacle hit (Tables 3 and 5)

The collisions against an obstacle are much more serious than against another vehicle: they represent 22% of the cases, and 51% of the fatalities

For the driver the most serious collisions are those against trees, for both indicators chosen (13% and 50%). Then come walls and posts, the order depends on the indicator, and followed by trucks. The least serious collisions are against another touring car, no matter which indicator you choose. (1.1% and 11%).

For the front passenger, the most serious collisions are also against trees, no matter which indicator you choose (8% and 50%). They are significantly less serious than for the driver in terms of rate of mortality, but not in terms of rate of seriousness. Then come walls, posts and trucks, in an order according to the indicator used. The least serious collisions are against another touring vehicle (1.4% and 14%).

c. Comparison of Obstacle Hit and Damaged Part (Table 1)

The distribution of the damaged parts differ significantly according to the obstacle hit.

The front strikes an obstacle more frequently than it hits another vehicle, which is an example of the high degree of seriousness of front collisions (proven in a).

The left front hits other vehicles about twice as often as the right front, although their frequency in striking obstacles is not significantly different, as shown in the great seriousness of right front collisions for the front seat passenger.

Trees are hit about twice as often as other obstacles by the right or left center, which is shown by the very grave results of side collisions and crashes into trees.

Conclusion

The seriousness of touring car collisions depends on the obstacle or vehicle hit and the point of impact. The latter is quite important. Therefore in matters of crashworthiness, we should associate the angles of impact with the corresponding obstacles. In particular,

TABLE 4

Using Card Index of 1/10 of Accidents in 1968
State of Front Passengers of Touring Cars or Vans in Collisions Against An Obstacle or Another Vehicle According to the Part Hit

(7,087 Accidents)

	Front	Rear	Left Front	Left Center	Left Rear	Right Front	Right Center	Right Rear	No Answer	TOTAL
Killed	33.9% 58 2.9%	0 % 0 0 %	14.0% 24 1.4%	7.0% 12 3.0%	1.8% 3 1.4%	18.7% 32 3.4%	13.5% 23 7.0%	2.9% 5 3.2%	8.2% 14 5.2%	100% 171 2.8%
Serious Injuries	39.9% 471 23.7%	1.3% 16 6.2%	19.7% 233 14.0%	5.6% 66 26.3%	1.3% 15 7.0%	15.5% 183 19.6%	6.9% 81 24.7%	1.9% 22 14.2%	7.9% 93 34.3%	100% 1180 19.0%
Light Injuries	32.5% 1022 51.6%	4.1% 130 50.6%	27.9% 879 53.1%	6.3% 198 48.9%	2.9% 93 43.4%	15.1% 475 50.9%	5.0% 158 48.2%	2.4% 75 48.4%	3.8% 120 44.6%	100% 3150 50.7%
Total Victims	34.5% 1551 78.2%	3.3% 146 56.8%	25.2% 1136 68.5%	6.1% 276 68.0%	2.5% 111 51.6%	15.3% 690 73.9%	5.8% 262 79.9%	2.3% 102 65.8%	5.0% 227 84.4%	100% 4501 72.5%
No Injuries	25.4% 432 21.8%	6.5% 111 43.2%	30.6% 522 31.5%	7.6% 130 32.0%	6.1% 104 48.4%	14.3% 244 26.1%	3.9% 66 20.1%	3.1% 53 34.2%	2.5% 42 15.6%	100% 1704 27.5%
No Response	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0% 0 0 %
TOTAL	32.0% 1983 100%	4.1% 257 100%	26.7% 1658 100%	6.5% 406 100%	3.5% 215 100%	15.1% 934 100%	5.3% 328 100%	2.5% 155 100%	4.3% 269 100%	100% 6205 100%

the front collision seems to be most often associated with the limited obstacles, and the off-center collision are most often associated with another vehicle (possibly simulated by a wall).

To be able to define priorities among the possible vehicle improvements, and more generally among the road safety measures, we must evaluate the gains in deaths and injuries for these different types of collisions. Then, thanks to the facts we are going to present, the total gains relative to the various improvements, that will be compared on a cost basis, will be evaluated. If we accept the criteria generally accepted in France for road safety investments, these extra costs should not exceed $500 per vehicle for an improvement of nearly 100%.

TABLE 5
Using Card Index of 1/10 of Accidents in 1968
State of Front Passengers in Touring Cars or Vans in Terms of the Type Of Obstacle or Vehicle Hit

(7,087 Accidents)

	Post	Tree	Wall	Other Obstacles	Touring Car	Truck	Other Vehicles	TOTAL
Killed	5.3% 9 2.8%	16.4% 28 7.7%	15.8% 27 6.1%	8.8% 15 2.7%	31.0% 53 1.4%	21.0% 36 5.1%	1.7% 3 6.5%	100% 171 2.7%
Serious Injuries	9.0% 106 33.2%	13.0% 154 42.3%	12.5% 148 33.6%	12.8% 151 27.0%	39.9% 471 12.5%	12.1% 142 20.1%	0.7% 8 17.4%	100% 1180 19.0%
Light Injuries	5.2% 163 51.1%	4.6% 146 40.1%	6.7% 211 47.8%	9.6% 304 54.4%	60.8% 1914 50.8%	12.4% 390 55.2%	0.7% 22 47.8%	100% 3150 50.8%
Total Victims	6.2% 278 87.1%	7.3% 328 90.1%	8.6% 386 87.5%	10.4% 470 84.1%	54.2% 2438 64.7%	12.6% 568 80.4%	0.7% 33 71.7%	100% 4501 72.5%
No Injuries	2.4% 41 12.0%	2.1% 36 9.9%	3.2% 55 12.5%	5.2% 89 15.9%	78.1% 1331 35.3%	8.2% 139 19.6%	0.8% 13 28.3%	100% 1704 27.5%
No Resonse	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0 % 0 0 %	0% 0 0 %
TOTAL	5.1% 319 100%	5.9% 354 100%	7.1% 441 100%	9.0% 559 100%	60.8% 3769 100%	11.4% 707 100%	0.7% 46 100%	100% 6205 100%

WHY CITROEN CHOSE 1500 LB. VEHICLE FOR ITS STUDIES AND EXPERIMENTS

M. Maurice Clavel, Citroen

After having conducted several hundred tests with impacts and collisions attaining speeds at impact of more than 70 kilometers an hour (or more than 45 mph) we have ascertained that the majority of the standards dictated by the Federal Administration, Standards 201, 204, 208, 214 and 215 for example, such as they are in application or in their short term development, unequivocably doom to the point of eliminating the small, low-range European car of about 1400-1600 pounds empty weight.

It is always possible and even easy by the addition of significant pounds or by the enlargement of the dimensions of a small vehicle to make it respond to the impact standards in force and even the more severe to come. But this increase in mass and volume which automatically causes a corresponding inflation of power, brings about a car with a weight, bulkiness and finally a cost price which pushes it definitively out of its category as a low-range European car, all the while risking a reduction of its fundamental qualities of active safety without, however, having attained the objective "effectiveness" desired in the matter of passive safety.

The "small car" is thus definitively eliminated, giving way to a hybrid vehicle of an experimental nature, but economically unacceptable by the user.

This serious outlook insofar as economical, ecological and social consequences can not be accepted and this for the obvious reasons which follow:

1. The small low-range European car is by its dimensions an essential factor for the fluidity of urban traffic.
2. The small, low-range European car, aside from not being aggressive, behaves just as well in the case of a

collision against or by a 4000 pound car as a 4000 pound car does in a collision against or by one of the trucks of more than 10 tons which plow our roads. Its turning qualities and its performance on the highway (holding of the road and braking ability of a high level) furthermore allow it unquestionably to avoid certain collisions better than a bulky car with less turning ability or inferior handling performance.

3. Inasmuch as the volume of pollutant gases emitted by the motors (carbon monoxide, hydrocarbon, nitrogen oxide, etc.) is roughly proportional to the mass of the vehicle, the use of a small car limits in some important degrees the pollution of cities by automobiles. It is among other things the reason that the pollution problem of big metropolises is less acute in France than in the United States.
4. Finally, "last but not least," in Europe, where the average individual income and the standard of living do not measure up to American levels, the small, low-range car is economical to buy and to use, and it is the sole means of access to motorization by the less affluent socio-professional categories. Unless they are eliminated through regulations, the European fleet of this type of vehicle will reach some twenty-three million units in 1976. In this regard, the elimination of this class of functional vehicles would not fail to provoke in a large segment of the population a feeling of frustration. The character of which no government would be able to accept. Under the effect of ill-adapted and discriminatory regulations, the automobile might undergo a backward evolution and once again become the prerogative of the few well-off classes.

In order to escape from this menacing impasse, all the while helping administrations to establish realistic safety regulations, and in order to save the little car and confer upon it effective safety/collision characteristics without, however, encumbering the weight, the road holding qualities and the cost price, our Society has undertaken a series of research and experiments which can be placed in the body of the program proposed by the French government, A Thematic Action for Secondary Safety by the study of structures and of components: in English, Experimental Safety Sub-System (E.S.S.S.).

Citroen's studies and experiments spaced out over a minimum of two years explore and will explore, for a small vehicle weighing 1500 pounds when empty, the development of classical structures and, still in matters of structures, diverse new orientations touching upon the capacity for absorption of energy, upon the formation of survival spaces after impacts and upon volumes and original arrangements in the seats which allow for a shifting of the driver and of the passengers equipped with restraining systems adapted to physiologically acceptable decelerations.

Mr. Bohers is going to report to you the main orientations of our research program in the light of experience gained during the course of already accomplished experiments on collisions at accelerating speed, with some experiments yet to be made.

You will note that in a Maoist fashion we don't hesitate to constantly question through analysis and comparison the results obtained in the course of this exploration of two years.

So, while pursuing the continual process of the perfecting of its effectiveness, "global safety," we are opposed to the elimination of the small vehicles, victims of regulations of rapid and unforeseen development. A number of these regulations aim to compensate in passive safety for the inperfections of certain vehicles awkward in active safety.

So doing, along the lines of our traditions, we will continue to work for the democratic diffusion of these small vehicles, of which the anti-inflationist and social impact, the road-handling qualities and the highly advanced technology are the long ripened fruit of an innovative European effort.

CITROEN'S PROGRAM OF THEMATIC ACTION FOR SECONDARY SAFETY OVER A PERIOD OF TWO YEARS

M. Serge Bohers, Citroen

CITROEN'S PROGRAM OF THEMATIC ACTION
SECONDARY SAFETY (ESSS) OVER TWO YEARS

1 – SUBJECTS CHOSEN BY CITROEN IN THE FRAMEWORK OF THEMATIC ACTION
2– REASONS FOR OUR CHOICE
3 – UNFOLDING OF THE STUDY
4 – ACCOMPLISHMENTS AND EXPERIMENTS ON PROTOTYPES

Slide 1

1. Subjects Chosen By Citroen Within The Framework of Thematic Programmed Action

Among the eleven topics of interest proposed by the Institute for Transportation Research, the Citroen Society has chosen, for small-range vehicles, the study of the three following points:

- Improvement of the survival space in case of front-end impact (code IRT 4.1)

- Study of new energy-absorbing structures (code IRT 5.4)
- Structure and interior arrangement (minimization of wounds in the case of a bump of the head on the vertical pieces, supports and forward cross pieces)

2. Reasons For Our Choice

As Mr. Clavel has reported, the growing severity of safety regulations, as much in the USA as in Europe, compromises the existence of the small vehicle, and it is necessary to know for this type of vehicle the limits of possible action in the matter of secondary safety, without, however, sacrificing primary safety and the price.

The three points mentioned in the preceding paragraph are those which *condition* the vehicle the most, and each one of them can not be studied independently of the two others, whether it be a question of a new vehicle or the adaption of existing vehicles.

It seems more easy to us to study *a posteriori* the other research subjects proposed by the IRT. Certain ones have long been in the process of being studied by our society and have already been the object of partial realizations (e.g. lighting from the SM – code IRT 4.10 – Lighting).

3. Framework Of The Action Of The Study

To reach our objectives, we believe that the framework of the action of the study should come about according to the following process:

3 – UNFOLDING OF THE STUDY
- 3.1. CONDUCTING OF COLLISION EXPERIMENTS AT THE WALL AND AT THE TESTING GROUND.
- 3.2. CARRYING OUT OF SEVERAL PROJECTS KEEPING IN MIND:
  - 3.2.1. THE POSITION OF THE SEATING AREA WITH RESPECT TO THE MECHANICAL WORKS
  - 3.2.2. THE SHAPE OF THE SEATING AREA
  - 3.2.3. THE PLACING OF THE PASSENGER INSIDE THE SEATING AREA
- 3.3 CRITICAL ANALYSIS OF THE PROJECTS IN THESE POINTS OF VIEW:
  - AUTOMOBILE QUALITY
  - WEIGHT AND PRICE

Slide 2

3.1 Procedure of the Collision Experiments

3.1.1 At the wall, of some existing vehicles with very diversified structures, at impact speeds comprising between 48 and 75 km/h

This, to try to extract information about:
- The influence of the relative positions of the "mechanics" and of the seating area.
- The advantages or inconveniences of certain particular devices, upon which we will enlarge further on.
- The pounds/performance yield as concerns the absorption of energy by typical structures (platform, box structure, body).

3.1.2 At the testing stand

Tests of impact at the wall at speeds progressively higher than 48 km/h give only an aggregate qualitative result of the behavior "in fine" of the vehicle and of its structure, but they don't supply the technician with the elements necessary to know what would be the most judicious thing to do; and the examination of the films,
- if it shows the general behavior of the structure as seen from the exterior
- if it allows for the following of the displacements of direction
- if it offers the possibility of establishing some curves: space/time, speed/time, acceleration/time

of the different parts of the seating area, it is insufficient for grasping the mechanism of the absorption of energy.

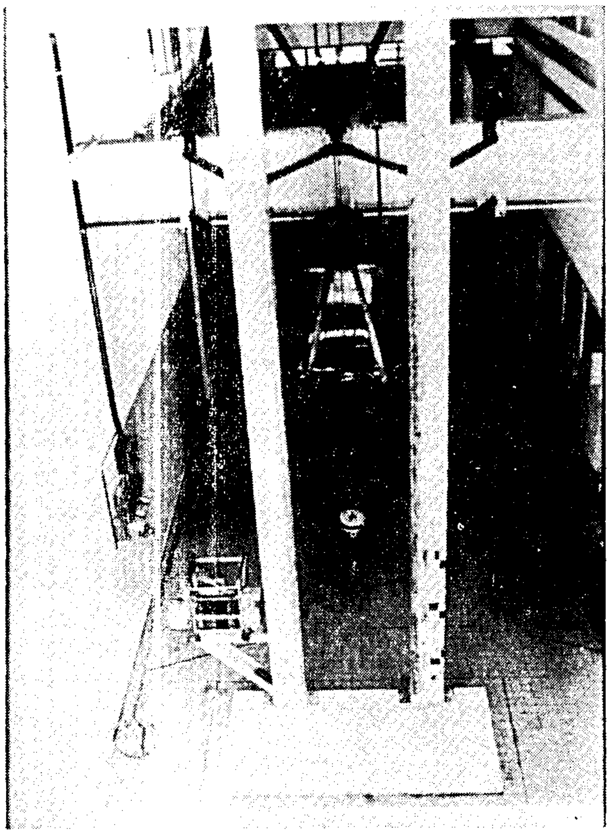
Of course, the examination of the deceleration curves draws attention on certain weaknesses if the curves don't have the purity that would be wanted for the exam, but again it is necessary to analyze the *why* in order to bring about the best adapted and most profitable remedies.

In an effort to understand, we have, since some time ago, begun to carry out, on a throwing tower installed in our technical center, a series of vertical drops at progressively higher speeds. This allows us to see in what order deformities occur (see Slide 3). This may be able to be done on entire vehicles, but also – and especially – on half-vehicles or even on partial systems.

This method, which necessitates a standardization with respect to the experiments at the wall and a certain habit on the part of the experimenter, is interesting because it allows the filming on top, underneath and along the sides (see Annex I and the slides).

3.2. The carrying out of several projects, while taking into special account the following remarks:

- The mechanical motor system and gear box is a non-compressible whole, representing an important part of the mass of the vehicle, and therefore of the kinetic energy. It seems therefore desirable to position it well in advance so that this energy can act



Slide 3

upon the structure during the least amount of time possible.

- The axles, the transmission and the suspension system are rigid elements which can favor the introduction of efforts in the structure, in zones not affecting the survival space, and eventually help this space in stemming or in transferring a part of these forces, or just the opposite, they can represent some dangerous protrusions.
- The steering wheel remains for the driver that which is the closest to his chest, and it is vital not only to limit the backwards movement of this but also the vertical trajectory, which presents a danger for the neck and head of the driver.

3.2.1. Position of the seating area in relation to the mechanics

The true problem seems to appear at this stage of the analysis and study, and our research as to the path to follow will continue without a doubt until the end of our work.

a) Is it necessary to be content with making timid developments yield to classic and familiar structure, example of which developments are reinforcements, adding of cross pieces, side pieces and arches?

b) Is it necessary to simply separate the seating area from some compact mechanical systems, in such a way as to arrange the free zones for the absorption of energy?

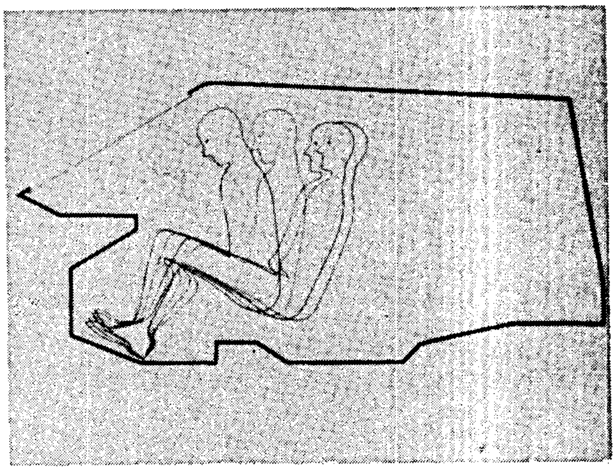
c) Or well, is it necessary to seek out other forms of cars and other devices for the occupants, while abandoning considerations linked to habits and to certain normalizations, which themselves have come out of statistical works performed on actual vehicles?

The first two paths seeming to *a priori* require us to weight down and lengthen a vehicle which we want small and light, we will endeavor to make our action more and more profound, and of a more free fashion while further exploring the third path.

Certain parts of the actual seating areas show a marked reticence for holding of a front-end impact (the front feet and all the higher portion of the vehicle in particular).

The position of the windshield, relatively close to the front occupants, can hamper these people in their displacement in the interior of the seating area, and sets itself up in opposition – out of lack of space – to the realization of new methods of restraint.

Slide 4 shows a picture of the front passengers retained by a three point belt and gives evidence of the importance of the position of the windshield.



Slide 4

3.2.2. Shape of the seating area

The general considerations previously reported, and in particular the "crankshaft" set up by the system of the wing, the wing sheathing, the wheel passage, and the front foot, that one finds in actual vehicles, have brought us to believe that a structure presenting a foot of windshield

- projected far forward
- in continuity with the shaft of the sedan

- bolstered by the forward post higher than the door entrance
- continuous in a geometrically simple surface being a part of a one-piece side panel

could give birth to a rigid and light seating area, our purpose being to make the whole of the structure participate in the absorption of energy. The reinforcements can only be justified when the normally used material has already brought its maximum contribution to the holding of a frontal impact.

3.2.3 Placement of the passengers in the interior of the seating area

We haven't yet spoken of the placing of the occupants in the interior of the structure which we have just sketched out and of which one of the main characteristics is to present a windshield and feet projected way out in front.

How can one position the driver and the passengers?

If we don't arrive, by a certain mental conception, at liberating ourselves from actual texts concerning the visibility through the windshield and the demands attached to its sweep, our first idea will be to position the occupants in classical style (2 and 2 abreast), making the driver the closest possible to the center, in order to assure him visibility in concordance with the SAE norms in force.

This first step, illustrated schematically (see Slide 5) stays very conformist. It offers, to our mind, the following apparent advantages:

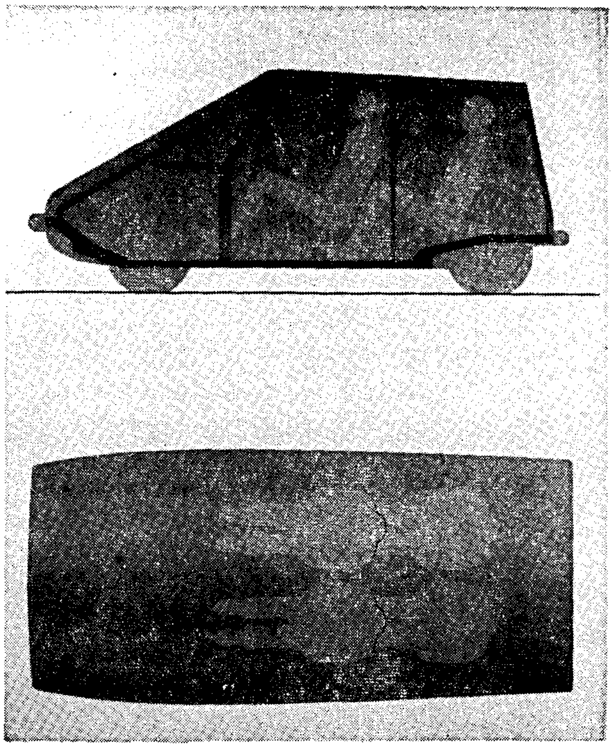
- doesn't upset the habits of the clientele
- larger space between the occupant and the sidewall

This notion is perhaps only suggestive, and it remains to be shown that the separation of the passenger in relation to the wall (independently of the penetration of an offending vehicle, which should be kept in mind) is the sole solution for resolving the whole of the problem for the secondary impact – dummy onto the seating area – is an important factor to be considered. The instant of deceleration in the dummy doesn't take place at the moment of impact, but when the dummy collides with the wall.

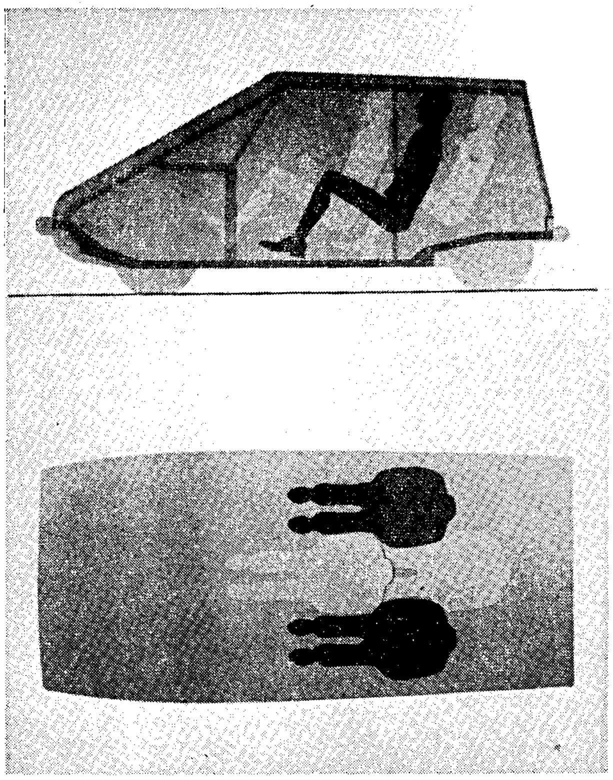
This also allows one to picture that the front seats having been separated from the wall, access to the back seats would be able to be accomplished without having recourse to tilting forward the front seats in a vehicle having only 2 side doors, one on the right and one on the left.

It is well known that having only one door on a side panel gives to this panel a rigidity superior to the two-door solution.

This always with the perspective of arriving at a safe structure and a structure with a reasonable cost.



Slide 5



Slide 6

If we will now free ourselves from "customs" and regulations, this same shape of the seating area allows us to imagine an unusual placement by which the driver would be over the center of the vehicle; two side passengers would be placed on one side and the other of the driver, a bit toward the rear of the latter, and a fourth passenger could place himself behind the driver in center of the vehicle, further back than the side passengers, thus forming that which we will call "the rhombus placement" (Slide 6).

We see therein the following advantages:

- the driver being in the center of the vehicle, the visibility becomes symmetrical rather than the practice now. For a vehicle with a size of between 1 meter 52 and 1 meter 62, the stipulated angles are respectively 17° to the left and 51° to the right.
- *the driver* is not hampered in lateral vision (crossroads) actually masked by the passenger.
- he is free in his movements, the side passengers having their breasts well behind his elbows.
- he can get out of the vehicle indifferently to the left or to the right without disturbing his passengers.
- the aggressiveness of the vehicle can be reduced to a minimum.
- *the side passengers* find themselves in a position allowing them to completely stretch out their legs (good support of footrests facilitating the supporting action).
- they are very far, at the same time, from the dashboard, from the windshield and its posts, and because of this fact, they have at their disposal some very important space for displacing themselves and deadening the front-end impact.
- they are bothered neither by the driver nor by arm movements nor by each other.
- In case of an impact from the side, they can move into the space toward the center of the vehicle.
- they have excellent visibility to the front and to the side.
- as far as the fourth occupant is concerned, one may consider, statistically speaking, that the total loading of a vehicle occurs less than ten percent of the time. It should be remarked that the highly reinforced

structure to the level of the first foot allows us equally to believe that its behavior in a roll could be judged excellent.

A similar structure and rhombus-shaped placement of the passengers has not been manifestly envisioned by lawmakers; also, it appears necessary to us to await the results of diverse actions undertaken in the field of safety in order to promulgate new norms, and to be assured that governments will then modify regulations in force (field of vision of the driver in particular).

3.3. Critical analysis of projects, in these points of view

- *Automobile quality* – Primary safety remains for us a constant care and we cannot envision keeping solutions which would sacrifice the qualities of road holding, of comfort – whence the fatigue of the user – or of the behavior of the vehicle in braking (distribution of weight). So, the very heavy bumpers foreseen by the Federal Norm are of such a nature, while modifying the geometric center, as to influence the road holding of the vehicles.
- *Weight and Price* – The purpose of our action is to allow for the survival of the small car, economical to buy and to use.

4. Accomplishments and Experiments on Prototypes

4.– ACCOMPLISHMENTS AND EXPERIMENTS ON PROTOTYPES

4.1 FIRST STAGE
ADAPTATION ON EXISTING VEHICLES OF DEFINED AND TESTED ELEMENTS ACCORDING TO 3.

4.2 SECOND STAGE
PRODUCTION AND EXPERIMENTS WITH SEVERAL EXAMPLES OF THE DEFINITIVE PROTOTYPE.

Slide 7

4.1. First Step

After analysis of the diverse projects and orientations, among which can be found those which have just been reported, as regards:

- automobile quality
- weight and price

and some information garnered from the experiments at the wall and at the testing grounds, we will equip several existing vehicles with sub-systems seeming to us to be the best adapted, for the purpose of experiments against the wall and narrow obstacles, keeping a record of the precise weights.

In the course of these experiments there will be studied

- the behavior
- the trajectory

of dummies restrained in the seating area by safety belts, as well as the decelerations that they undergo.

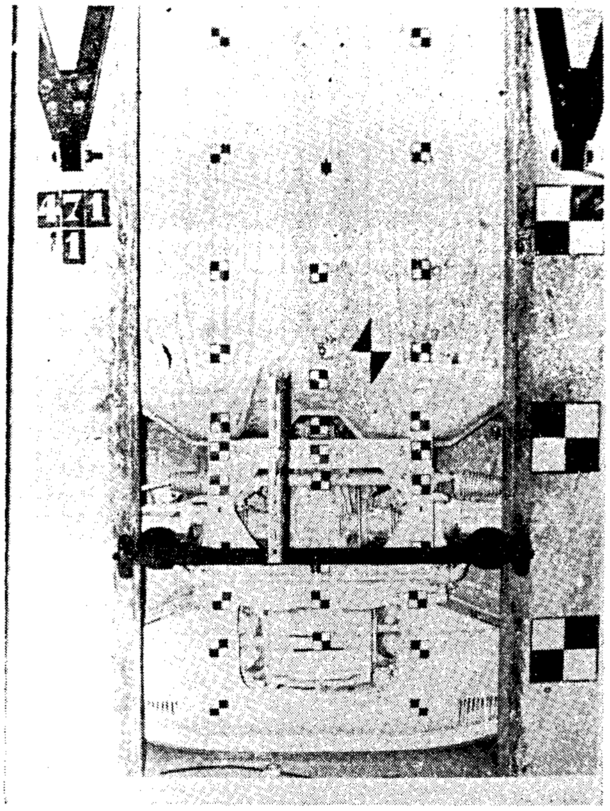
4.2. Second Step

This consists in the production of prototypes according to the information gathered in the preceding step, for the purpose of confirmation experiments.

Addition I

Slides illustrating collision experiments at the testing stand

Slide 8 – A vehicle GS before the test with the marks allowing one to note by particular points the displacements one wants to follow.



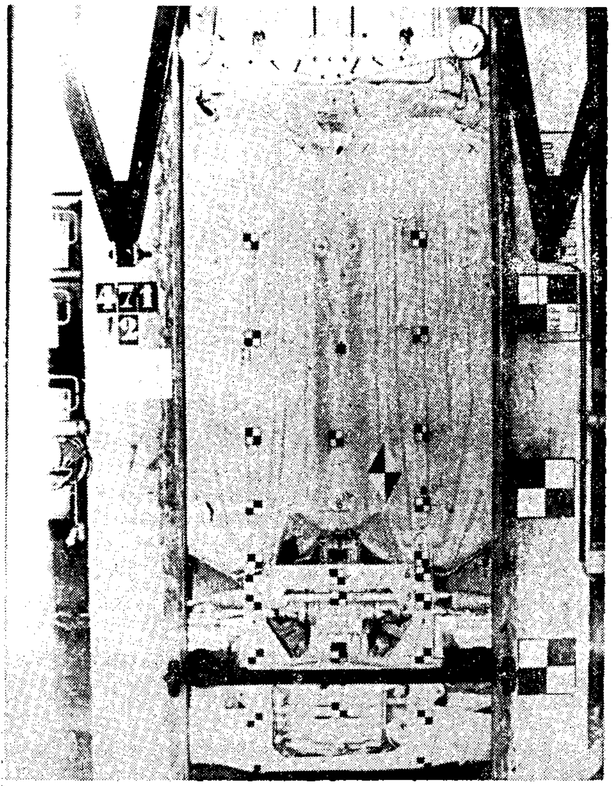
Slide 8

Slide 9 – The same vehicle after two successive falls at 23 and 40 km/h. One notes the relative displacement of the elements of the structure, and the analysis can be continued fall after fall.

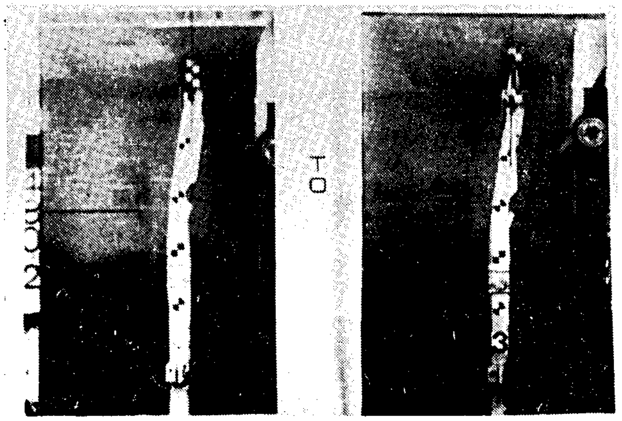
Slide 10 – A study concerning the platform of a 2.3 CV type vehicle. a) 0 time.

- The views on the left show an actual system, those on the right the same system with those particular structural elements designed to progressively absorb energy
- The two tests have been conducted under the same conditions, to wit: 500 kg burden, impact speed of about 20 km/h.

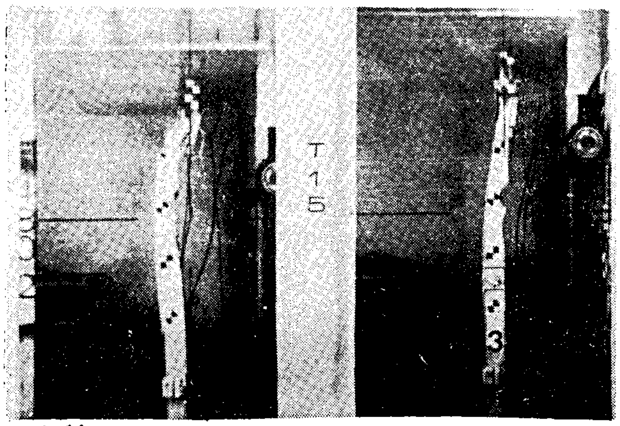
Slide 11 – b) 15 milliseconds time. One ascertains that the deformities of the system are starting on the manufactured system and that the second platform hasn't undergone any deformities.



Slide 9



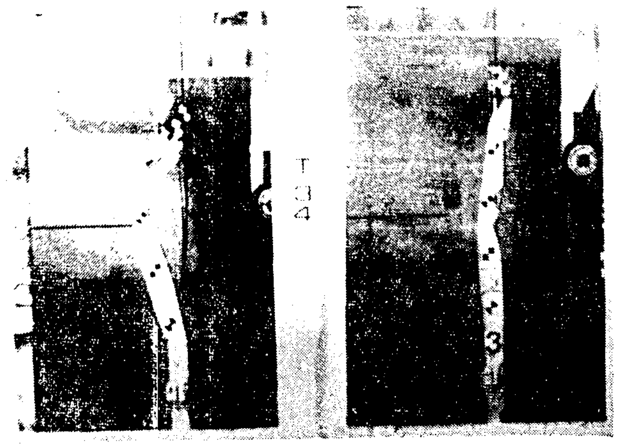
Slide 10



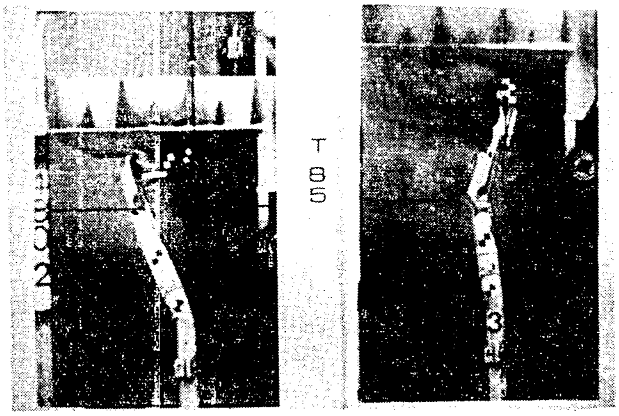
Slide 11

Slide 12 – c) 34 milliseconds time

- A double bending in the manufacturer's system
- Still nothing in the second



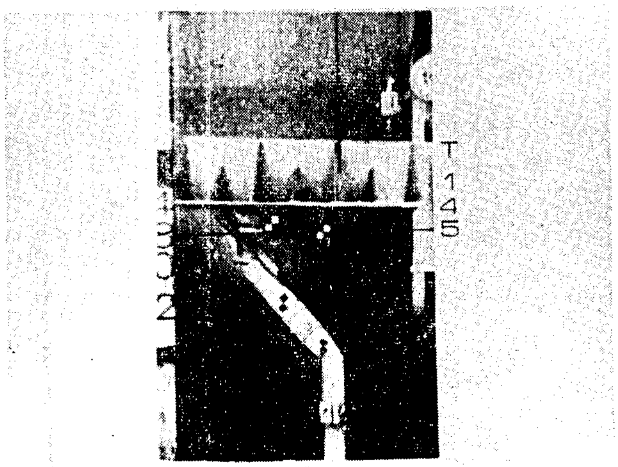
Slide 12



Slide 13

Slide 13 – d) 85 milliseconds time. The deformities grow greater in the system on the left. In the system on the right the deformities have ceased. The experiment is finished.

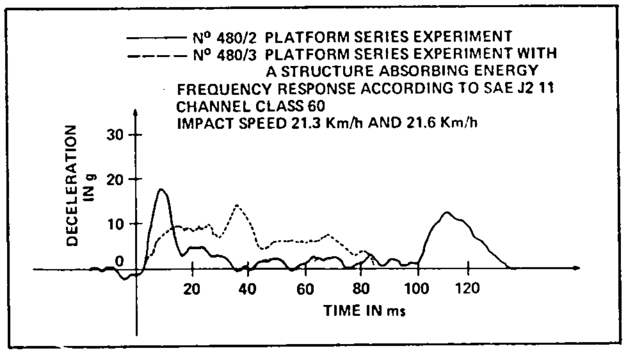
Slide 14 – e) 145 milliseconds. It is the picture of the original platform at the end of the experiment. One can remark that for the same amount of energy absorbed



Slide 14

- The experiments space out respectively at 85 and 145 milliseconds
- The destructions are very clearly different and the penetration remarkably improved in the second case.

Slide 15 – Decelerations as regards time in the two cases.



Slide 15

WORK PROGRAM OF THE RENAULT/PEUGEOT PARTNERSHIP IN CONNECTION WITH IMPROVING VEHICLE BEHAVIOR IN FRONTAL COLLISIONS

Mr. Ventre

Introduction

Work carried out by the Renault-Peugeot partnership comes within the scope of the French Programmed Thematic Actions which deals with 11 points, and we intend illustrating the work method by an example, the first point of the French program – frontal collisions.

For a car manufacturer, solving frontal collision problems means defining, for a given objective, the most effective "protection yield," i.e., the best performance at the lowest price, at the same time having a non-aggressive car.

Our thoughts were directed in the following manner:

- Improving vehicle behavior during a frontal collision at high speed comes down basically to giving one's attention to saving the occupants. The final state of the vehicle will be conditioned only by what is necessary for protecting occupants.
- Saving the occupants, in the light of present day knowledge means complying with the injury criteria currently accepted, or at least imposed by the present American regulations and work statement of the ESV.

This objective being defined, it was important to know the mechanical, physical and reasonable chances we had of succeeding. To do this, if we assume the occupant to be a single mass, we can define a "performance index" for the combined vehicle-restraining device allowing the smallest possible average deceleration limit to be defined to which we should tend if this could be done so that:

$$\text{Average deceleration} = \frac{\text{square of the impact speed}}{2\,(\text{vehicle deformation} + \text{occupant travel inside vehicle})}$$

So, for example, if we take a vehicle which, in an 80 km/hr. collision with a fixed barrier is deformed by 50 cm., and if we assume that the occupant inside the vehicle can travel 30 cm., we can obtain, theoretically, an average deceleration of 30 g. This average deceleration has no physiological meaning but defines the ideal limit which we could not go beyond. This implies that we know how to completely use the deformation energy of the restraining devices in the vehicle as well as that engendered by such restraining means when travelling in relation to the ground; in other words, we have coupled occupant and vehicle. This thought shows that the restraining device must:

- Have little occupant play
- Be quite stiff, which is expressed by the rising distance of stress and the top limit of this stress so as to attain as quickly as possible, at beginning of collision, the top limit of restraining device.

We have considered a trapezoidal diagram for the restraining device, which means we have a limited-stress device that we can now bring into effect either by absorbers on the safety belt or by the air-bag.

From the moment we have a limited-stress restraining device and, consequently, limited decleration of the occupant it's restraining, the compartment deceleration is not entirely a requirement, which is a fundamental point for a manufacturer desirous of making small, but safe cars.

If we had to specify, in a statement of work, a maximum deceleration for a vehicle in a frontal collision, it should so be, not only as a function of impact speed, but mainly of its mass.

Our line of course has been, for a long time, to maintain the "survival space," i.e., to leave the maximum of available space for the highest possible impact speed so that the restraining device may function.

On a concrete basis, this is represented by:

- Maintaining passenger compartment non-deformed for the highest possible speed and, consequently, to do this, raise the deceleration levels so as to reduce deformation.
- Using limited-stress restraining devices so as not to go beyond accepted injury criteria.
- Improving the occupant-vehicle coupling by reducing play between occupant and restraining device, increasing stiffness of restraining device and by preloading occupant as soon as collision starts.

Analytical Phase

Once this philosophy at the outset was stated, we undertook the analytical study of structural behavior to impacts.

We wanted to find out the characteristics of energy dissipation in a mixed, complex structure made from thin sheet subjected to different types of impacts.

This analytical work can, in fact, become fundamental research work such as, for example, the study of the influence of deformation speed on the mechanical characteristics of a material or structure made from this material (Fig. 1 and 2).

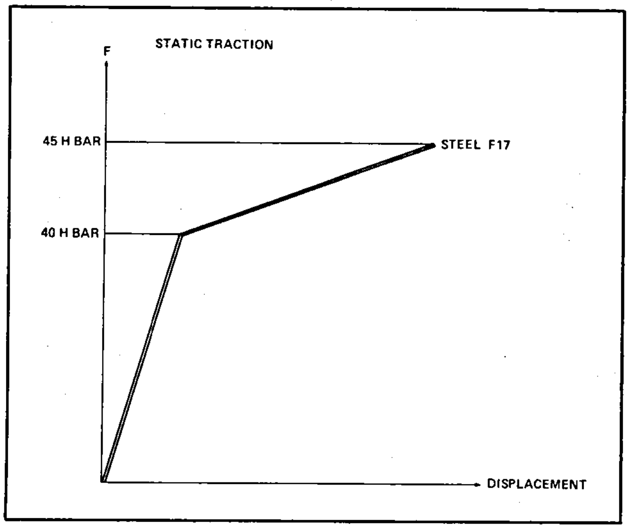


Figure 1

Indeed, this point is not to be neglected, for recent work has shown that the elastic limit of a given material can be almost doubled when passing from a deformation speed of a few millimeters per minute to several tens of meters per second.

In the case of the front unit of a car, the analytical problem is made difficult by the complexity of the structure and by the presence of incompressible parts such as the engine, gear box, etc.

The analytical method used consists, from information supplied by measurements made during impact tests, of a study as detailed as possible of energy dissipation during deformation, so allowing a precise knowledge to be obtained on the dynamic stiffness of the vehicle and of its capacity to dissipate the maximum energy per deformed unit of length.

Knowing the aspect of the "dissipated energy" diagram as a function of deformation, allows the zones where stresses in the structural members have gone

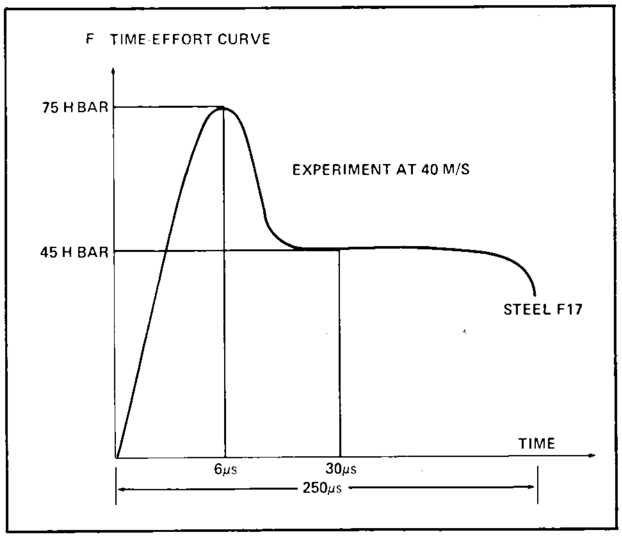


Figure 2

beyond local buckling limits and where deformation has taken place thus reducing its energy absorption capacity, to be shown. Cross checking of the calculations is now carried out, firstly on their own, then in comparison with high-speed films taken during impact, and finally using a dynamometrical buffer.

In the graph (Fig. 3), we can see that the R.12 Series

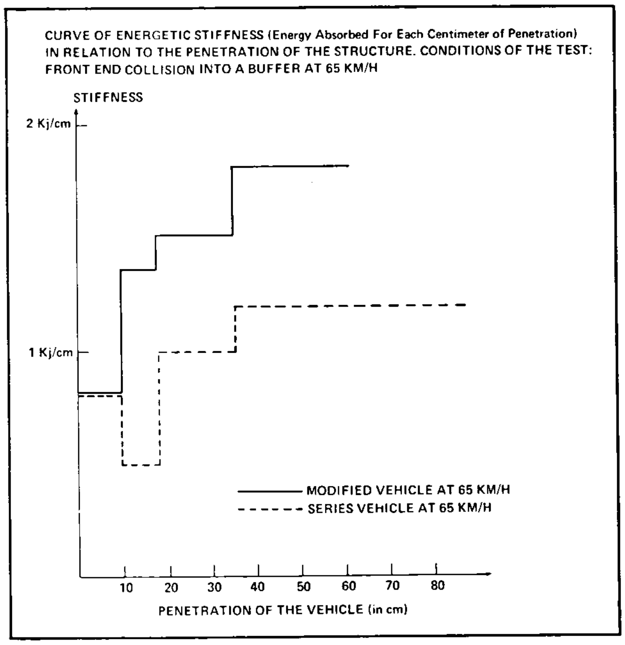


Figure 3

showed a weaker zone at approximately 10 cm. of deformation, which disappeared in the reinforced vehicle.

The dynamometrical buffer (Fig. 4) comprises 12 Kistler piezo-electric cells arranged on three blocks of wood 500 x 500 x 200 mm. thick, designed on one hand to protect the cells and on the other hand to filter the high frequencies of the impact. Connecting of the different cells is carried out as required depending on whether you want an overall value or a distributed value from top to bottom or from right to left.

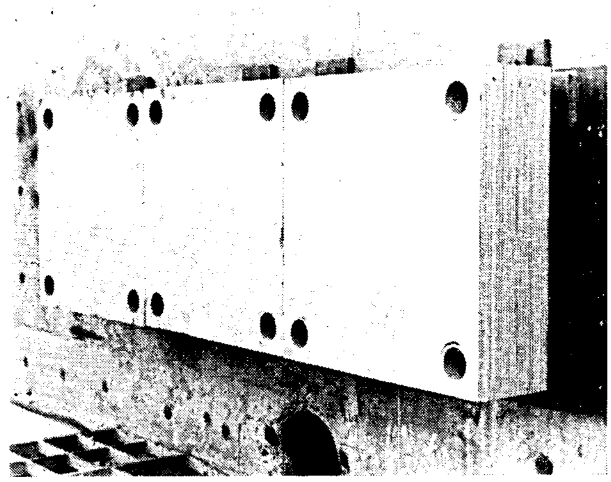


Figure 4

In Figure 5 can be seen the types of curves obtained with this measuring device.

In spite of practical difficulties, this curve allows the decelerated, effective, equivalent mass to be obtained at every moment of deformation. A calculating program

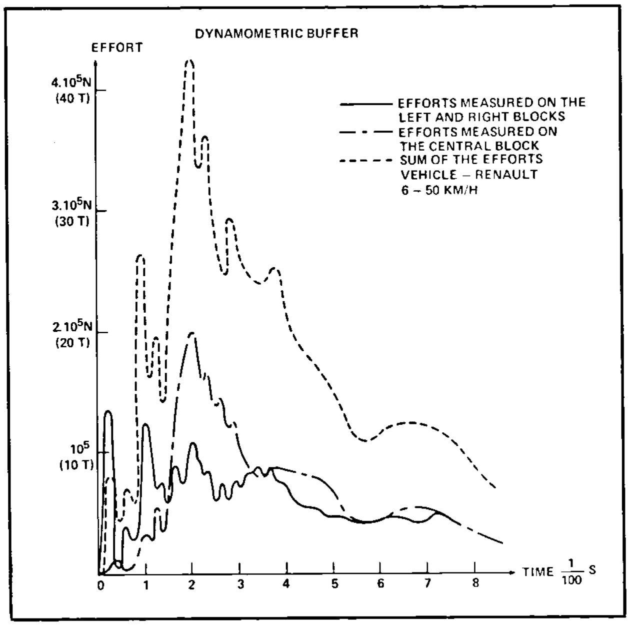


Figure 5

has been developped allowing the influence of the occupants on the energy dissipation in the structure as a function of their restraining devices to be defined. In actual fact, though it is easy to find the equivalence in terms of energy between an empty vehicle and a vehicle in which the occupant mass is an integral part of the vehicle mass, the problem is more complicated when some of the occupant energy is dissipated in the restraining devices.

Indeed, although the total energy dissipated is the same, the result is totally different, from the vehicle deformation point of view, depending on whether the structure stress and that of the additional masses are superimposed, or if the structure decelerates on its members and then the additional masses decelerate on their restraining devices by passing the stresses through the structure out of phase in comparison with those of the vehicle and modified by the restraining devices (Figs. 6, 6a, 6b).

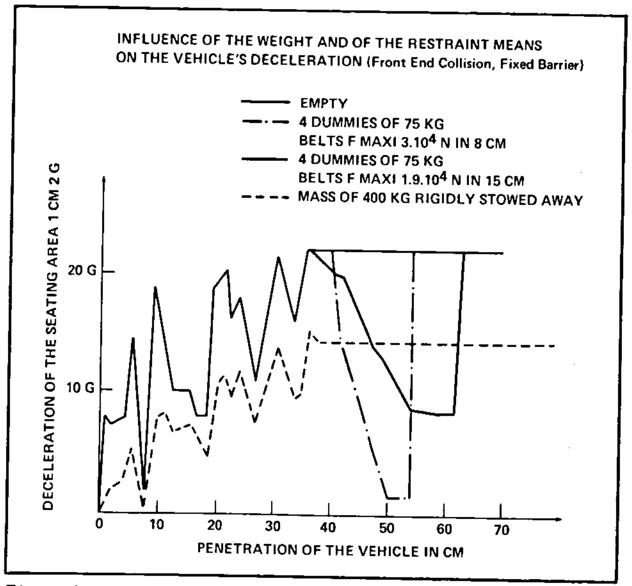


Figure 6

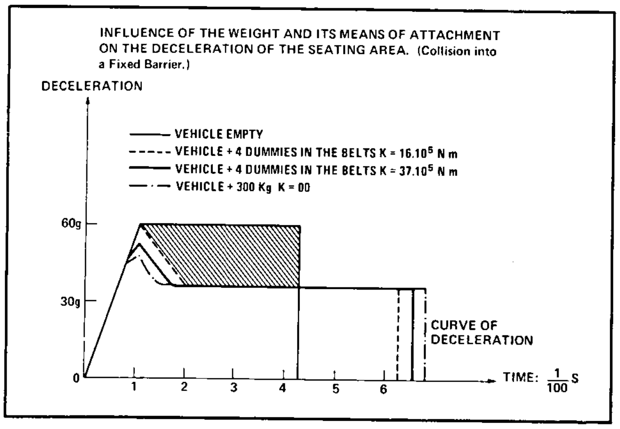


Figure 6a

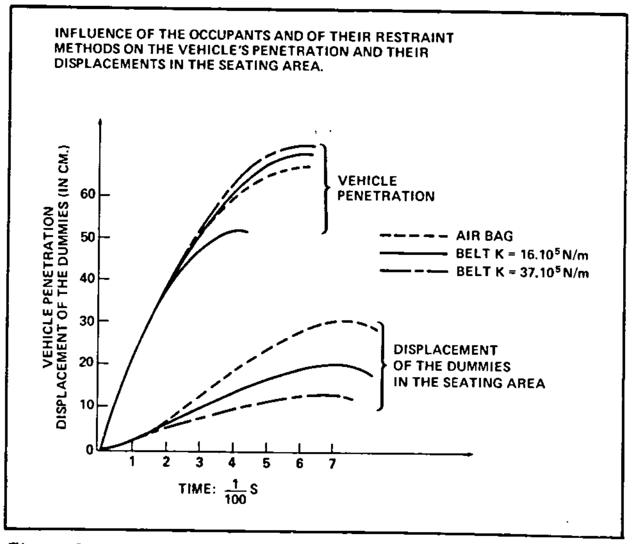


Figure 6b

This difference is shown in the table Figs. 7, 7a, 7b in which, so as to really materialize the influence of the restraining devices, we have, on one hand, characterized these devices by their strength, which is a little simplified, for one must take account of its energy absorbing

INFLUENCE OF THE ATTACHMENT OF THE WEIGHTS ON THE QUANTITY OF ENERGY DISSIPATED BY THE STRUCTURE

IMPACT SPEED	WEIGHT OF VEHICLE	RESTRAINT MEANS USED	SPEED WHEN EMPTY NECESSARY TO MAKE THE STRUCTURE ABSORB THE SAME QUANTITY OF ENERGY
48 km/h	EMPTY		48 km/h
48 km/h	4 DUMMIES AT 75 kg	BELTS OF A STIFFNESS 16.10^5 N/m*	53 km/h
48 km/h	4 DUMMIES AT 75 kg	BELTS OF A STIFFNESS 37.10^5 N/m*	56 km/h
48 km/h	MASS OF 300 kg	STIFFLY ATTACHED INFINITE STIFFNESS	61 km/h

*RAISED IN EFFORT BEGINNING WITH 5 cm DISPLACEMENT OF THE DUMMIES

Figure 7

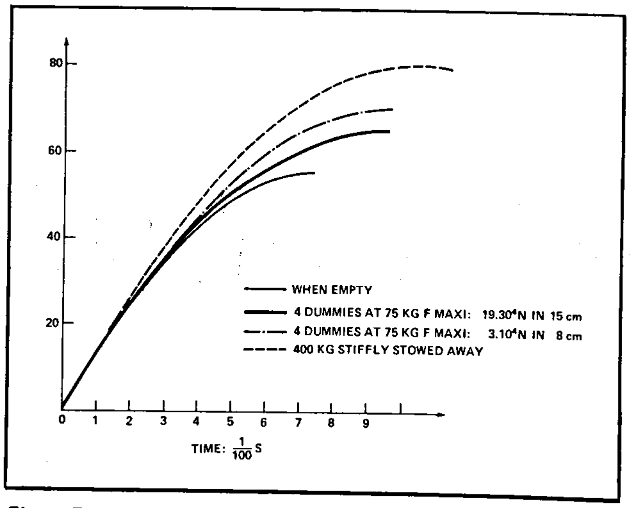


Figure 7a

capacity and, on the other hand, we have pointed out its influence by expressing it in terms of the impact speed of an empty vehicle so as to obtain an equal deformation. These calculations and measurements were carried out on a Renault 16.

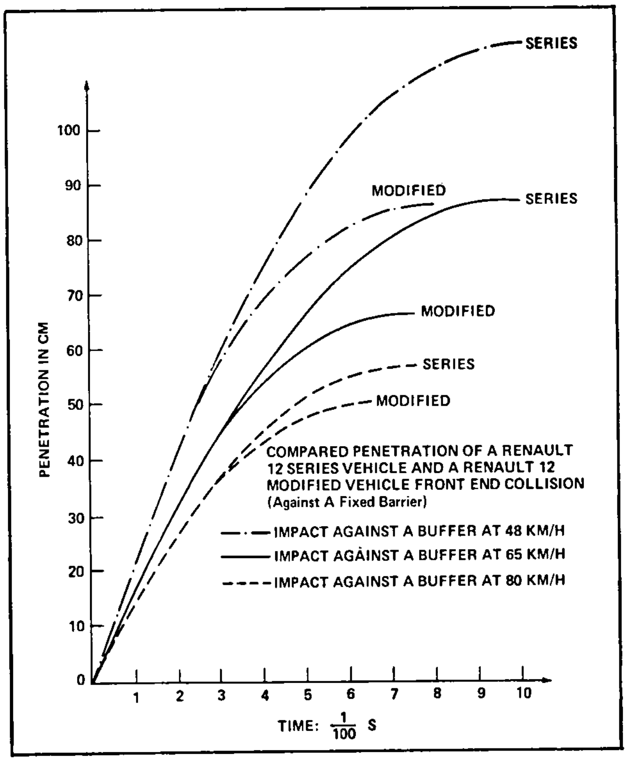


Figure 7b

It is to be noted in passing that it is an arbitrary act to impose a vehicle deceleration law for a frontal impact with a fixed barrier without taking account of the vehicle mass, the occupant mass and the characteristics of their restraining devices.

Experimental Phase

All these thoughts needed, and still do need, experimental support; neither ourselves, nor any other serious manufacturer has made a complete safety vehicle each time we have wanted to check such and such a point or reasoning.

The first theoretical tests were carried out on standard production vehicles on which the reinforcing principles were modelled by steel sections or thick steel plates. We quickly realized that this system, though having the advantage of simplicity and quickness, presented the following disadvantages:

1. Fastening is not carried out industrially and information gathered, consequently, is not complete.
2. Does not take account of methodical requirements.
3. Does not take account of architectural requirements (indispensable part openings, for example).

We have now passed to a more advanced stage consisting of modifying a standard production vehicle but incorporating structural variants taking all imperatives into account. This method has the disadvantage of necessitating more drawings and hours of fabrication but eliminates all the other faults stated, and the test results can be directly used, step by step, at any stage of the research. Furthermore, the vehicle remains standard.

This being the normal work of the design office, we will not go into further detail.

At the same time as the analytical tests on strength of structures as complex as the front part of a vehicle, we undertook work, as have done most of the other car manufacturers, to compare the advantages of the different types of architecture and positioning of mechanical parts. To do this, we proceed in the same way as above, i.e., working on existing vehicles but which do not all belong to the company's range, thus allowing the field of investigation to be widened. We are sure that in this field, an exchange of results between manufacturers would result in a saving of time and money.

It is in this spirit that we started modifying an R.12 according to the first method and soon passed to the second solution (Fig. 8 and 9).

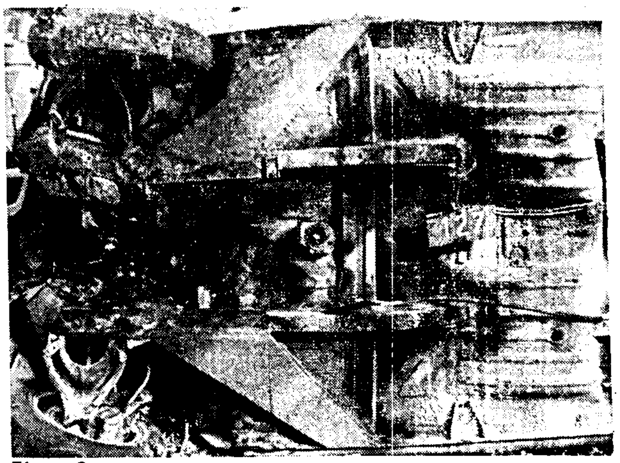


Figure 8

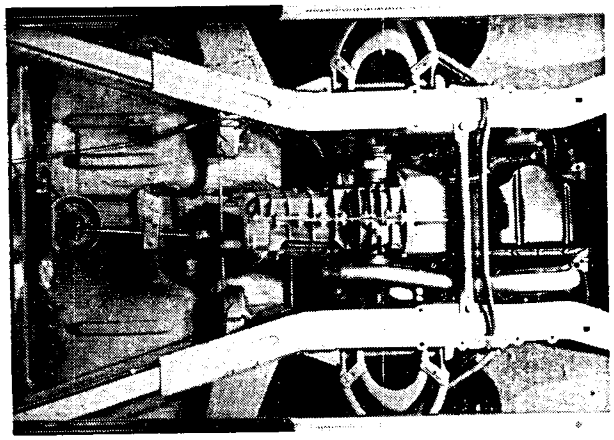


Figure 9

We are now going to show you the film of a test impact at 80 km/hr. of an R.12 thus modified on a fixed barrier.

(Film)

This film shows the enormous difference in difficulty in passing from 65 to 80 km/hr.

You are going to see a test at 85 km/hr. on a vehicle that looks like a Renault 12 but which has a modified structure and, so as to show up the influence of the extra energy to be dissipated between these two speeds, you will see the corresponding sequences, at 70 km/hr. of the same type of vehicle with roughly the same reinforcement although slightly lighter. For this investigation, the Renault 12 vehicle serves as a support for the tests because it is a standard production vehicle and is easy to obtain in large numbers, but the modifications carried out for testing purposes are, for the moment, far from industrial.

SIMPLIFIED COMPARISON
REINFORCED RENAULT 12, 70 KM/H
REINFORCED RENAULT 12, 85 KM/H
FRONT END COLLISION, FIXED BARRIER

TYPE	V	PENETRATION	AVERAGE G	WEIGHT OF STRIPPED BODY
REINFORCED RENAULT 12	70 KM/H	65 CM	23 G	275 KG
REINFORCED RENAULT 12	85 KM/H	95 CM	29.5 G	275 KG

Figure 10

The first view is a left-hand side view at 85 km/hr; the second view is a left-hand side view at 70 km/hr.; the third view is a top view of front unit at 85 km/hr. and the last view is a top view of front unit at 70 km/hr.

It is plain that the nature of the problem is different. Furthermore, we have no example at the present time of a real accident giving, on this type of vehicle, even non-reinforced, deformation levels of this importance.

As you have no doubt noticed, the test vehicle is not fitted with special bumpers for the "pole" collision, for these apparatuses are designed and calculated separately as they are part of the equipment, the weight and price of which are high, and for which the advantage of cost-efficiency remains to be proved.

Indeed, this requirement of the "pole" impact worries us, for at the present moment, we have no exact statistics clearly showing that in a frontal collision, this type of obstacle is a frequent cause of serious injury for occupants. Nonetheless, we set to work on tests and calculations which showed us that, depending on the architecture of the vehicle, engine length-wise or cross-wise for example, the result is quite different. The weight of the metal and, consequently, the price for this one case of impact, is in the same range as what has to be spent for the other cases of frontal collision.

Comparisons With Real Accidents

Detailed analysis of real accidents and vehicle/vehicle test impacts allows a comparison between accidents, standardized impacts and legal requirements to be made.

For example, in the barrier/frontal impact, a front wheel drive architecture with the engine behind the front axle is unfavorable, for the engine backward movements into the vehicle are quite considerable, although we have never found a real accident producing this phenomena. In a head-on frontal collision, the different vehicle heights, different front architectures and the relative strengths of the vehicles, are the reason for the engine not stopping as abruptly in a real accident as against an extremely rigid wall. On the other hand, an offset, frontal collision in a real accident, which is the most frequent, and is closely related to the 30° impact on a fixed barrier, creates problems that are completely different from those of the head-on collision with the wall:

1. Increased stresses in structure, which is deformed on one side only.
2. Wheel penetration not visible in frontal collision.
3. Compared with frontal impact at same speed, the severity of the impact is reduced for the occupant if the survival space is maintained, because:

   a. The speed variation of the passenger compartment is less, due to the existance of a residual speed instead of a rebound speed.
   In the case of impact at 13.3 m/sec., the speed variation for the occupant passes from 14.5 m/sec. in the frontal impact (initial V + rebound V) to 12.5 m/sec. in the impact at 30° (initial V – residual V). The energy to be dissipated in this restraining device is, in this case, reduced by 30%.

b. The greater deformation plus the longer impact time allow an extra gain to be had because of a better coupling.

This explains why, in accidents in which the vehicles appear to be badly deformed, the occupants who are not attached come out of it alive. But this assumes once again that the survival space has been maintained.

In the same spirit, it is possible to show up what may be called "the speed paradox." Let's take the case of a vehicle weighing one ton crashing into a rigid corner with little interference at high speed, 144 km/hr. for example. If we assume that the energy dissipated in cutting the vehicle is three times that dissipated in a frontal collision with a wall at 50 km/hr., we can calculate the residual speed of the vehicle after this terrible collision: 114 km/hr. The passengers on the side opposite the impact have undergone a speed variation equivalent to that in a collision with the wall at 30 km/hr., whereas the front, right-hand passenger risks touching a fixed obstacle at 140 km/hr.

Figure 11 shows a vehicle badly deformed in an offset, frontal collision, out of which the driver, who was not wearing safety belts, came unscratched.

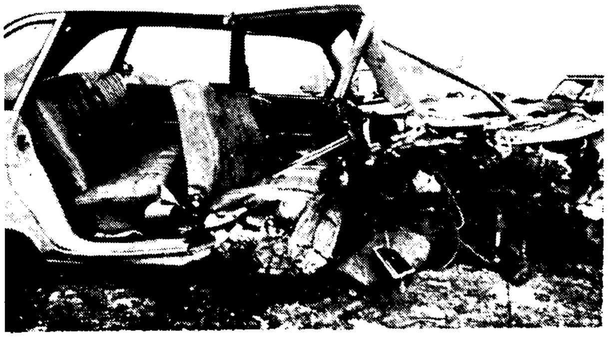


Figure 11

On the other hand, a thorough study of vehicles damaged in road accidents has shown us a certain number of very important points which are not visible in the standardized, frontal collision with a fixed barrier.

1. As many frontal collisions are offset, the impact points, more often than not, are near the front pillar. Our idea is now that the front pillar, side member and toe-board cross member assembly should be particularly strong and carefully made.

2. The compressive strength of body side and, consequently, of doors, is as important as its resistance to side impacts.

3. The interior sheet metal assemblies must be carefully designed and realized because many injuries are caused by more or less irregular sheet edges appearing when considerable deformation takes place.

Conclusions

The frontal collision with a fixed barrier at high speed does not seem to us the most representative of reality and rather than make tests more severe by increasing impact speed, it would seem to us wiser to try and find a more comparable and uniform test as, for example, the impact test at 30°, which would allow us to see more things in one, single test and, consequently, limit the different types and number.

The manufacturer must be left to choose the solutions and, so to do, must have to comply only with performance criteria to the occupants to ensure their protection and to give his attention only to stresses exerted by the vehicle so as to ensure uniformity of all vehicles made.

Careful work carried out on sub-assemblies should result in usable results, either for step by step use or for general research work on safety vehicles. This method allows requirements (for example in statement of work) to be fulfilled and details listed during real accidents to be improved. The safety vehicle should not be a dream car.

PEUGEOT/RENAULT ASSOCIATION PROGRAM ON LATERAL IMPACTS

M. Jean Hamon, *Peugeot*

General Statement – Importance of Aggressiveness

What we call aggressiveness is the action of a vehicle on other vehicles or on pedestrians, as opposed to protection which means the action of a structure on the occupants of the vehicle. It must be precised that aggressiveness has always undesirable effects in opposition to protection. Most of the tests performed till now to improve safety have actually been oriented only to protection, with no consideration for the risk of creating serious damages by increasing aggressiveness without any control.

At the first International Conference on ESV, this year in January, we already knew that aggressiveness plays its part in nearly the whole of the accidents (except those involving a vehicle traveling alone).

Aggressiveness has effects on:

- Non-protected persons (pedestrians, cyclists, motorcyclists).
- Vehicle occupants in multiple crashes.

In a *front crash* between two vehicles, any increase of the mass and structure stiffness of one of the vehicles supposes that the other vehicle will be absorbing a greater part of the kinetic energy of the impact, increasing sometimes considerably the crushing in of its front parts. In a front crash, a vehicle will be more *aggressive* as *the stiffness of its front parts and as its mass are increased* and more *vulnerable* as its stiffness and mass are decreased.

In a *rear impact*, the problem is similar but the consequences are increased owing to the fact that statistically the rear structures are less strong than those of the front end and that the petrol tank is frequently located in that part of the vehicle.

In *lateral impacts* aggressiveness is the most important factor owing to:

- The reduced thickness of lateral structures non-permitting the dispersion of a great part of the energy of the impact.
- The softness of the vehicle side which cannot resist to the intrusion of a more stiffened part.

Exploratory Stage Of The Program Description Of Lateral Impacts

We have conducted a great number of impact tests involving passenger cars within a range of velocity from 25 to 65 km/h. These tests have been performed either with an angle of direction of 45° or perpendicular to the impacted car, using vehicles with mass ranging from 1,000 kg to 2,000 kg.

We are going to see a film which is a retrospect of the most interesting impacts. All these tests show the same crushing in process.

- At first, the upper structure of the impacting vehicle penetrates in the door frame *with no displacement of the impacted vehicle*; the impacting vehicle not having any stiffened structure under its front bumper, the only forces involved are related to the door resistance in flexion these forces being unable to counterbalance the tire grip of the impacted vehicle.

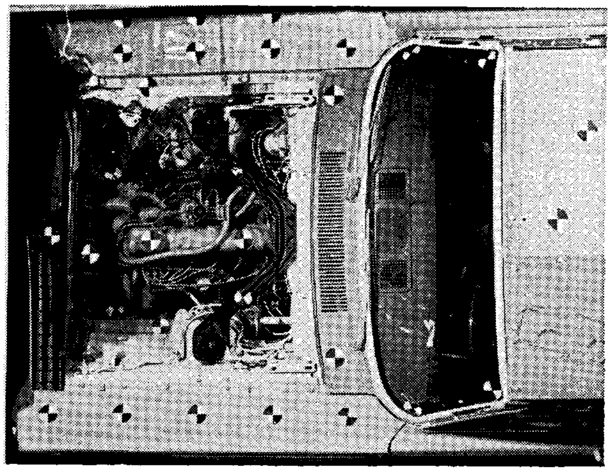


Figure 1

- At second, after the wheels have got in touch with the lower side member, the forces are quickly increasing and the impacted car starts moving. *The intrusion is by this time ranging from 30 to 40 cm*, in

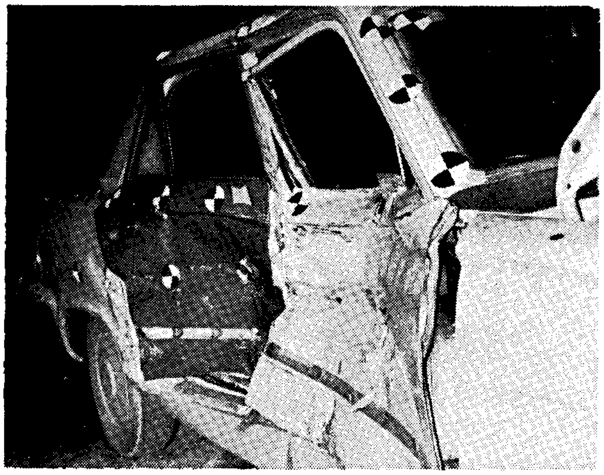


Figure 2

a 50 km/h perpendicular impact, and the deformation is almost completed when the impacted vehicle starts moving. Moreover these preliminary tests have shown evidently the importance of the seats; we have observed that with no seat the intrusion of the door panel increases from 7 cm to 15 cm, in a 45° impact test at a velocity of 24 km/h.

Then, systematically a very low distortion of the impacting vehicle front end is observed, this involving that the greater part of the energy of distortion is abosrbed by the impacted vehicle side, which is the less resistant part of the car.

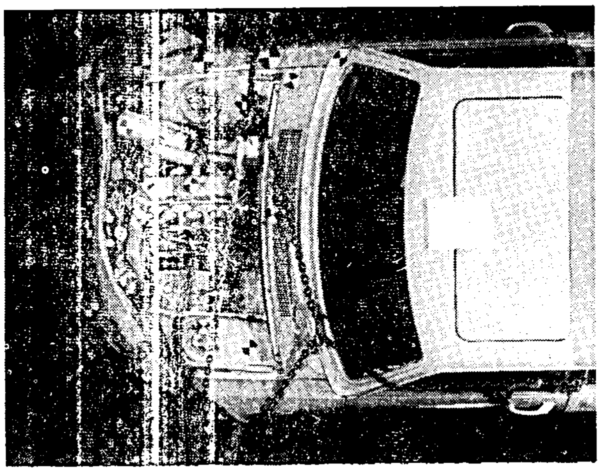


Figure 3

The figures 1 to 4 make a comparison between the distortions supported by the vehicle side and the impacting vehicle front end in a crash between two big vehicles (Fig. 1 and 2) and between two medium sized vehicles (Fig. 3 and 4).

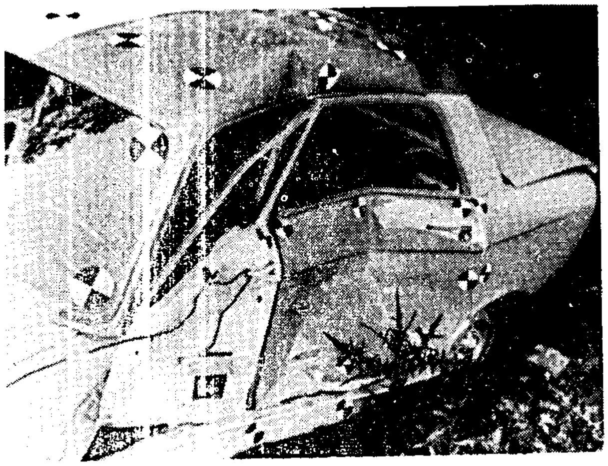


Figure 4

Definition Of The ESSS For Lateral Impacts – Principles Of Reduction Of Aggressiveness

Theoretical Survey Of Aggressiveness

To describe and interpretate the distortions in lateral impacts, we have developed a calculation model (Fig. 5)

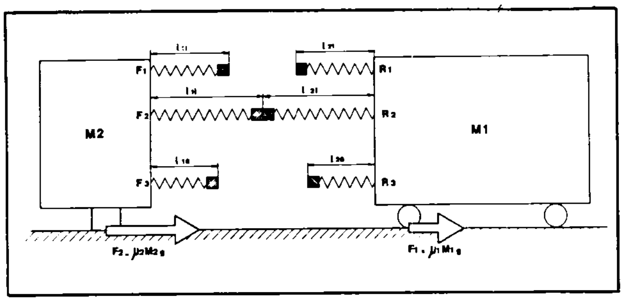


Figure 5

which will be explained with more details at the next Fisita Congress in June 1972. That model (Fig. 6) conforms to the level of experimental results, we therefore applied it to the study of the parameters on aggressiveness.

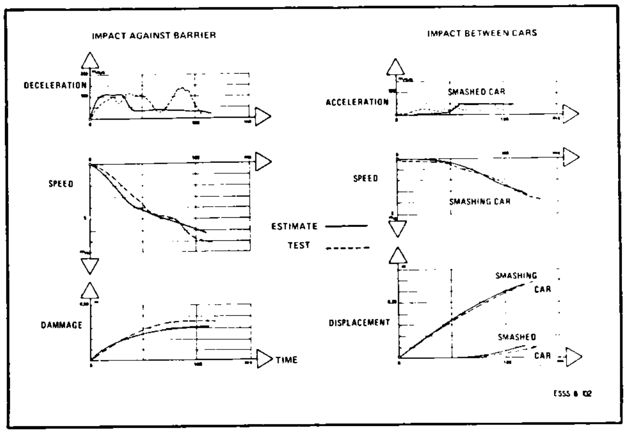


Figure 6

Survey Of parameters

The basic configuration of the calculation is corresponding to an actual 24 km/h lateral impact performed with two "404" model vehicles. The values of stiffness, introduced in the calculation, are directly deducted from experimental static constraint rules with a dynamical factor correction.

Using that model we considered the importance of the vehicle side and front end stiffness, the incidence of the geometrical configuration of the structure, and the consequences due to a variation of the mass of each one of the two vehicles.

Importance Of The Stiffness Factor

Indeed, strengthening of the vehicle side has a considerable influence (Fig. 7), however that possibility is limited owing that it is impossible to carry on boundless strengthening of doors.

On the other hand, an only 10 cm crushing in of the front end structure of the impacting vehicle leads nearly to the same results than doubling the door strength (Fig. 7). It involves that aggressive cars with a high front end structure having a great resistance in the first 10 cm crushing in, could cancel out the results obtained in strengthening the vehicle side.

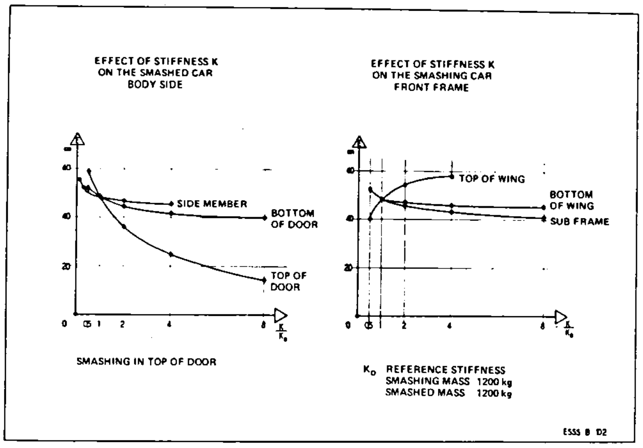


Figure 7

This is applicable to every part of the front end structure facing the impacted door frame and especially the bumper which, owing to aggressiveness, must not be too much stiffened.

Aggressiveness Due To The Geometrical Configuration Of The Impacting Structure

Referring to calculation, we can conclude that the relative positioning of stiffened elements in the vehicle front end is most important in relation with their aggressiveness. Particularly, a protruding stiffened upper structure with a recessed lower part is unfavourable. That protruding part is frequently corresponding to the distance between the bumper contact edge and the wheel, which is not usually protected by a strong structure. It may range about 40 to 50 cm.

The result obtained in decreasing the length of that protruding part is shown by Figure 8; it seems very efficient. On future models we must accordingly provide a stiffened structure at the very front and under the bumper, at the level of the impacted lower part.

Variation Of Vehicle Mass

Any increase of mass is at any case unfavourable, on both impacting or impacted vehicle (Fig. 9). It means that for an impacting vehicle at a fixed impact velocity, *the intrusion will be accordingly important as the impacted vehicle is heavy.*

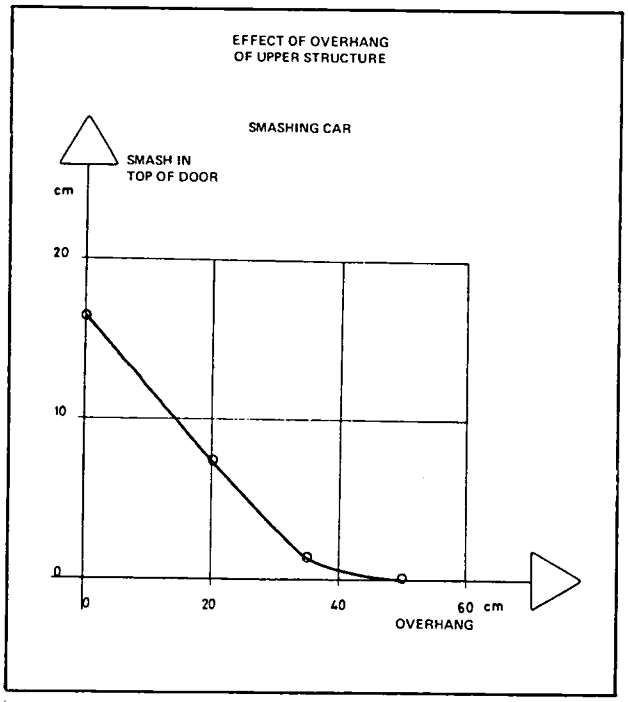


Figure 8

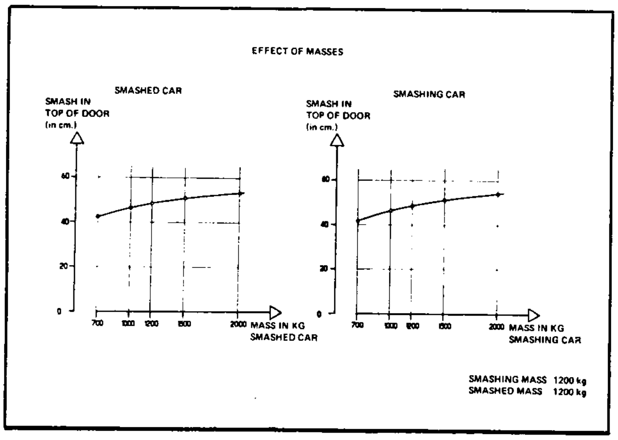


Figure 9

In this point of view the Figure 10 shows the similitude in the variations of the vehicle mass and the strengthening of the vehicle doors. In the case where a limitation of intrusion would be required, corresponding to a 1200 kg vehicle impacting a 2000 kg vehicle equipped with strengthened doors complying with U.S. Standard requirements, a reduction of the door strength corresponding to U.S. requirements x 0.8 is enough to obtain a similar intrusion when the impacted vehicle mass is decreased from 2000 to 1200 kg.

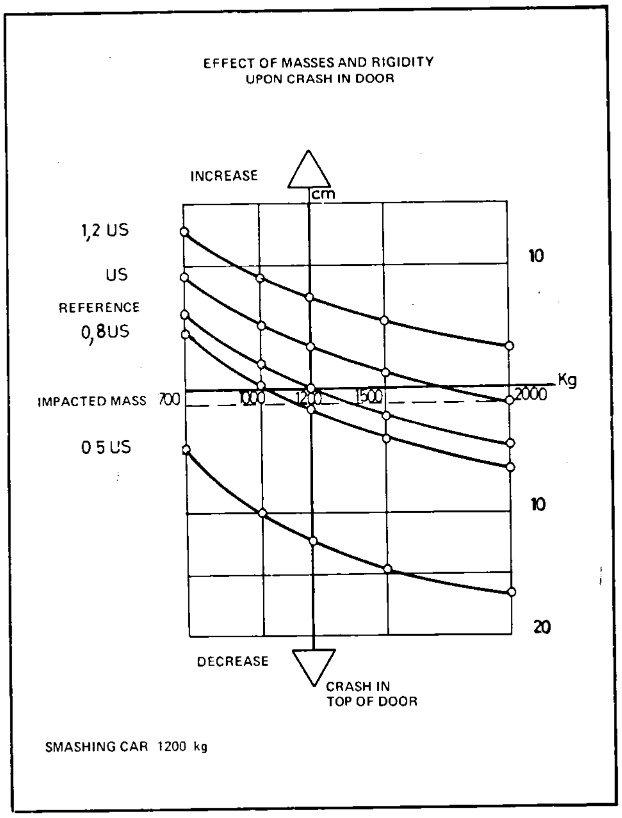


Figure 10

Principles For The Development of ESSS Lateral Impacts

Impacting Vehicle – Decrease In Aggressiveness (Fig. 11)

ESSS involving a reduced aggressiveness have been designed with low parts located as far as possible to the front, *under the level of bumpers* that are always facing impacted door frames while being aggressive according to their excessive strength. The upper part of the front structure is *soft on a 20 cm length*, then the structure is strengthened and shows a good resistance when impacting a wall.

It must be noticed (Fig. 12) that a reduction of the protruding parts of the upper structure improves the interest of strengthening the lower parts both on impacting and impacted vehicles.

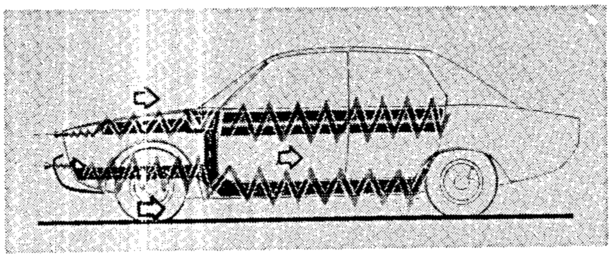


Figure 11

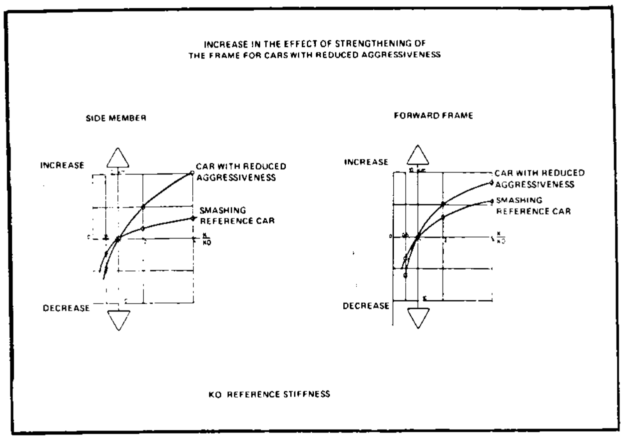


Figure 12

Impacted Vehicle – Strengthening The Vehicle Side (Fig. 13)

The strengthened lateral ESSS involves:

- door strengthening by members having a consequential effect to each other.
- Strengthened cross members near the cowl, the floor (lower part of the dash board, cross rails under the front and rear seats) and the backrest, intended to increase the transverse stiffness of the body by adding structures resisting by lateral flexion
- strengthened seats (Fig. 14) ensuring additional reinforcement of the body sides.

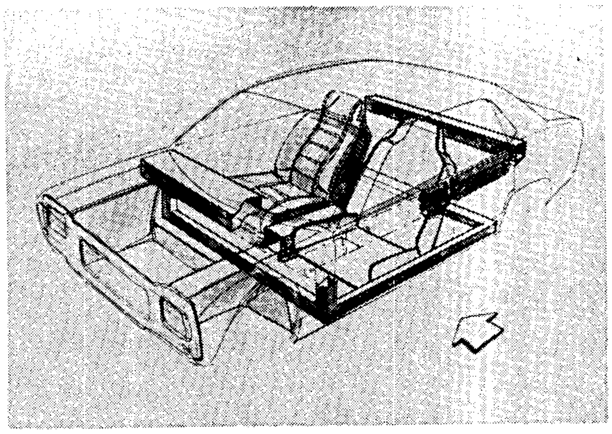


Figure 13

Testing The ESSS In Lateral Impacts

We performed a perpendicular lateral impact at a velocity of 50 km/h. The figures 16 and 17 show the condition of the two vehicles after the impact; they may be compared with Figures 1 to 4. We can see a considerable decrease of the distortions on the vehicle side related to an increased crushing in of the impacting vehicle front end.

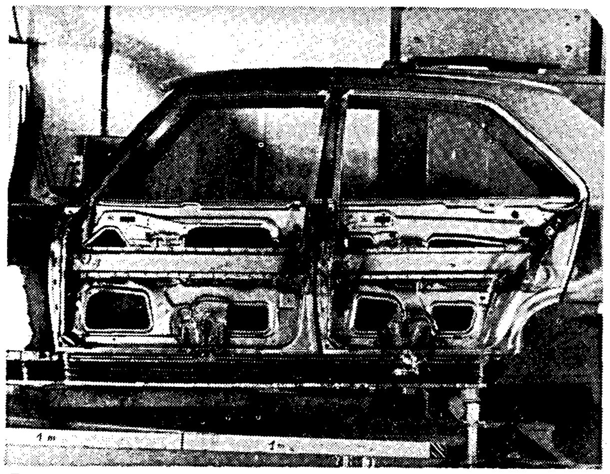


Figure 14

After seeing the film of the test, where the impact test with ESSS is compared with a crash between non-modified cars in the same test conditions, it is obvious that the lower part of the non-aggressive impacting vehicle starts pushing the strengthened im-

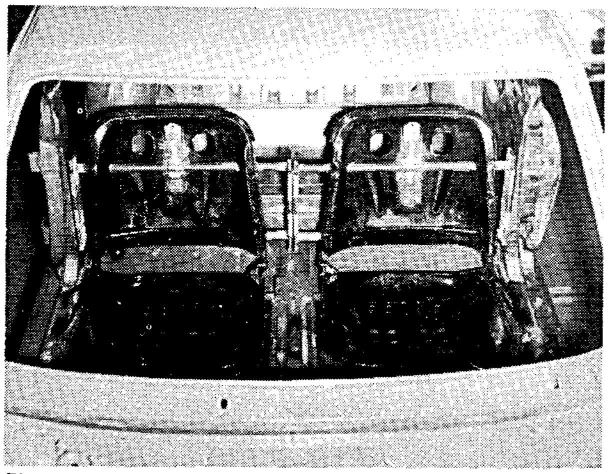


Figure 15

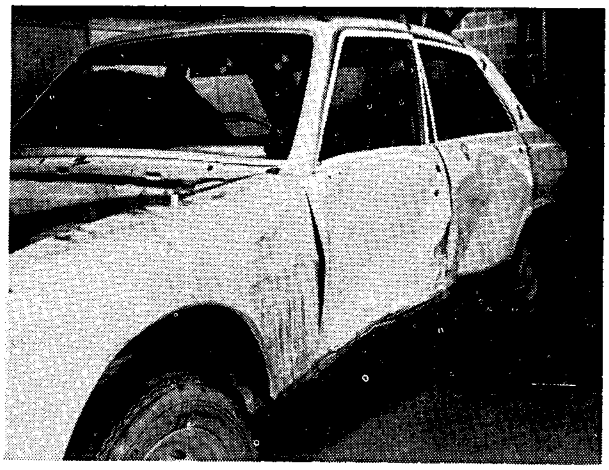


Figure 16

pacted vehicle rather sooner than in the first case, reporting the greater part of the constraints on the side member. The wheel of the impacting vehicle no longer applies on the impacted member.

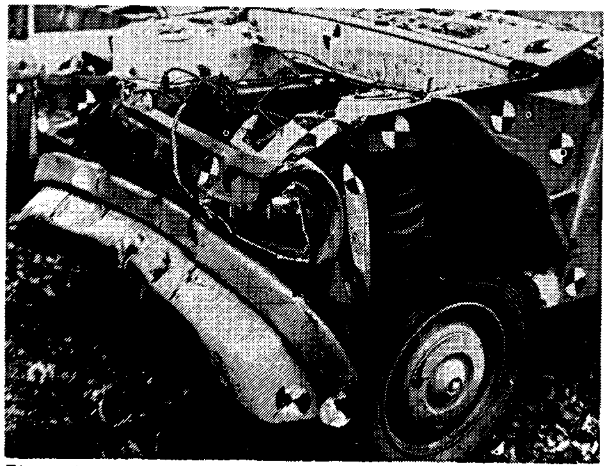


Figure 17

The door panel interior intrusion which ranges about 30 to 40 cm on most of non-modified cars is of 2 cm in the ESSS test.

Finally, the figure 18 shows that the acceleration of the impacted passenger compartment is not considerably increased, the maximum average value is about 20 to 30 g, the only difference is that it starts sooner after the impact.

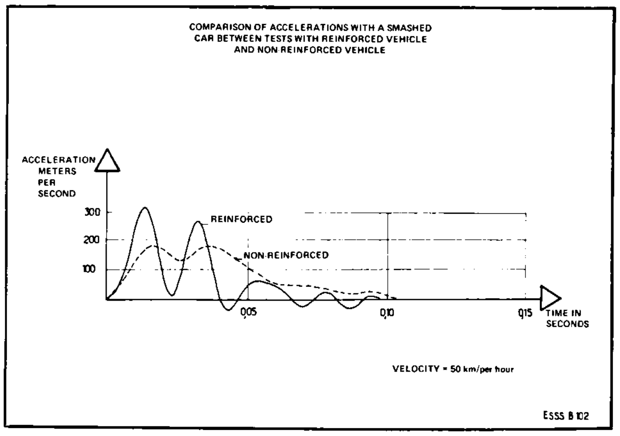


Figure 18

Conclusion

Reducing the aggressiveness of vehicle front ends and the body sides vulnerability, the principles to be applied seem to be the following:

a. *On the impacting vehicle.*

- Decrease the stiffness on a short length of the upper part of the structure.

- Adding a strengthened lower part leading as far as possible to the front and located under the door sill of all vehicles.

b. On the impacted vehicle.
- Reinforcement of the lower parts at the level of the floor.
- Strengthening with cross members the two sides of the body with structure elements or strengthened seats.
- Reinforcement of the door resistance to flexion.

Finally, it seems to us indispensable to investigate if any solution involving the structure and supposed to improve protection, would not increase the aggressiveness for the vehicle occupants.

REASONS FOR THE LINE TAKEN BY THE PEUGEOT/RENAULT ASSOCIATION IN STUDIES REGARDING SAFETY

M. Georges Boschetti, Peugeot

When safety research emerged from the secrecy of the laboratory and when study contracts were proposed by Governments, the Peugeot/Renault Association selected the following lines:

1. To first develop a free research program so as to experiment, and then, to gain better knowledge without, at first sight, laying down unnecessarily restrictive specifications.
2. To ascertain the relationship between cost and effectiveness by developing or examining the enquiries concerning real accidents and by carefully placing a figure on the cost of the solutions under consideration.
3. Attempt to apply, as soon as possible, the solutions that are partially advantageous on current models and more completely on future models with more integrated solutions.

Firstly, therefore, we wish to experiment, before deciding, and it is to remain faithful to this principle that we have, today, preferred to ask Mr. Ventre and Mr. Hamon to first present our studies on the front impact, the side impact and on aggressivity before explaining our main ideas.

You will then understand why we were spontaneously in agreement with the French Government who first proposed studies on safety cars in sub-assemblies with free specifications, since called ESSS by the NHTSA, by leaving everybody free to continue later with the ESV synthesis of the complete vehicle.

By this as it may, I believe that the two methods should not be artificially opposed. What we have seen over the last year in various publications and in the very work of this conference confirms this.

- The manufacturers that accepted ESV programs are, in actual fact, working on the ESSS to prepare their ESV.
- The manufacturers that accepted ESSS programs work in the same manner.

We so believe that the time has come to call for an armistice in this war of terminology.

For its proponents, the determination, at first sight, of specifications more rapidly mobilizes energies but, for us, it has the very great defect of fixing and, above all, crystallizing specifications that can sometimes be unnecessary or even be a concern.

For example:

- Mr. Ventre recalled that the mandatory requirement of a maximum driver/passenger compartment deceleration of 40 g. after a front impact is absolutely disastrous where the improvement of light cars is concerned and, in our opinion, unnecessary for heavier cars.
- Doctor Tarriere – Chief of our Physiological Laboratory – this afternoon, will explain that, out of 400 accidents analysed, the front crash as specified, very rarely exists.
- In the test against post, it is not evident that the very special solutions that it will require will be the best in the case of other impacts as in the optimum synthesis.
- Mr. Hamon has shown that the abnormal reinforcement of car front parts is very bad for protection in the case of side impacts.

I will insist on this side impact against which, as we have shown, large cars are no better protected than small cars. Door thicknesses do not enable, and this by far, structures that are as large as the deformable structures of the front and back parts of cars.

The important point is the lowering of the center line of the most aggressive rigidity.

Since it is fairly natural that the bumper be the most protruding component of this aggression center line, we insist on countering any policy of raising bumpers which is contrary to the sought-for aim.

We are pleased that the NHTSA has amended Standard No. 215 thereby making it possible not to aggravate this misunderstanding as was the case with the original standard which appeared, to us, to be a serious mistake.

This concept of aggressivity is not limited to the improvement of structures.

It is the entire behaviour of drivers that is in question. The latter are not the only ones, with their passengers, that must be protected. Third parties also have the right to this in the same manner and for the same reasons.

Furthermore, instead of seeing study programs developed concerning safety for oneself and, later, to see along the same lines safer cars praised, I would rather yet hear talk of cars that are less aggressive and less dangerous to others.

Our second aim is the study of the cost/effectiveness criterion.

For this, the Peugeot/Renault Physiological Laboratory works in relation with the hospital at Garches – near Paris – in collaboration with the local police, under the Patronage of the National Road Safety Office. It analyses the origins and true cause of accidents in relation with active safety but, above all, analyses for passive safety, the origins of characteristic injuries and the car components in question.

We thus hope to find truly useful solutions and then prepare good tests; because there are both good tests and bad tests.

It is most important to select the tests that result in the greatest effectiveness for a given cost meaning those that will best protect passengers in the greatest number of cases.

In actual fact, it must never be forgotten that safety solutions based on tests cannot protect occupants under all accident conditions.

It would be most serious for the public to believe, and it must not be led to believe that people will be protected in all cases because compliance with a test has been established. This would be a breach of trust.

To complete our cost/effectiveness studies it would be necessary to further improve the information for manufacturers on the statistical level.

We particularly request the insurance companies and the National Authorities to give us more, and, if necessary, confidential information concerning all the statistics which could lead to progress in our research work.

If we calculate, with the greatest possible accuracy, the extra cost of the solutions as such and the supplements due to weight and volume increases, it is absolutely necessary for us to have the information as to their true utility available.

Our third line of action is the application of the solutions retained.

Research work by component by taking, as a material basis, production cars that are more or less extensively modified, enables a faster application of solutions that could be found interesting whilst, more completely testing the audacious futuristic solutions.

For information purposes, the Peugeot/Renault Association has already destroyed 450 vehicles during impact tests and will probably destroy a further 200 next year.

We are attempting to well separate, in application, what can be done fast, what will require three or four years and the more ambitious solutions that prepare the cars of the future.

I will conclude by recalling that the consequences of all these studies, as you know, will be larger, heavier and more expensive cars and this is even truer to fight if anti-pollution solutions are added, which, as such, are rendered more difficult for heavier cars requiring higher powers.

Now, it is not unknown to you that the public, at least in France, and, I believe, in a large number of European countries, is clamouring for cheaper and smaller cars.

The laws of the market, alone, do not enable us to meet these contradictory requirements.

What, then, must European manufacturers do?

We do not believe that this is solely their problem since, with a sufficient delay, they can develop their production in the direction which they will be required to follow.

This is, above all, a problem of general policy which concerns, not only the price level but also town planning and the environment. This is why the question has been raised with all our Governments.

We are ready and I believe that our colleague manufacturers are also, to progressively develop all solutions leading to true progress in safety.

However, the public should be warned of the economic consequences of the choices that the Governments will make in their name.

SECTION 3

CRASHWORTHINESS SEMINAR

Part 1 – Introduction

Mr. Edward M. Chandler, *Chairman*

Part 2 – Structures

Dr. H. Appel, *Germany, VW*
Mr. William J. Wingenbach, *USA, AMF*
Dr. H. Appel, *Germany, VW*

Part 3 – Restraints and Occupant Simulation

Dr. G. E. Sutherland, *USA, Rocket Research*
Dr. H. P. Willumeit, *Germany, VW*
Dr. Reidelbach, *Germany, Daimler-Benz*
Dr. M. A. Macauley, *United Kingdom, Motor Research*
Mr. J. Leroy, *France, O.N.S.E.R.*
(Presentation not available)

Part 4 – Subsystems, Testing and Other Considerations

Mr. Robert Schwarz, *USA, AMF*
Mr. R. Van Laethem, *Belgium, Glaverbel*
Mr. C. R. Ennos, *United Kingdom, Ford*
Dr. C. Tarriere, *France, Renault*
Mr. W. Rosenau and Mr. U. Seifert, *Germany, VW*

SECTION 3

PART 1 INTRODUCTION

Chairman:
Mr. Edward Chandler
Office of Experimental Safety Vehicle Programs, National Highway Traffic Safety Administration, United States Department of Transportation

Good afternoon. It is a real pleasure to take part in another open forum on crash injury reduction with the participants in the International ESV Program. We were very pleased with the discussion sessions in Paris at the First International ESV Conference. It has been seldom, if ever, that so large a number of people have focused so effectively on the technical aspects involved in crash energy management as was done at this meeting. Also, we felt that the discussions were carried on frankly and with candor. We are sure that the seminar today will proceed in the same manner and again update our understanding of the broad fundamental problems involved in reducing injuries and fatalities from automobile crashes. In addition, we believe that this session will give us a better understanding of some of the special problems encountered in this field.

I will briefly review the discussions in Paris where the United States used its performance specifications for the Family Sedan to structure the proceedings. Our position was then, and is now: 1) that we were presenting a first attempt at formulating such performance specifications, 2) that we recognize the need for further study and possible revision of some of those specifications as feasibility studies proceed, and 3) that we invite your comments and constructive criticism. More important, however, was our desire to make the specifications available to other nations, to be used to the extent they are applicable, as a base from which to formulate your own requirements. At the same time, we certainly have profited from the feed-back we have received from you.

It is our intention that this seminar shall be of the same general character as the Paris discussions, but with a somewhat revised format. By this, we mean that rather than using our specification for format, we have selected certain topics for discussion that we believe present common problems to us all. These suggested topics were sent out in the proposed agenda and, with minor changes in order to group them, appear in the final agenda. If we have inadvertently omitted some topics of broad interest, we invite you to introduce them, to the extent that time permits.

With regard to time, it appears that we may be pressed. We have 13 papers that have been submitted for this seminar and we have divided them into three groups as shown on your agenda for this session. One hour has been allowed for each session with a 15-minute break between sessions. With this many papers, we can only allow ten minutes per paper if we are to provide any time for discussion. Only three papers have been scheduled for the first session, but if we can save some time on this session, we will move onto the next session. By the same token, if we lose time here, we will have to make it up later. Therefore, I may be forced to call for some speakers to conclude their presentations earlier than they wish. All papers that were submitted will be published in the Report of the proceedings of this Conference, even if we are able to spend only a little, or possibly no, time on some of them.

BENEFIT/COST ANALYSIS FOR EVALUATION OF ESV IMPACT TESTS PROPOSAL FOR REDUCED REAR END IMPACT SPEEDS

Dr. Hermann Appel, Germany VW

Survey

Benefit/cost considerations show that ESV crash tests are not equivalent in their relation to each other. For the design of the rear structure in ESV terms the benefit/cost factor is considerably smaller than for the front and side structure.

A reduction of the relative impact speed front-to-rear from 75 mph to 50 mph results in a better matching of the benefit/cost factors and thereby in a more significant balancing of the test conditions.

The present derivation has only the character of a model, since the statistical results of the accident research entering the benefits are subject to criticism and the cost estimates are based on coarse assumptions. Absolute values for benefits costs, or benefit/cost factors are of lesser importance than relative relations.

1. Benefit/Cost Studies

The question whether the essential tests for testing the vehicle structure established by the USA Specifications.[1]

50 mph frontal collision against fixed barrier
75 mph front-to-front collision
30 mph front collision against side
75 mph front collision against rear

are meaningful in relation to each other, can apparently be answered only be means of benefit/cost studies. The starting point is the present condition, that is, the present construction of the vehicles to which the results of statistic accident research refer. If the improvements of front, side and rear structures required to meet the specified tests are always resulting in the same benefit/cost factor, the assumption may be made that the tests are meaningful in relation to each other. If not, the use of an additional cost unit in one structural member would bring more effectiveness than the same cost unit when used for another structural member.

While the expenses (cost) for a given improvement of the structure can be calculated, the determination of the respective effectiveness must be based on statistical results of accident research.

This procedure is connected with some uncertainty for the following reasons:

a. the discrepancy of tests and real accidents;
b. the inaccurately estimated impact velocities;
c. the assumption that the future traffic-system will be similar to that today.

A few significant results are shown below:

1. More than 50% of accidents are vehicle-vehicle collisions[2,3] refer to Figure 1.

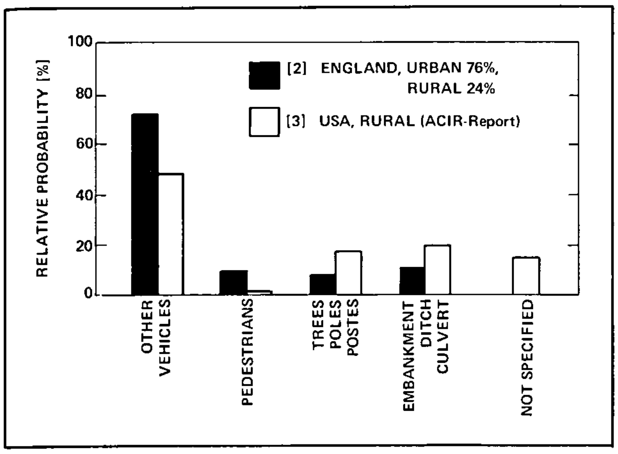


Figure 1

2. Approximately 50% of all serious accidents are front impacts, 25% are side impacts, 15% are rollovers and 2% are rear impacts[4], refer to Figure 2. In cities, the share of front impacts drops to 35%, the share of side impacts increase to 35%[5].

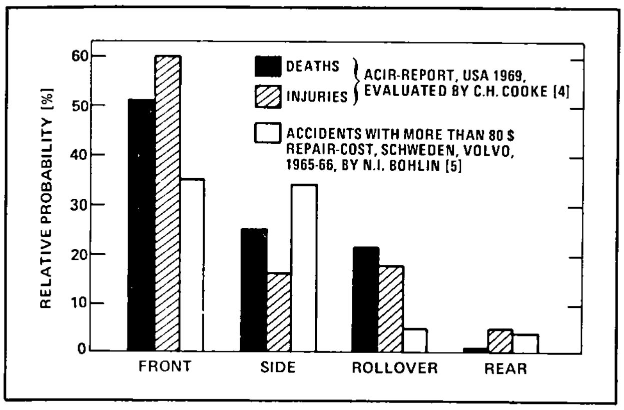


Figure 2

3. In 50% of all accidents the impact speeds are lower than 25 mph (city traffic[2,5]) or 45 mph (rural traffic[2]), refer to Figure 3.

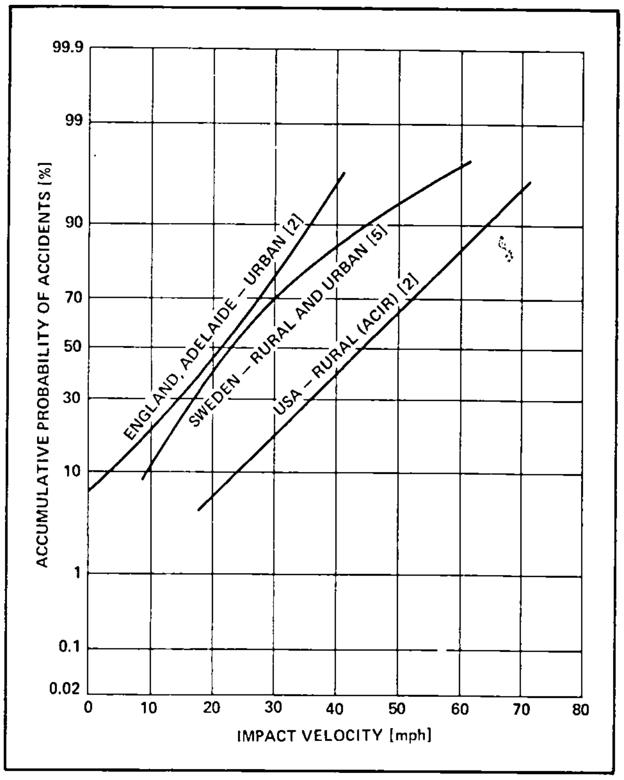


Figure 3

4. At a given impact speed the risk of injuries and death increases from the single-vehicle-side-impact via the single-vehicle-front-impact and the vehicle-to-vehicle-front-impact to the most dangerous type, the vehicle-to-vehicle-side-impact[4], refer to Figures 4 and 5.

In view of the ESV tests Figures 4 and 5 provide the following information:

1. Protection up to 30 mph against vehicle-to-vehicle-side-impacts would save 55% of (for this type of accident) the injured and 38% of the dead.

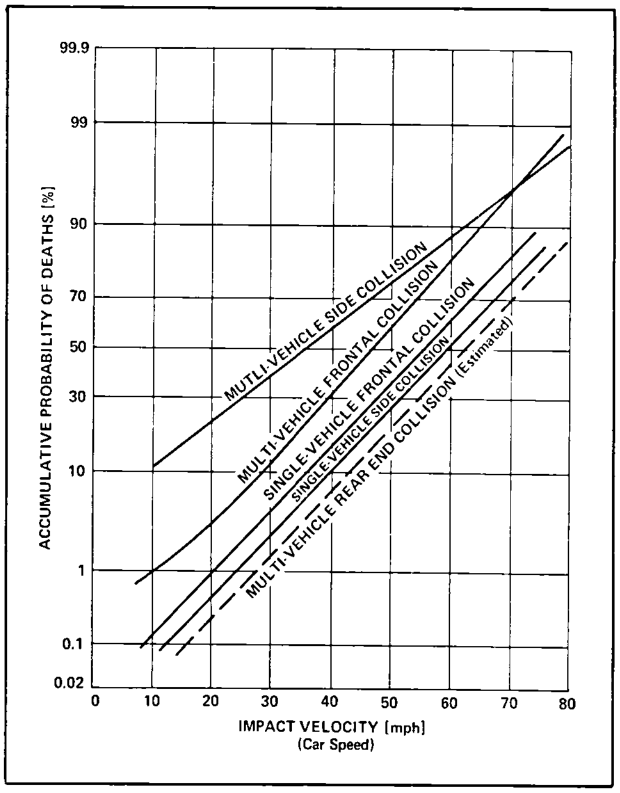


Figure 4

2. Protection up to 75 mph relative speed (that is 37.5 mph vehicle speed) at vehicle-to-vehicle-frontal-collisions would save 50% of the injured and 25% of the dead.
3. Protection up to 50 mph for single-vehicle-frontal-collisions would save 66% of the injured and 35% of the dead.

The surprising part of these results is the low percentage of effectiveness expressed in terms of persons injured and dead in view of the relatively high impact speeds.

As an example, Bohlin[5] says that the use of safety belts alone in the Volvo P 11 and P 12 reduced the fatality rate by 82% and at speeds of 60 mph even by 100%!

The statistical data[4] for the above figures appear in fact not too plausible and in need for a thorough checkup. An essential reason for the discrepancy may be the fact that the statistics[4] include a considerable share of eccentric, angular impacts, while the estimates of the effectiveness are referring to a straight, central impact, a much sharper test condition. This discrepancy is assumed to have no influence on the following information, since only relative relations are of importance.

Statistical results concerning the interrelation of probable injuries and fatal accidents in dependence of the impact speed during rear collisions are not given in[4]. On the basis of the results shown by Cooke[4] the upper limit of the estimates is that up to a rear impact speed of 75 mph or 50 mph relative speed, 80% (95%) or 20% (50%) of the dead (injured) can be saved (refer to Fig. 4 and 5).

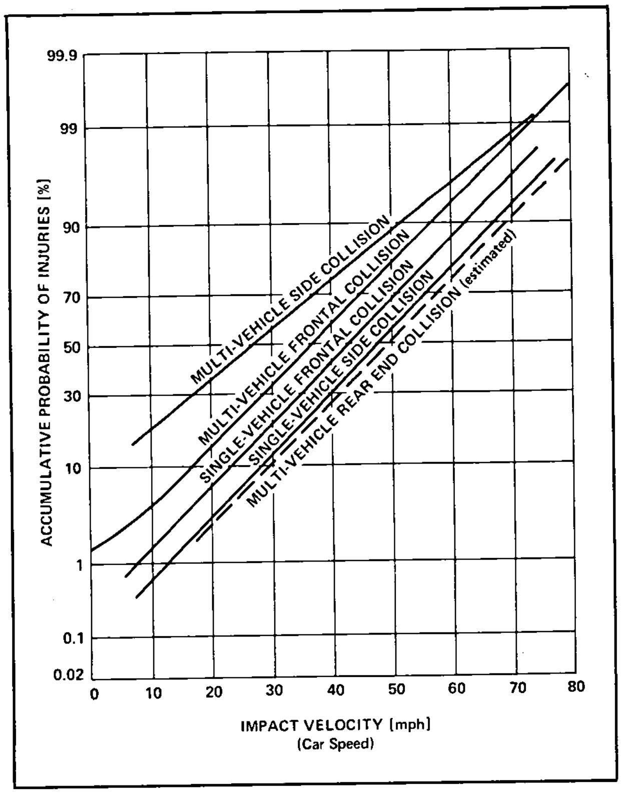


Figure 5

Table I shows that the frequency of serious frontal and rear accidents is at a ratio of about 10 : 1. To compute the effectiveness when meeting the conditions of the main impact tests the results (1969, USA) of Cooke[4] which are differentiated according to injured and dead are used as a basis (refer to Table II). The table shows that when meeting the ESV tests an approximately 7-fold effectiveness with regard to frontal accidents as compared with rear accidents will result. Since the costs for the improvement of the front and the rear structure are about the same, 0.60 for the front structure are indicating a considerably higher benefit/cost factor than the rear structure at 0.11 (refer to Table III), in fact a ratio of 5.5:1. The pertinent ratio for a 30 mph side impact is 2.4:1.

Therefore the assumption can be made that the front and the side tests are equivalent as the result of a benefit/cost factor which is about the same. But the rear end impact test is much too sharp. The use of one cost unit in the rear end structure provides only a fraction of the effectiveness which would result when investing such a cost unit in the side or even in the front structure.

Since at 75 mph rear impact speed the cumulative-injuries speed curve according to the estimate of 95% saved is already in the asymptotic range, and since the costs rise at more than the square of the test speed, a reduction of the rear impact speed will result in an increase of the benefit/cost ratio and thereby in a more effective matching to the other test conditions.

TABLE I
Probability of Frontal and Rear End Impacts

	Share % Frontal Impact			Share % Rear Impact		
	Total	Injuries	Deaths	Total	Injuries	Deaths
USA [4] 2,056,000 Accidents 1969	60	60	51	4.7	4.8	1.1
USA [3] Rural 25,000 Accidents 1967	59	–	–	6.9	4.5	2.8
England [6] Rural, Urban 296 Accidents 1967-1968	–	–	45	–	–	0
England [2] Rural, Urban 656 Accidents 1965-1969	55	–	–	10	–	–
Sweden [5] Rural, Urban 28,000 Accidents 1965-1966	36	–	–	<8.7	–	–
Australia [7] Rural, Urban 408 Accidents 1963-1964	43	–	–	6.8	–	–

TABLE II
Benefits For ESV – Specifications

Impact Type	Deaths Total Injur. Total USA 1969 by Cooke [4]	Losses Total[1] 10^6 \$	% Cases Within Prot. Speed Range by Cooke [4]	Total Economic Benefits 10^6 \$
50 mph single vehicle frontal	5,660 296,000	244 650 } 894	35 66	85 430 } 515
75 mph multi vehicle frontal	15,780 745,000	680 1,640 } 2,320	25 50	170 820 } 990
30 mph multi vehicle side	8,220 214,000	354 470 } 824	38 55	135 258 } 393
75 mph multi vehicle rear	458 93,000	20 205 } 225	80 (est.) 95	16 195 } 211
50 mph multi vehicle rear	458 93,000	20 205 } 225	20 (est.) 50	4 103 } 107

[1] \$43,000 loss per fatality [8]
[1] \$ 2,200 loss per injury [8]

TABLE III
Benefit/Cost Ratios for ESV Specifications

Impact Type	Total Benefits 10^6 $	Total[1] Costs 10^6 $	Benefit/ Cost Ratio	Benefit/ Cost Ratio related to 75 mph rear
50 mph single vehicle frontal	515 } 1.505	2,500	0.60	5.5
75 mph multi vehicle frontal	990			
30 mph multi vehicle side	393	1,500	0.26	2.4
75 mph multi vehicle rear	211	2,000	0.11	1.0
50 mph multi vehicle rear	107	500	0.21	2.0

[1] $10 \cdot 10^6$ new cars per year [8]
$250 improved front structure per car (estimated)
$150 improved side structure per car (estimated)
$200 improved rear structure per car (estimated) for 75 mph
$ 50 improved rear structure per car (estimated) for 50 mph

2. Reduced Rear Impact Speeds

For the derivation of a meaningful speed for the impact of the rear end against a fixed barrier within the scope of the other test conditions the following assumptions are made:

1. The 50 mph frontal impact against a fixed barrier is meaningful.
2. Modern front structures are designed to meet the SAE Recommended Practice J 850 a, that is a 30 mph frontal impact against a fixed barrier.
3. The additional costs for the improvement of the front and rear structure beyond the present condition are to be in the ratio of the losses for frontal and rear impacts, that is (894 + 2.320) / 225 = 14.3/1 (refer to Table II).
4. The costs for structures are proportional to the possible energy absorption.
5. During a rear impact of two equal sized cars the energy absorbed at the rear is to be similar to the energy absorbed at the front.

As an example, a 1,000 kg passenger car of conventional design is used.

Present Costs For Front Structure:

$$A_{F1} = c \cdot \int F \cdot dx_{/1} = c \cdot ½m \cdot v_{F1}^2 = c \cdot 8.96 \cdot 10^4 \text{Nm}$$

in which

- c = Proportionality factor
- F = Force
- x = Deformation Length
- m = 1,000 kg mass of passenger car
- v_{F1} = 30 mph

Costs Required For Front Structure:

$$A_{F2} = c \cdot \int F \cdot dx_{/2} = c \cdot ½mv_{F2}^2 = c \cdot 24.6 \cdot 10^4 \text{Nm}$$

in which
v_{F2} = 50 mph

Present Costs For Rear Structure:

$$A_{R1} \approx ½A_{F1} = c \cdot 4.58 \cdot 10^4 \text{Nm (measured)}$$

Approach According To Assumption 3:

$$\frac{A_{F2} - A_{F1}}{A_{R2} - A_{R1}} \equiv \frac{\text{Losses Front}}{\text{Losses Rear}} \equiv \frac{14.3}{1}$$

Costs Required For Rear Structure:

$$A_{R2} = A_{R1} + \frac{1}{14.3}(A_{F2} - A_{F1})$$
$$= c \cdot 5.68 \cdot 10^4 \text{Nm}$$

The energy balances provide equivalent rear impact speeds:

1. Impact rear against fixed barrier

$$A_{R2} = c \cdot ½mv_{R2}^2 \qquad V_{R2} = 23.9 \text{ mph}$$

2. Impact of moving barrier of similar weight against rear:

$$A_{R2} = c \cdot ½\frac{m \cdot m}{m + m}\Delta v_B^2 \qquad \Delta v_B = 33.8 \text{ mph}$$

3. Impact of similar vehicle front against rear:

$$2 \cdot A_{R2} = c \cdot ½\frac{m \cdot m}{m + m}\Delta v_c^2 \qquad \Delta v_c = 47.8 \text{ mph}$$

With the inclusion of approximately 4% safety the following rear end impact speeds are proposed:

Fixed barrier	v = 25 mph
Moving barrier	Δv = 35 mph
Vehicle-vehicle	Δv = 50 mph

To check the inclusion of the reduced rear impacts into the other specifications the benefit/cost factor is now computed. Figure 5 shows that with protection up to a relative speed of 50 mph rear impact speed approximately 50% of the losses will be saved. Tables II and III are showing computations or estimates of the absolute benefits and costs. The resulting benefit/cost factor of 0.21 is within the order of magnitude of the other specifications. The reduced rear impact test is therefore equivalent to the front and side impact tests.

3. References

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LIMITATION OF INTRUSION DURING SIDE IMPACT

Mr. William J. Wingenbach, AMF

Abstract

"Limitation of Intrusion During Side Impact"

One of the more difficult engineering problems encountered in providing vehicle crashworthiness is that of limitation of intrusion during side impact.

The work done on the AMF Experimental Safety Vehicle project has led to the evolution of a design concept which has as its basic element an aluminum honeycomb sandwich door panel. The sequential modes of behavior of the concept under increasing load levels are elastic beam action, plastic beam action, honeycomb crush, and finally, membrane stretching. As these behavioral modes progress, very large resistance to transverse loads develops even though transverse deflection remains small.

The concept has been modeled and analyzed for load deflection characteristics, and several evolutionary models have been built and tested under both static and dynamic loading, including full-scale vehicle crashes. Actual behavior has agreed very well with analytically predicted behavior enabling the side structure system to meet ESV design goals.

Introduction

The Advanced Systems Laboratory of AMF Incorporated at Santa Barbara, California, has been engaged in the development of an Experimental Safety Vehicle for the U.S. Department of Transportation. The scope of this project includes the complete span of activity from original conceptual design through developmental testing and evaluation, and culminates with the delivery of complete vehicles at the end of this year. To the extent possible, the project utilized a systems approach wherein each component was synthesized, analyzed, designed, and tested and evaluated with consideration of the interfaces with other components and of total vehicle objectives.

This paper is concerned specifically with the work associated with resistance of intrusion into the vehicle passenger compartment during side impacts. Included are an enumeration of technical objectives, descriptions of the system and method of analysis and a discussion of the results of developmental testing.

Objectives

The design of the AMF Experimental Safety Vehicle side structure was directed towards a set of objectives derived from explicit and implicit Department of Transportation goals. This set of objectives is as follows:

Passenger compartment intrusion is to be limited to three inches measured from a normal inside surface when struck on the side by the front bumper of a vehicle of equal mass. Impact velocity of 30 mph is normal to the side and at any point along the side. The impacting bumper structure is equivalent to the required ESV front bumper system which has the characteristics of providing override/underride protection over the range of 14 to 20 inches above ground, and a vehicle acceleration force which is velocity dependent. Maximum permissible vehicle acceleration versus impact velocity is shown in Figure 1.

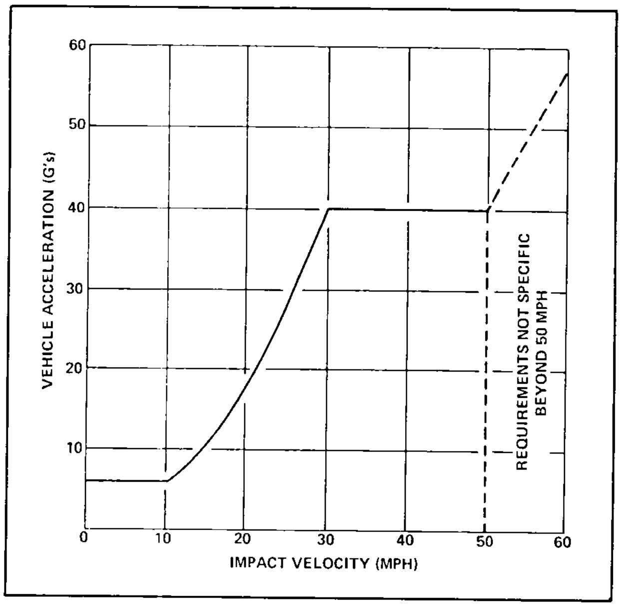


Figure 1

Passenger compartment intrusion is to be limited to three inches at the pillars and four inches at the longitudinal centerline of doors during impact into a fixed 14-inch pole. Impact velocity of 15 mph is normal to the side and at any point along the side.

Passenger compartment doors are to remain closed during any ESV specified crash condition. These conditions include front and rear impacts up to 50 mph and impact angles up to 45 degrees; rollover at 60 mph and side impacts. Impacts may occur with vehicle carrying five restrained or unrestrained occupants.

Passenger compartment doors are to remain operable after impact at any specified ESV crash condition.

Intrusion resistance is to be accomplished with minimum impact on overall vehicle cost and weight. Design concepts employed on the ESV should be susceptible to mass production.

Passenger compartment door systems are to provide ease of opening and closing, and ease of passenger ingress and egress equivalent to current production vehicles.

Side structure is to provide maximum driver field of view. There are to be no more than four pillars of minimum width within the driver's 270 degrees of forward view.

System Description

Major components of the intrusion-resistant side structure are the door panel, door retention hardware, and the passenger compartment side structure. A description of these components and their intended functions follows:

The door panel is an aluminum honeycomb sandwich consisting of an outer sheet, a honeycomb core, an inner sheet and a pair of vertical beams as shown in Figure 2. Door retention hardware along with the passenger compartment structure serve to provide the door panel with non-yielding pin supports fore and aft. Under transverse deflection of the panel, the pin supports develop a longitudinal tensile force which tends to stretch the door panel.

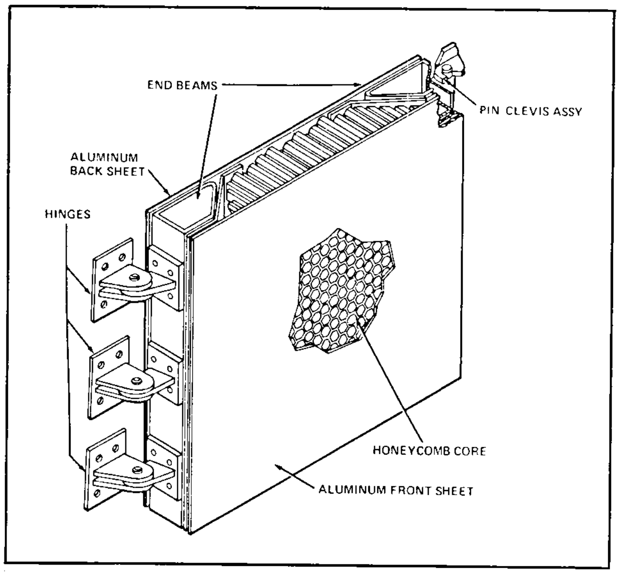


Figure 2

The sequence of behavior of the door panel under transverse loading is initially elastic and then plastic beam action during which the outer sheet is loaded in compression and the inner sheet is in tension. With increasing transverse load, the hoeycomb core begins to crush, decreasing the effectiveness of the panel as a beam. During this action, stress in the outer sheet reverses from compressive to tensile, while the inner sheet increases in tension. When the honeycomb is completely crushed both the inner and outer sheets are plastically stretched as membranes under tensile stress. This tensile stress in the sheets is reacted by the vertical beams which transmit the load to the door retention hardware. During deformation of the door panel, energy is absorbed in crush of the honeycomb and in plastic membrane stretching of the door sheets. In addition, a small amount of energy is stored by elastic deformation of the various structural elements.

Door retention hardware consists of three high-strength steel hinges, three pin clevis assemblies and a conventional door latching assembly. The hinges and pin clevis assemblies serve to provide the non-yielding pin supports for the door panel. As such, they provide the load path to the structure for the applied external transverse force and for the generated longitudinal tensile force. The conventional latch is adequate to resist internal transverse forces generated by an occupant striking the door during impact. The door retention hardware, and door panel along with a molded fiberglass inner and outer panel, window and window actuating mechanism, interior padding, etc., form the complete door assembly shown in Figure 3. Front and rear doors are similar in concept, although slightly different in shape. Rear doors also have fixed glazing.

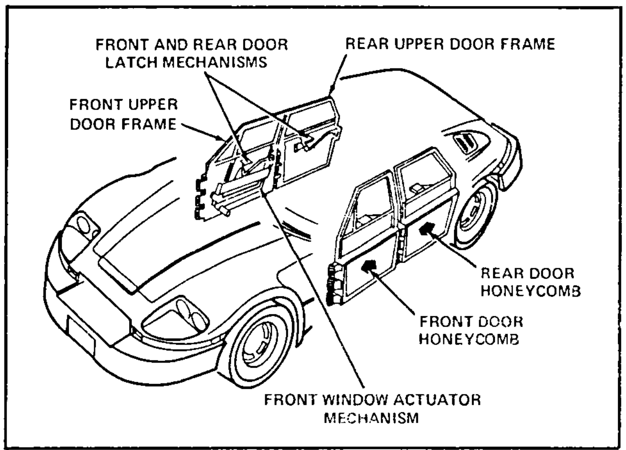


Figure 3

The portion of the passenger compartment structure which is involved in intrusion resistance to side impacts includes the A, B, and C posts and pillars, the perimeter frame, roof rails, and a honeycomb sandwich padding. In addition, there are several auxiliary transverse and longitudinal members which are employed to distribute loads throughout the vehicle. With the exception of the honeycomb sandwich padding, the structure is fabricated from high-strength sheet and tubing. The assembly is an all-welded integral structure shown in Figure 4. During impact by another vehicle, the side structure remains essentially elastic.

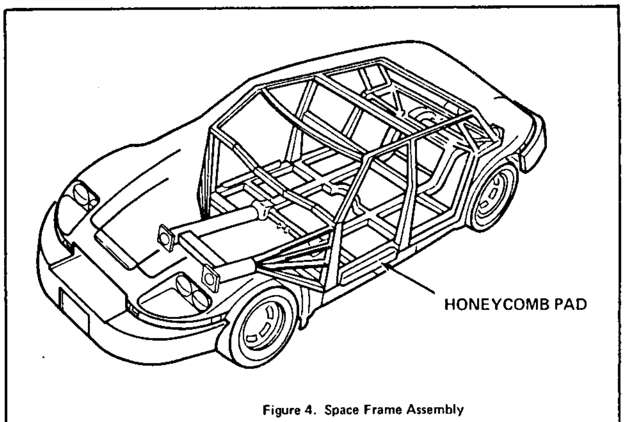


Figure 4. Space Frame Assembly

Figure 4

The aluminum honeycomb sandwich is installed outside of the perimeter frame in the region of the front door. During pole impact in this region, the honeycomb is crushed absorbing energy and distributing the load to the perimeter frame which remains essentially elastic. Pole impacts in the region of the shorter span rear door or at the posts will result in plastic deformation of the structure. A summary of properties of material utilized in the intrusion-resistant side structure is given in Table 1.

TABLE I
Properties of Material Utilized in Intrusion-Resistant Side Structure

	Material	Property
Door-Honeycomb sandwich, outer sheet	6061-0 AL	17 ksi-Ultimate
Door-Honeycomb sandwich, core	ACG AL	178 psi-Crush
Door-Honeycomb sandwich, inner sheet	7075-T6 AL	76 ksi-Ultimate
Door-Vertical beams	6061-T6 AL	42 ksi-Ultimate
Hinges & Pin Clevis Assembly	AISI-4140 ST	200 ksi-Ultimate
Latch Assembly	American Motors	5000 lb.-Transverse
Passenger Compartment Structure	ASTM-517 ST	100 ksi-Yield
Frame-Honeycomb sandwich sheets	2024-T3 AL	65 ksi-Ultimate
Frame-Honeycomb sandwich core	5052-H39 AL	750 ksi-Crush

Method of Analysis

The general method of achieving a design is shown in Figure 5, and involves three separate analyses. The first is a deflection analysis to obtain the load-deflection characteristics of components of a structural system. Depending on complexity and the nature of the structure, this is accomplished through hand analysis or by use of a suitable computer model. The second analysis is that of determining the dynamic response loads of a structural system under various crash conditions. This is accomplished using a computer model, and the load-deflection data previously obtained. Finally, stress levels in the structure are calculated at the peak dynamic response. A preliminary design may be cycled several times through the analytical loop before acceptable results are obtained.

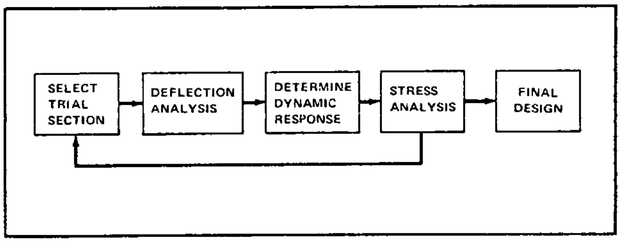


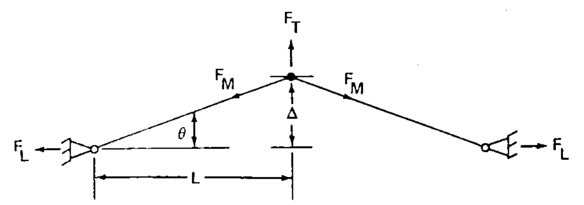
Figure 5

There are currently three mathematical models utilized in the analysis of impact problems. These are:

- SHOCK – a nonlinear, lumped mass, dynamic response program for determining the behavior of systems under impulsive loadings.
- STRESS – a finite element beam program for the solution of space frame type structures.
- SAP – a general finite element program providing versatility in modeling three-dimensional structures.

The manner in which this approach was utilized in the specific problem of designing an intrusion-resistant side structure under the pole impact condition follows. The critical design condition was considered to be pole impact at the center of the front door.

STEP 1 Determine load deflection characteristics of door panel. The load-deflection behavior of the door panel was obtained by superposition of the various behavioral modes of the structure. Sequentially, the behavioral modes involved are: (a) elastic beam action; (b) plastic beam action, slight stretching of inner and outer sheet; (c) crush of honeycomb core, stretching of outer sheet, gradually increased stretching of inner sheet; (d) pure membrane stretching of inner and outer sheet. Membrane behavior was modeled and analyzed for load deflection characteristics using the truss model shown in Figure 6. This model is based on the



LOAD-DEFLECTION EQUATIONS OF FULLY-YIELDED MEMBRANE

$$F_T = 2F_M \sin\theta$$

$$F_L = F_M \cos\theta$$

$$\theta = \arctan \frac{\Delta}{L}$$

$$F_M = \sigma_y th$$

WHERE σ_y = YIELD STRESS OF MATERIAL
t = THICKNESS OF MEMBRANE
h = HEIGHT OF MEMBRANE

Figure 6

assumption that a plastic hinge is initially formed at the load point and that the membrane behaves as a truss mechanism in post-yield behavior. The equations governing the load-deflection behavior of the mechanism in the fully plastic stage are presented in Figure 6. The accumulative load deflection curve for the panel is shown in Figure 7. Three regions under the curve are defined. Region "A" indicates the energy absorbed through beam action which also provides most of the panel stiffness at low deflections. Region "B" indicates energy absorbed by crush of the honeycomb core. Region "C", which accounts for the major energy absorption capacity of the panel structure is obtained through membrane stretching of the sheets.

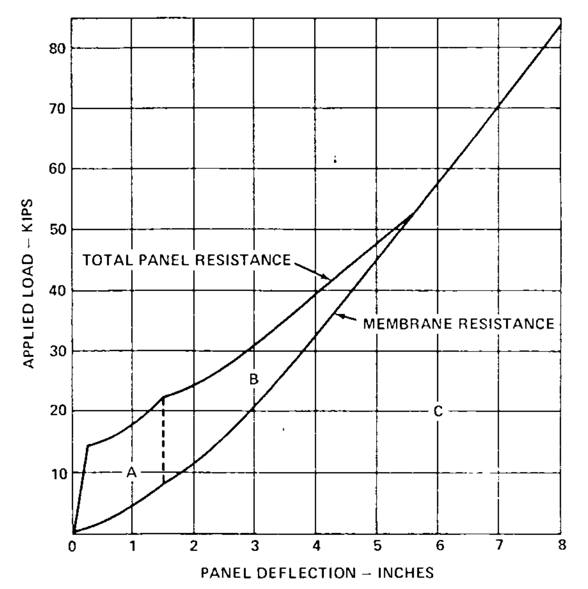


Figure 7

STEP 2 Determine load deflection characteristics of the frame honeycomb sandwich panel. The load deflection characteristics of this panel are shown in Figure 8.

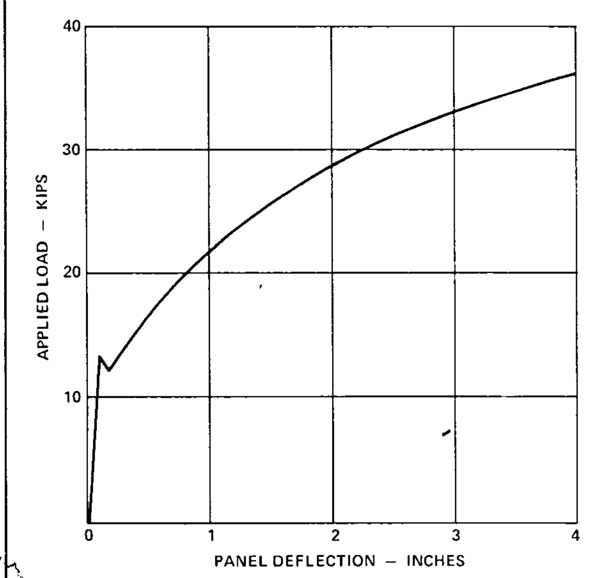


Figure 8

STEP 3 Analysis of the system under dynamic loading. The side structure system was modeled as shown in Figure 9. Included are the load-deflection characteristics of the door panel, frame honeycomb

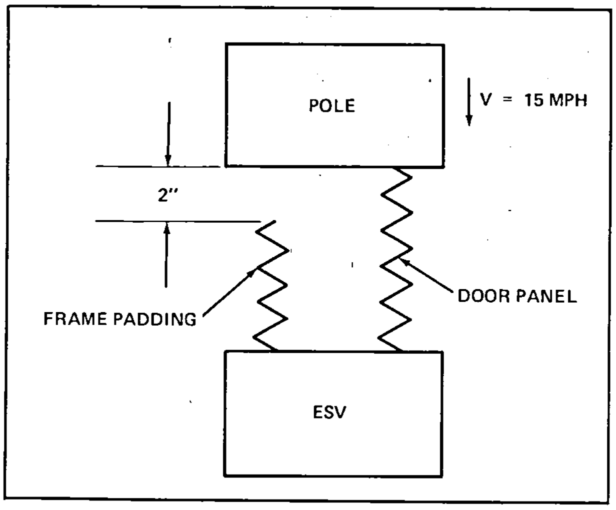


Figure 9

sandwich panel, mass of the vehicle and velocity discontinuity at the point of impact with the pole. A more complete model would include load deflection characteristics of the "A" and "B" posts and the perimeter frame, as well as rotational moments and vehicle moment of inertia. This model was exercised using the SHOCK computer code. The results of the analysis indicated that the pole would intrude into the striking vehicle about 7¼ inches measured from the point of initial contact with the door panel. This would result in an intrusion of the vehicle inside surface of approximately 3¼ inches compared to the allowable 4 inches. Door panel transverse load at this deflection is approximately 72 kips while the longitudinal load applied to the "A" and "B" posts is approximately 129 kips. The analysis indicated that the frame honeycomb sandwich panel would be completely crushed allowing direct pole contact with the pι rimeter frame resulting in a short duration load spike.

STEP 4 Design of structural elements. The final step in the analysis is that of sizing structural members using the dynamic response loads developed previously. In general, this step is an iterative process in which element dimensions are selected, analyzed and new dimensions chosen until a satisfactory design is achieved.

The passenger compartment side structure was designed using the STRESS computer code. The structure was modeled as shown in Figure 10, and analyzed for the loading conditions given in Table 2. Loads given in Table 2 are derived from the dynamic response analysis while the applied moments are those developed by the door retention hardware. A summary of member cross-sections and calculated peak axial and bending stress in each member is given in Table 3. These results were considered satisfactory, and the structure was fabricated for testing as modeled.

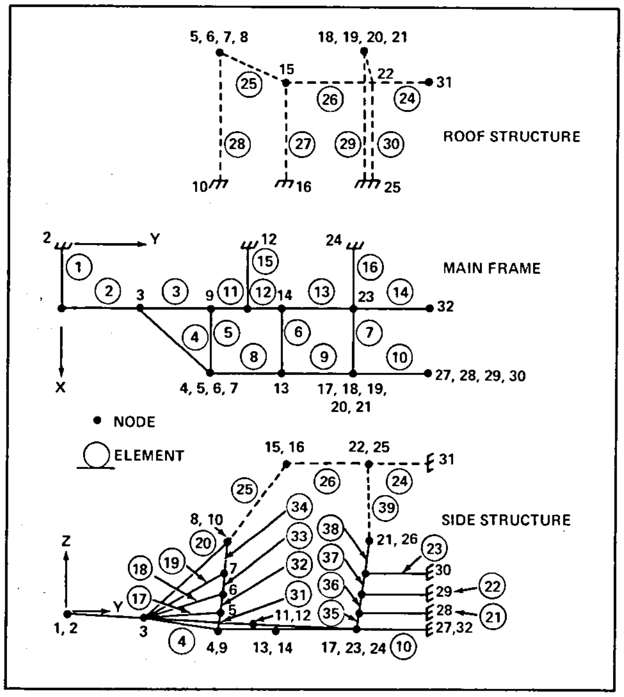


Figure 10

TABLE II
Applied Loads During Pole Impact

Node	Type	Direction	Magnitude
5	Force	X	-12.0 k
5	Force	Y	43.0 k
5	Moment	Z	150 in k
6	Force	X	-12.0 k
6	Force	Y	43.0 k
6	Moment	Z	150 in k
7	Force	X	-12.0 k
7	Force	Y	43.0 k
7	Moment	Z	150 in k
18	Force	X	-12.0 k
18	Force	Y	-43.0 k
18	Moment	Z	-150 in k
19	Force	X	-12.0 k
19	Force	Y	-43.0 k
19	Moment	Z	-150 in k
20	Force	X	-12.0 k
20	Force	Y	-43.0 k
20	Moment	Z	-150 in k
13	Force	X	-100 k

Test Results

The test program supporting the development of the intrusion-resistant side structure was conducted in two phases. The first phase involved component development in which several evolutionary versions of the aluminum honeycomb panel and door retention hardware were built and tested until satisfactory results were obtained. The second phase involved the construction and testing of a complete structural vehicle.

TABLE III
Side Structure Cross-Sections & Peak Stresses

Element	Name	Section	Axial	Bending
1	Front Housing Stabilizer	3x3x.120	6.8 (ksi)	63.2 (ksi)
2	Front Housing	3x5x.188	1.3	46.3
3	Front Housing	5x5x.188	7.3	40.2
4	Lower A Post Support	2x2x.062	5.4	133.0
5	A Post Lateral	4x4x.120	22.4	116.2
6	Front Door Lateral	3x3x.100	85.9	40.7
7	B Post Lateral	4x4x.120	13.5	91.5
8	Floor Sill A to Center	5x4 to 3x3x.120	41.5	118.6
9	Floor Sill-Center to B	5x4 to 3x3x.120	66.4	64.3
10	Floor Sill B Aft	3x4x.120	29.3	33.1
11	Front Housing	5x5x.188	1.2	85.9
12	Main Frame	4x4x.120	4.5	131.2
13	Main Frame	4x4x.120	5.0	127.2
14	Main Frame	4x4x.120	9.7	21.2
15	Torsion Bar Frame	3x4x.120	56.4	58.4
16	Center Cross Frame	4x4x.120	32.0	34.3
17	Lower A Hinge Support	1¼x1¼x.250	18.5	20.8
18	Mid. A Hinge Support	1¼x1¼x.250	35.8	24.8
19	Upper A Hinge Support	1¼x1¼x.250	18.7	11.4
20	Upper A Post Support	1¼x1¼x.250	14.7	135.3
21	Rear Panel Simulation	1 3/8x.095		
22	Rear Panel Simulation	1 3/8x.095		
23	Rear Panel Simulation	1 3/8x.095		
24	Roof Sill-Aft	3x2x.188	15.5	37.0
25	A Pillar	2½x2½x.120	26.5	115.5
26	Roof Sill-Fwd	3x2x.188	14.9	128.9
27	A Roll Bar	2x2x.120	10.7	109.0
28	A Cross Frame	2½x2½x.120	35.5	122.5
29	B Cross Frame	3x4½x.188	22.9	112.1
30	B Roll Bar	2x2x.120	1.6	38.0
31	A Post	3x8 to 3x3x.120	12.5	101.5
32	A Post	Same as 31	5.2	112.8
33	A Post	Same as 31	11.4	139.5
34	A Post	Same as 31	11.1	139.5
35	B Post	3x8 to 3x3x.120	1.8	57.3
36	B Post	Same as 35	2.3	151.5
37	B Post	Same as 35	2.3	151.5
38	B Post	Same as 35	3.3	129.1
39	B Pillar	2x2x.120	1.3	143.2

The first phase – component development test program – was conducted using the AMF crash simulator. This facility, which has been utilized to support a variety of automobile research programs, has the following features:

- Volumetric capacity in excess of a full size automobile
- Static or dynamic load capacity
- Tri-directional loading capacity
- Load application capacity of 100,000 pounds, 25,000 pounds, and 15,000 pounds along orthogonal directions
- Ability to apply loads separately, sequentially or simultaneously
- Ability to simulate crash load pulses including control of onset rate, pulse magnitude and pulse duration
- Fixturing to mount and provide controlled retention of a wide range of component size, shape and configuration

The result of a dynamic test of the door panel and door retention hardware is shown in Figure 11, along with analytically predicted behavior. Up to the point at which a hinge attachment failed, the behavior was reasonably close to expected behavior and was considered to be satisfactory. The failure in a weld at the hinge attachment was attributed to a manufacturing deficiency and not to the design. Observations made using high-speed photography and strain gages confirm the occurrence of expected sequential modes of behavior. Prior to failure, the panel had exhibited both elastic and plastic beam action, stress reversal in the front sheet and honeycomb core crush through more than half of its thickness. Peak loads were 39.6 kips, transverse, and 70.1 kips, longitudinal at a ram stroke of 4.25 inches. Post-test observation disclosed a vertical break through the front sheet at the point of contact. This was attributed to the occurrence of buckling while stressed in compression and subsequent failure in tension at the crease formed by buckling.

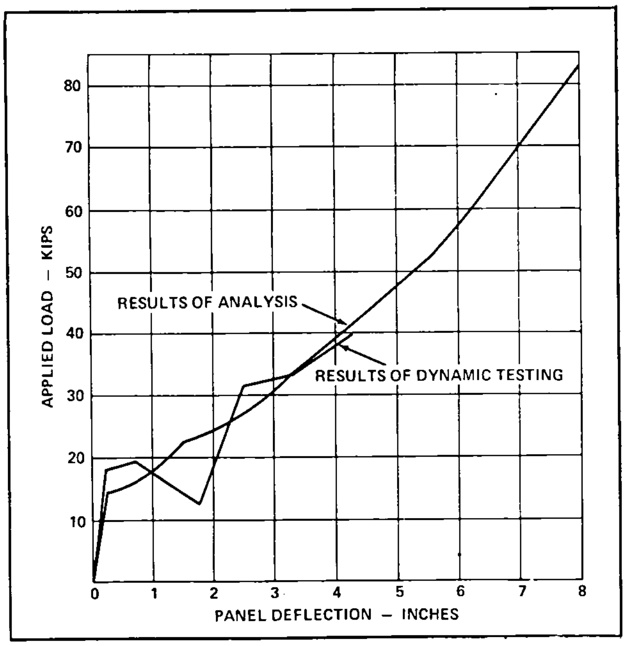


Figure 11

A door panel of the same design was installed on a structural vehicle. The assembly was impacted against a

13 inch rigid pole at 15 mph. Observations made during the event were:

- Maximum deflection of door panel – 7 inches
- Maximum intrusion into passenger compartment –3¼ inches
- Maximum pole load – 106 kips
- Complete crush of honeycomb core in door panel and frame padding

The side structure behavior during the test was considered to be satisfactory and close to analytically predicted behavior. Post-test observations revealed the occurrence of a crack through the outer door panel sheet identical to that observed during component testing. Prototype door panel design was modified to incorporate a slightly thicker and more ductile outer sheet.

Summary and Conclusions

A passenger compartment side structure system capable of resisting intrusion during side impacts has been designed, built, and tested for the Department of Transportation ESV program. The system consists of honeycomb sandwich door and frame panels, high-strength door retention hardware, and high-strength supporting structure.

Observed behavior of the system during component testing and full-scale vehicle crash testing is in close agreement with analytically predicted behavior and satisfies intrusion limits defined in performance objectives. Energy absorption capacity attributed to the various structural behavioral modes of the door panel are isolated and evaluated. This exercise demonstrates the value of the various design features of the panel, and will allow the design to be easily modified to satisfy a change in energy absorption requirement or a change in intrusion limitation.

The design of the side structure system concept discussed in this paper employs state-of-the-art materials and manufacturing techniques, although these materials and techniques may not be currently employed in mass production techniques. The concept is seen to satisfy the immediate objectives, but its ultimate worth is dependent on whether the design can evolve from a handcrafted laboratory version to an economic, reliable mass production version. To date, no study has been made of the feasibility or cost of this evolution. However, because of the fact that the system is relatively light weight, adaptable to varying requirements, and employs state-of-the-art materials and techniques, there is good potential for successful conversion to mass production.

OPTIMAL DEFORMATION CHARACTERISTICS OF FRONT, REAR AND SIDE STRUCTURE OF MOTOR VEHICLES IN MIXED TRAFFIC

Dr. Hermann Appel, Germany VW

Survey

Under the influence of economic needs and individual preferences the motor vehicles travelling on our roads will continue to be mixed in nature, that is, lightweight and heavy vehicles will be using the same traffic environment.

Keeping the decelerations and deformations encountered by the smallest passenger car under observation in the event of front, rear or side impacts with heavier passenger cars or trucks within survivable limits, *balanced deformation characteristics* in the front structures of *all* possible collision partners are required. Such deformation characteristics may be realized by force-deformation function which are constant, impact veloc ity sensitive and weight adjusted. They can be verified by an initial hydraulic stroke and a following plastic stroke giving some advantages:

1. Minimum deformations
2. Reduction of the aggressivity of the large car without decrease of crashworthiness:
   the large car is "sufficient weak" in the car-to-car collision,
   the large car is "sufficient hard" in the fixed obstacle collision.
3. The side structure has to sustain small forces in the car-to-car side collision.

The hydraulic strokes needed are:

1000 kg – PKW	:	21 cm
2000 kg – PKW	:	41 cm
36000 kg – LKW	:	$<$98 cm

The draft presented here is dependent on the weight of the vehicle and provides occupant protection for the following types of impacts:

Front impact	Vehicle against wall at 50 mph absolute speed
Front impact	Vehicle-to-vehicle at 75 mph relative speed
Rear impact	Vehicle front against vehicle rear at 75 mph relative speed
Side impact	Vehicle front against vehicle side at 30 mph relative speed

The weights of the colliding vehicles during vehicle-to-vehicle impacts are any combined within the range of 1,000 kg to 36,000 kg.

1. Introduction

The present rural and urban traffic is of a mixed nature, that is, the partners travelling in a given traffic environment are different in relation to their size, their weight and their deformation performance, such as pedestrians, passenger cars, buses, vans, trucks and the like.

Seen from the point of view of passive safety such a traffic system is by no means an optimum of effectiveness, since in the event of an impact between two vehicles of different weight the lighter one will be subject to the larger change in velocity[1]. The trend to a diversification of motor vehicles from an economical and sociological point of view in the one hand and the resulting need and obligation for a crashworthiness designed in relation to collisions with partners of different size and different weight is emphasized by Cooke[2]:

> "To deal with those dispersions, inter-vehicular compatibility should be developed and controlled to a manageable level through vehicle standards, and operational controls should limit probable collisions within a corresponding level by correlated regulation of speed and weight mixture on the highways . . . however, in the on-going highway conflict, the citizen is exposed to adverse weight ratios of 30/1 as pedestrians versus average vehicles, or as occupants of vehicles subjected to 40/1 intervehicular weight ratios. The trend toward broader diversification of motor vehicles, small urban mobiles, heavier trucks, and more numerous buses is based upon profound needs of society and can be expected to continue. It should be noted that collisions involving extreme weight ratios can readily be managed by engineering measures such that maximum amplification of acceleration in the lighter vehicle would not be more than double that during collisions with equal weight vehicles. This can be accomplished through controlled crush characteristics which ensure shared energy absorption while restricting intrusion within tolerable limits."

The present paper presents a method for coordinating the crash performance of vehicles of different weight and especially the coordinating of vehicles having a weight above 1,000 kg. In practice, an extreme case would be a collision between a passenger car of 1,000 kg total weight and a truck of 36,000 kg total weight. The paper attempts to show a significant and practicable way to make collisions between vehicles of such a different design survivable for the passengers of the smaller vehicle up to the speeds named above. The inclusion of still further differentiated weight conditions in accordance with the method described here is possible, but will make its practical application more difficult.

To keep the problem clearly distinctive, simplified assumptions with regard to the mechanical model of a deformable vehicle as well as to the mathematical treatment are required. The numerical values provided should be considered in the nature of interpretations which must be still further refined in the course of additional theoretical and experimental research.

The Volkswagenwerk AG is using the contemplations presented here as a part of its design efforts for the Experimental Safety Vehicle (ESV). Obviously, a manufacturer of predominantly small vehicles will pay special attention to the problem of intervehicular compatibility. On the other hand, it is hard to deny that the problem of balanced energy absorption with stepwise changes in motivation is and should be of interest for the manufacturers of larger vehicles. Small passenger cars are at a disadvantage in collisions with large passenger cars, large passenger cars are at a disadvantage in collisions with trucks. The heaviest potential collision partner will in fact protect its occupants the best, but will also endanger all other participants the worst.

If the design measures proposed here with regard to intervehicular compatibility are expected to become effective in the future beyond the scope of the ESV, pertinent cooperation of vehicle manufacturers with regard to the verification of balanced energy absorption is an absolutely required prerequisite.

2. Presentation and Definition of Problem

The high-speed crash tests for the ESV as specified by the USA[3] (refer to Fig. 1, 2. 3) and the Federal Republic of Germany[4] (refer to Fig. 4, 5, 6) provide for collisions between vehicles of similar type. The front,

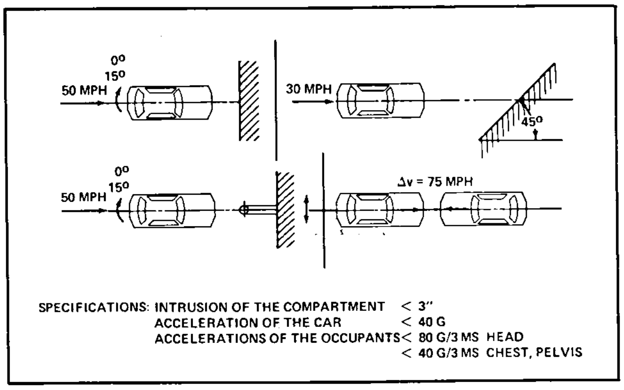


Figure 1

rear and side structures of these vehicles and their deformation performance are therefore in dependence of each other and should be balanced accordingly. Even though only collisions between uniform vehicles are considered, the above reasons make it more than reasonable to try and meet the named specifications also in the event of collisions between vehicles of different weight and different size. When this principle is put into effect, the front, rear and side structures of all vehicles of the weight range taken into consideration are dependent on each other and cannot be considered from an isolated point of view.

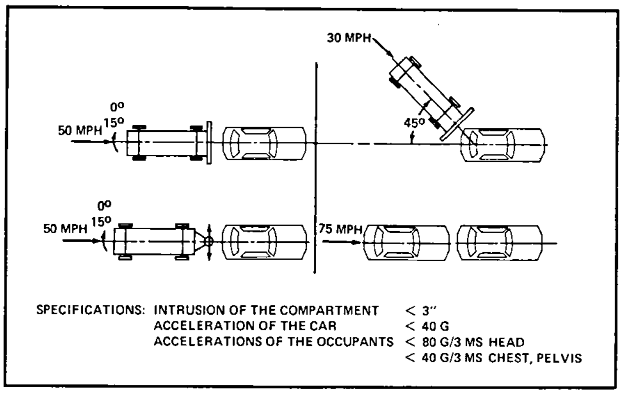


Figure 2

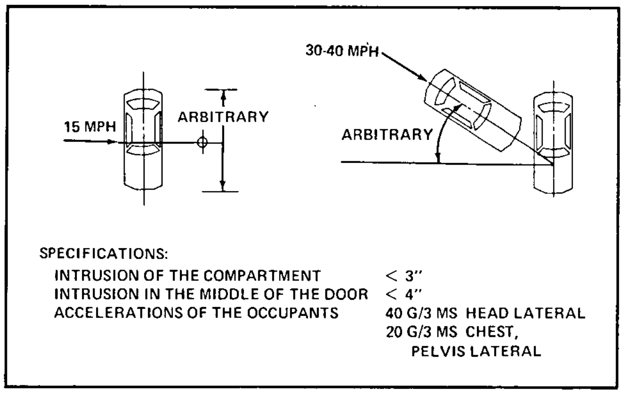


Figure 3

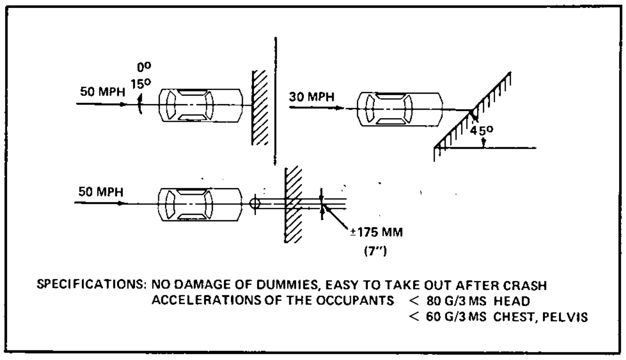


Figure 4

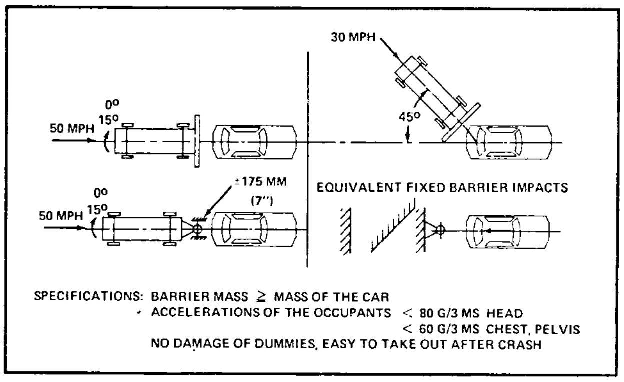


Figure 5

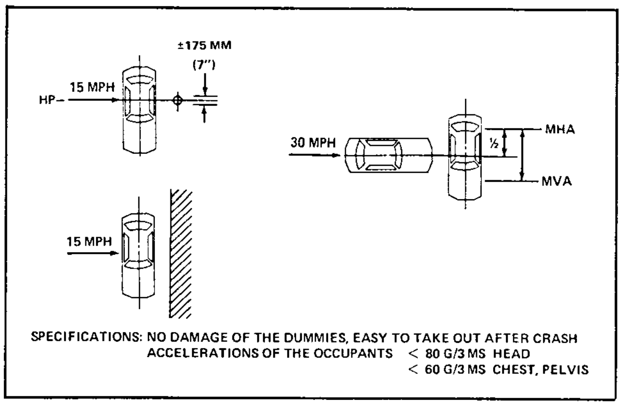


Figure 6

The efforts of research and development in the range of passive safety are at the end all directed to the protection of the occupants against unpermissibly high accelerations and surface pressures in the event of collisions with fixed, moving or moved obstacles. A look at the individual vehicle shows that the mechanical model consists essentially of four coupled components: the deformable vehicle structure, the passenger compartment, the restraining system for the occupant (belts, air bag, steering wheel, seats, upholstery, instrument panel, doors, windows and the like) and the occupants themselves.

This substitute system and the pertinent speed-time history for an impact against a fixed obstacle or barrier shows immediately the influence of the deformation characteristics of the vehicle structure on the deceleration of the occupants (refer to Fig. 7). The diagram shows a rising, a constant and a receding force-deformation function.

The deformation length of the vehicle and the restraining system, as well as the slack between the occupant and the restraining system is in each case assumed to be the same. For simplification, the mass of the occupants and of the vehicle deformation structure is assumed to be small with regard to the mass of the passenger compartment. Comparing the three speed-time diagrams in which deformations are shown as areas and decelerations as slopes, will show that receding characteristics of the vehicle permit the smallest deceleration for the occupants[5], but that constant characteristics provide almost the same favorable data. Since receding characteristics are hard to achieve, and since constant characteristics with specified deformation length and energy absorption will result in minimum forces for the passenger compartment, constant characteristics will represent the best compromise.

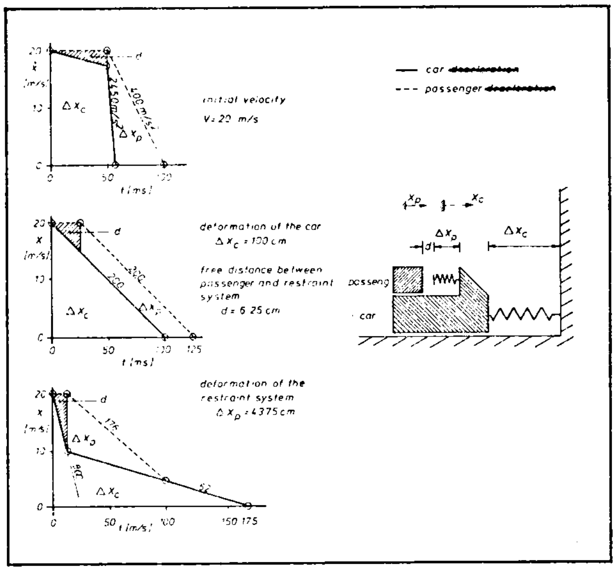


Figure 7

In addition to the demand

1. Constant force-deformation characteristics of deformation structure of vehicle

Figure 7 shows the two other essential demands for minimum occupant acceleration:

2. The slack between occupant and restraining system should be as small as possible, so that the occupant participates in the vehicle deceleration as soon as possible[6].
3. The restraining system should have constant force-deformation characteristics matched to the prevailing conditions (for example force limited belts)[6].

When the requirements for optimal occupant protection in relation to the vehicle have been defined, the complete problem of "passenger protection" can be broken down into individual problems. On the following pages, only the deformation characteristics of the vehicle structure are examined. Unless otherwise stated, the force-deformation characteristics are considered to be constant.

The restricted problem is now generally as follows:

Design the vehicle structure in such a manner that during specified collisions of vehicles of different size and weight the decelerations and the deformations of the passenger compartment are held within survivable limits.

The special problem can be defined as follows:

The parameters for describing the front end structures which are dependent on the impact speed should be specified to meet the following demands:

1. Upon impacts against a fixed barrier the deceleration of the car should depend on the impact speed in such a manner that the curve specified in[3] is not exceeded.
2. Both small and large vehicles should not exceed the median deceleration of 30 g during a 50 mph frontal collision with a fixed barrier.
3. Both small and large vehicles should not exceed the median deceleration of 30 g and the deformation occurring under (2) during the 75 mph vehicle frontal collision. Size and weight may be of no significance but the smallest vehicle should have a mass of not less than 1,000 kg.

Upon determination of the front end characteristics the constant force-deformation function at the side structure and the impact velocity sensitive rear end structure will result on the basis of the pertinent impact test according to[3].

In extreme cases the following vehicle collisions must be considered:

Frontal impact of 1,000 kg passenger car against 36,000 kg truck or vice versa at 75 mph relative speed,
rear impact (front-to-rear) of 1,000 kg passenger car against 36,000 kg truck or vice versa at 75 mph relative speed,
side impact of 1,000 kg passenger car against 36,000 kg truck or vice versa at 30 mph impact speed.

3. Front End Structure

The single-mass model according to Figure 8 is used as a substitute for the vehicle. The deformation structure at front, on the sides or at the rear is considered to be massless. Forces and accelerations are therefore proportional in relation to each other. The mass of the occupants is contained in the total mass or not depending on the restraining system.

Figures 9 and 10 show the selected designations for deformations, forces and accelerations (decelerations). Symbols provided with a raised comma (for example a')

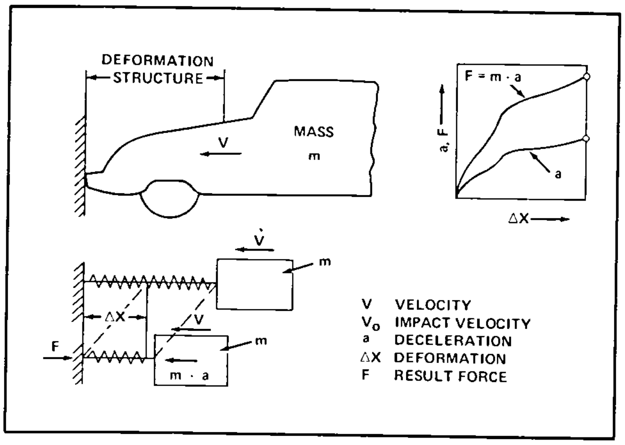


Figure 8

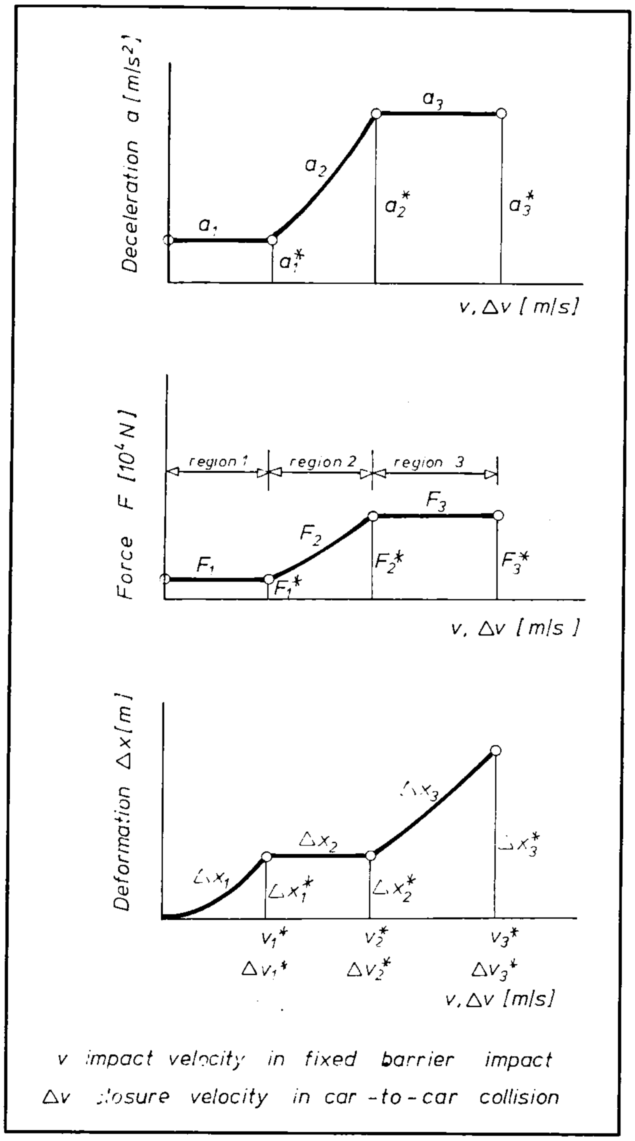


Figure 9

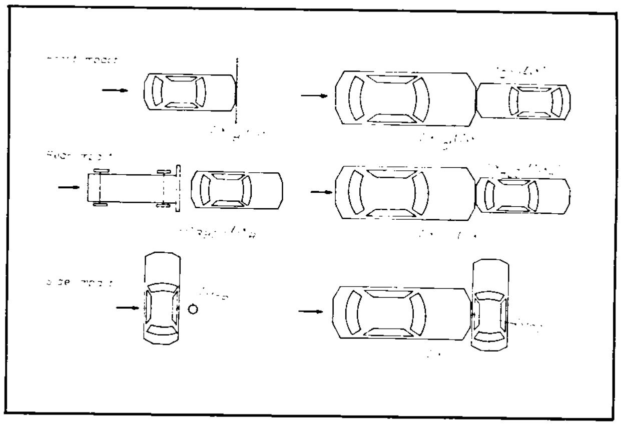


Figure 10

refer to the impacting and in general to the larger vehicle.

For the mathematical description of the substitute model only the energy balances of the straight, centric, fully-plastic impact are employed:

Impact of vehicle against fixed barrier:

$$\frac{1}{2} mv^2 = \int F_{(v, x)} \, dx$$

Impact of moving barrier (m') against vehicle (m) at relative speed Δv:

$$\frac{1}{2} \frac{m \cdot m'}{M + m'} \Delta v^2 = \int F_{(\Delta v, x)} \, dx$$

Impact of vehicle (m') against vehicle (m) at relative speed Δv:

$$\frac{1}{2} \frac{m \cdot m'}{m + m'} \Delta v^2 = \int F_{(\Delta v, x)} \, dx + \int F'_{(\Delta v', x')} \, dx'$$

Prior to the deviation of the weight-adjusted characteristics proposed here, the advantages of some ideal characteristics including as extreme cases the today characteristics will be described.

3.1 Linear Characteristics

Figure 11 shows the linear characteristics of the front end for a lightweight and a heavy passenger car independent of the impact speed when designed accord-

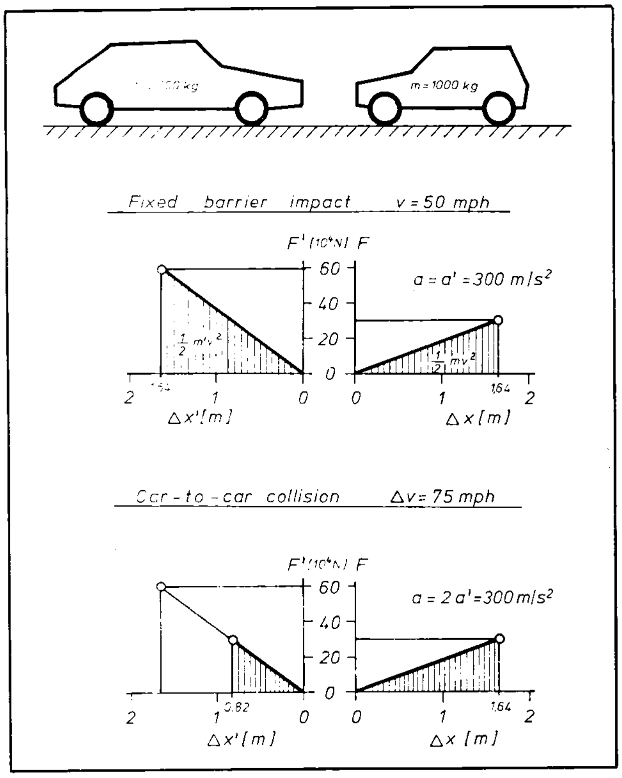


Figure 11

ing to ESV conditions. The disadvantage of these characteristics is that the required deformation length of 1.64 m is too long. An advantage is that

a. at low impact speeds only low accelerations will occur (refer to Fig. 12);
b. the deformation of the small vehicle at 50 mph barrier impact is as large as during a 75 mph heavy-vehicle-to-light-vehicle impact (refer to Figs. 11, 12, 13);
c. at vehicle-to-vehicle collisions the large vehicle absorbs 1/3 of the total energy at all impact accelerations (refer to Fig. 13).

3.2 Constant Characteristics

Figure 14 shows the constant characteristics of a light and a heavy passenger car independent of the impact speed when designed according to ESV conditions. Here, the advantage is that only small deformation lengths are required. Disadvantages are that

a. at low impact speeds the highest possible accelerations will occur (refer to Fig. 15);
b. the deformation of the small vehicle during a 75 mph heavy vehicle-to-light vehicle impact is larger than during a 50 mph barrier impact (refer to Fig. 14, 15, 16);
c. during vehicle-to-vehicle collisions the larger vehicle is not deformed and is therefore not contributing to energy absorption.

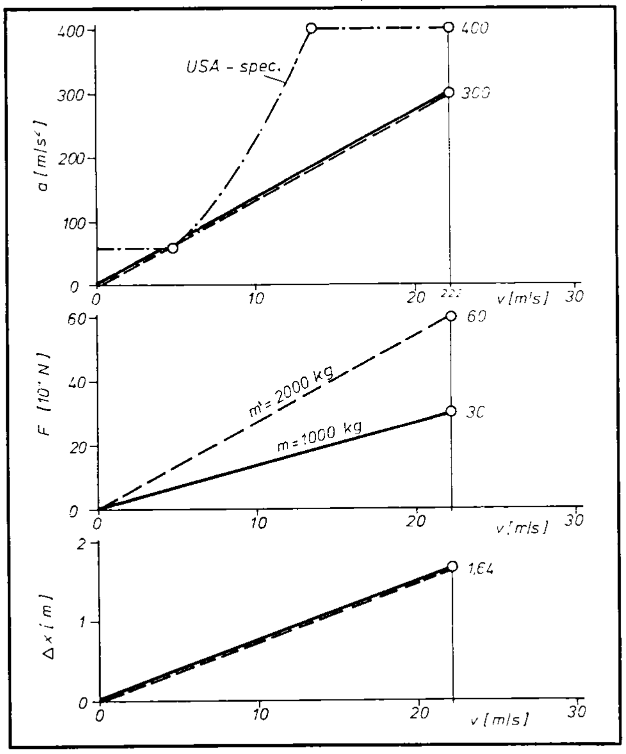


Figure 12

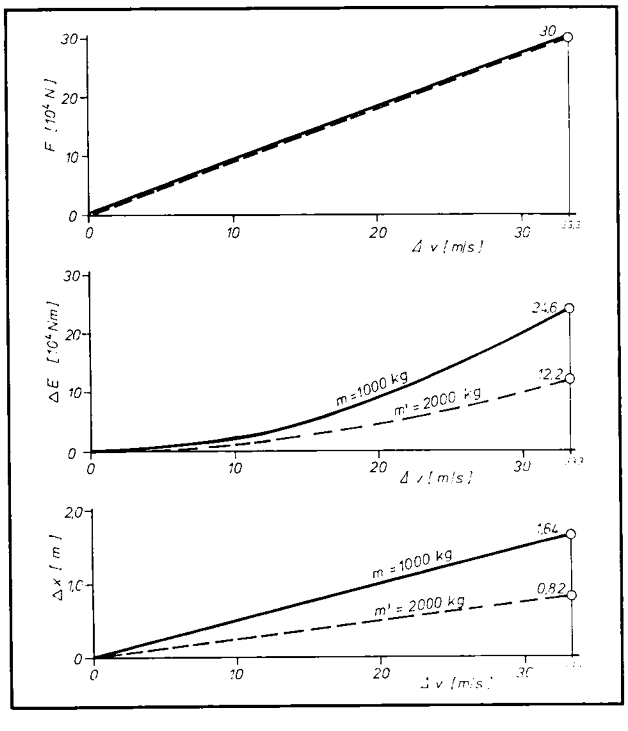


Figure 13

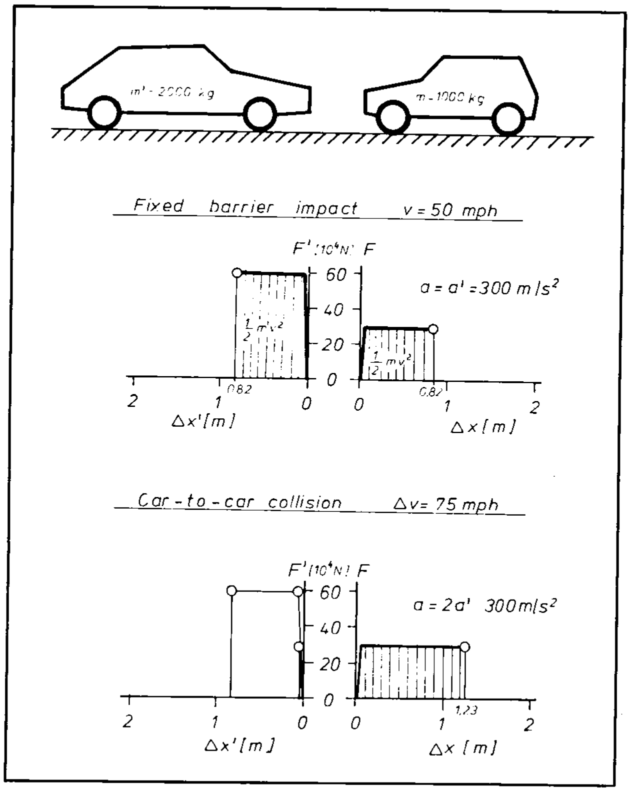


Figure 14

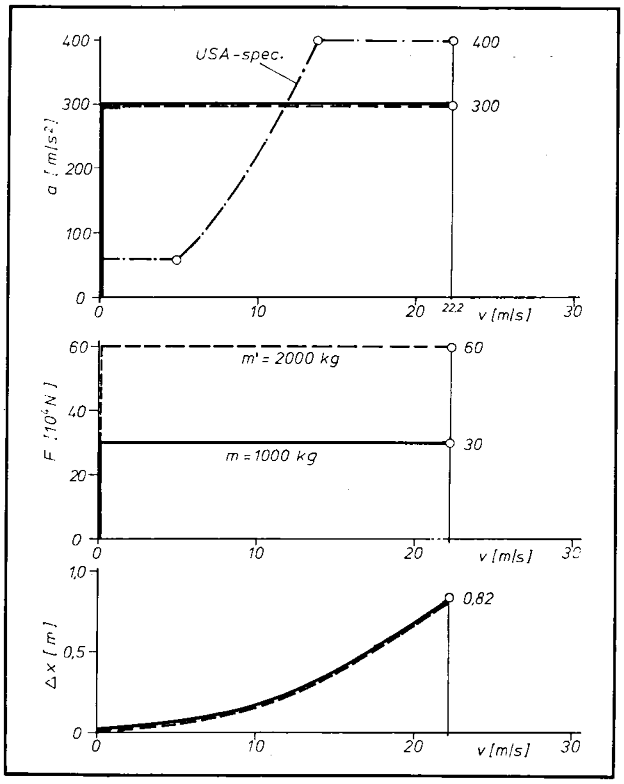


Figure 15

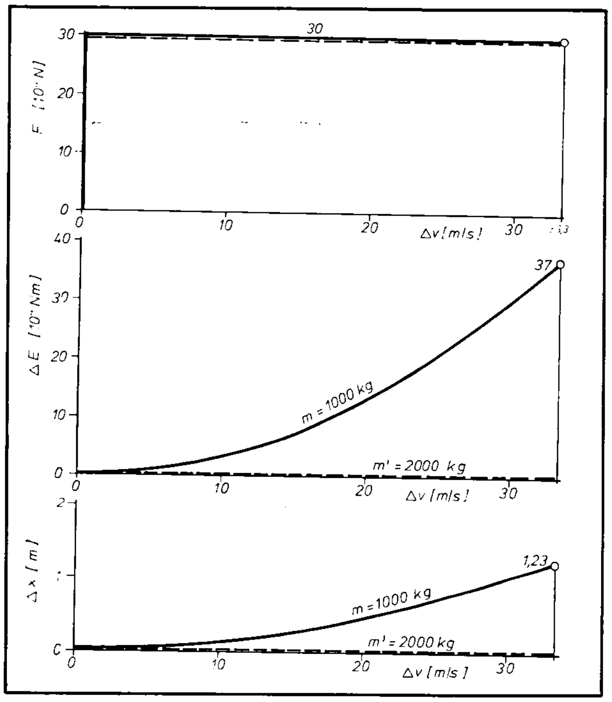


Figure 16

3.3 Constant, Impact Velocity Sensitive Characteristics according to USA Specification

Figure 17 shows the deceleration as a function of the speed at impact against a fixed barrier according to Figure IV of USA Specifications 3. This curve is modified by

a. selecting the exponent to 2.0 instead of to 1.85 in the ascending, median range;
b. determining the acceleration as design goal to 30 g in constant third range, in accordance with a safety zone of 10 g.

Assuming that the permissible decelerations for a small 1,000 kg vehicle and a large 2,000 kg vehicle are fully employed, the forces for the large vehicle are twice as big. The deformations are the same and are maximum 0.82 m.

Figure 18 shows forces, absorbed energies and deformations in a vehicle-to-vehicle collision in dependence of the relative speed. Two disadvantages of this fully exploited characteristic are shown:

a. at small impact speeds the large vehicle is not absorbing any energy,
b. at a maximum impact speed of 75 mph the deformation of the small vehicle of 1.03 m is larger than during the 50 mph barrier impact.

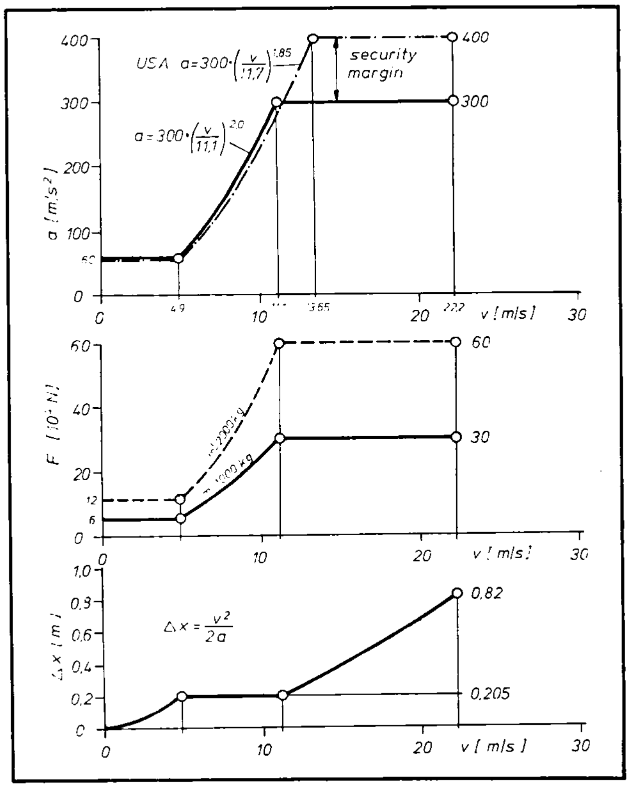


Figure 17

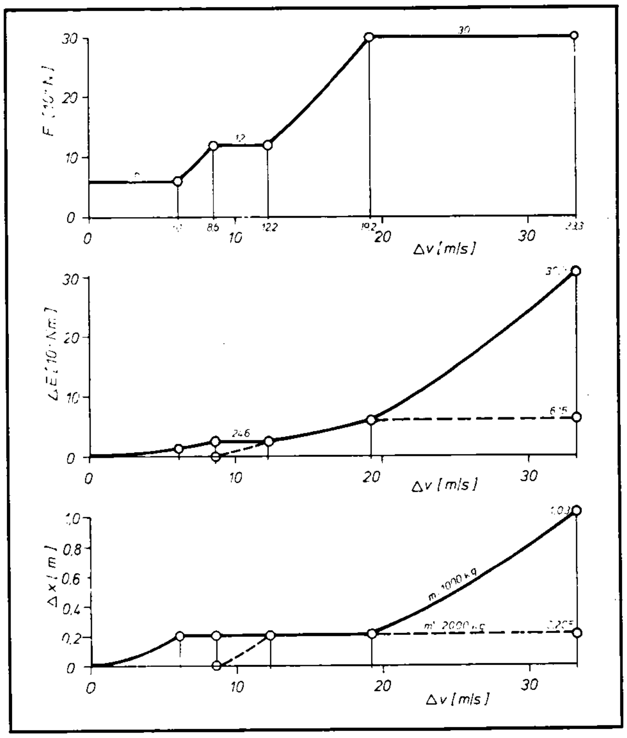


Figure 18

Compared with the constant characteristics independent of the impact speed the disadvantages of lacking energy absorption by the large vehicle and of excessive deformation of the small vehicle are, in fact, still there but considerably reduced. Figure 19 shows on the left an instructive view of the larger deformation in a vehicle-to-vehicle frontal impact and at the right the intended goal: equal deformation of small vehicle during a collision with larger vehicles or fixed barriers and obstacles.

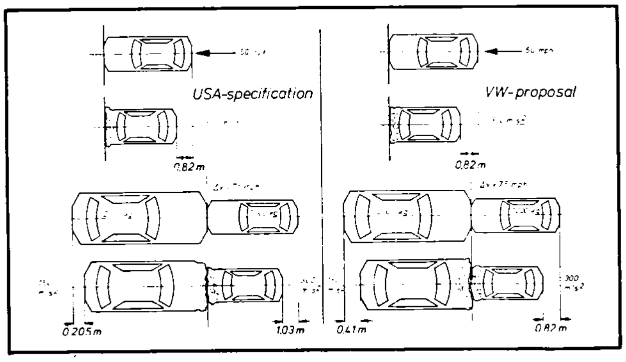


Figure 19

3.4 Constant, Impact Velocity Sensitive, Weight-Adjusted Characteristics

The starting point of the considerations is that in the 75 mph collision of a light and a heavy vehicle and while maintaining the maximum permissible deceleration level of 300 m/s² the deformation of the small vehicle is not larger than in the 50 mph fixed barrier collision, e.g., 0.82 m. From the total energy to be absorbed comes the deformation of the large vehicles, which has to become effective at forces set by the small vehicle. For the smallest vehicle considered here at a weight of 1,000 kg the required deformations of the collision partner in dependence of its mass are shown in Figure 20.

$$\frac{1}{2}\frac{m \cdot m'}{m + m'}\Delta v^{*}_{3}{}^{2} = F_3 \cdot \Delta x_{tot} = F_3 \cdot (\Delta x_3 + \Delta x_{2'})$$

$$\Delta x_{tot} = \frac{1}{1+m/m'} \frac{(\Delta v^{*}_{3})}{v^{*}_{3}}^{2} \Delta x^{*}_{3}$$

$$\Delta x_2' = \Delta x_{tot} - \Delta x_3$$

Below a collision mass of 1,242 kg$\Delta x_2'$ is constant in accordance with the minimum of $\Delta x_2' = 0.205$ m set by the USA Specification.

and are shown in Figures 23 and 24.

The dependence of the forces from the final deformation with the impact speed as parameter shows three characteristic ranges in the following shape (refer to Fig. 25):

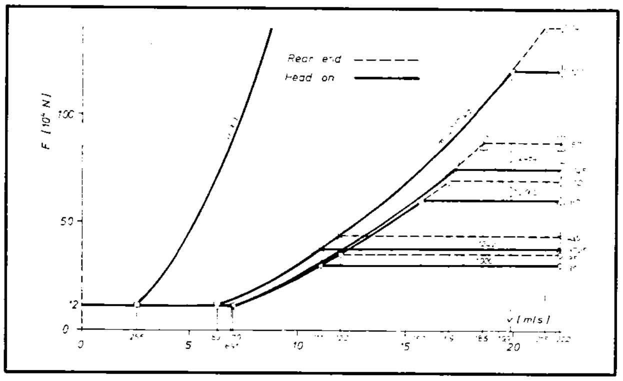


Figure 23

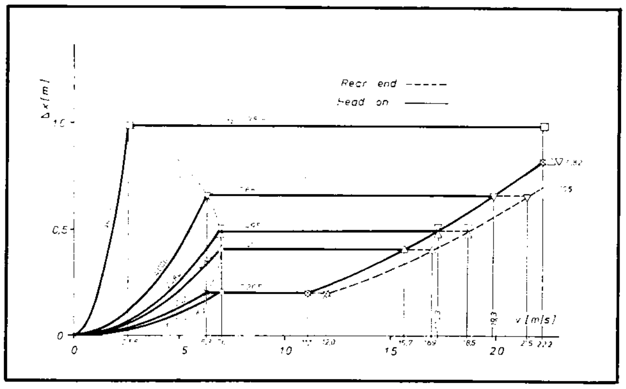


Figure 24

1. Force constant, final deformation increasing
2. Force increasing, final deformation constant
3. Force constant, final deformation increasing

The conjecture is that such characteristics can be obtained only with the aid of hydraulic elements: either by means of hydraulic elements for the entire deformation (required for 36,000 kg truck) or by connecting hydraulic elements in series (range 1 and 2) with plastic structure (range 3). The 36,000 kg truck requires a hydraulic stroke of 0.98 m. the 2,000 kg passenger car a stroke of 0.41 and the 1,000 kg passenger car a stroke of 0.205 m as a minimum. For passenger cars, such hydraulic strokes present no practical problems.

For a collision between a 1,000 kg vehicle and heavier vehicles, Figure 26 shows the forces and Figures 27 to 31 show the deformations as a function of the relative impact speed. Here too, it is shown how in accordance with the proposed design the deformations at the force level of the small vehicle increase with increasing mass.

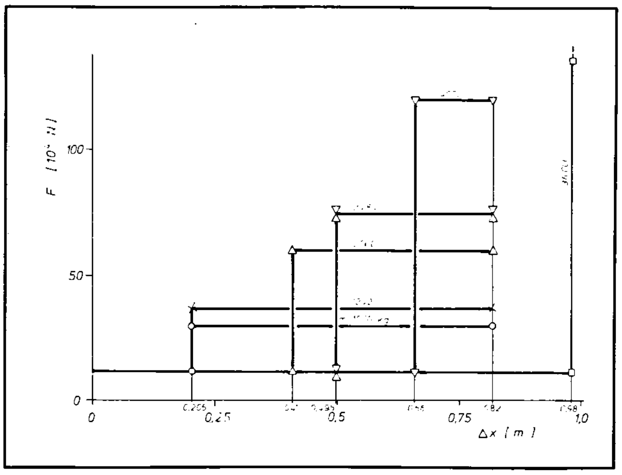


Figure 25

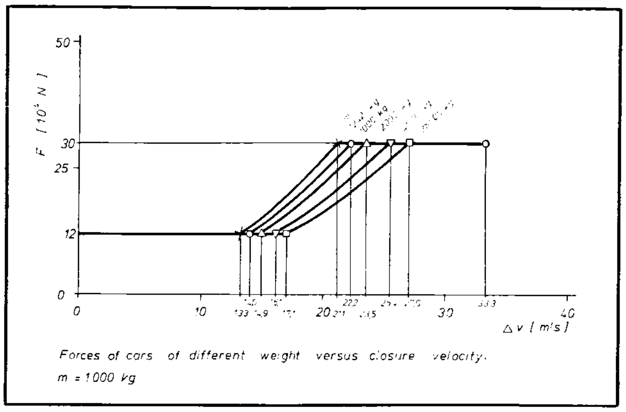


Figure 26

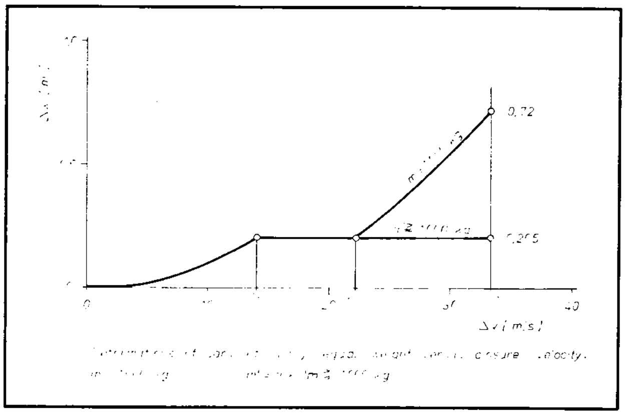


Figure 27

The maximum deformation of the small vehicle never exceeds 0.82 m.

Figure 32 shows a summary of this result for the maximum relative speed of 75 mph in the shape of forces and deformations as a function of the mass of the collision partner.

The pertinent results for the 2,000 kg vehicle are shown in Figure 33.

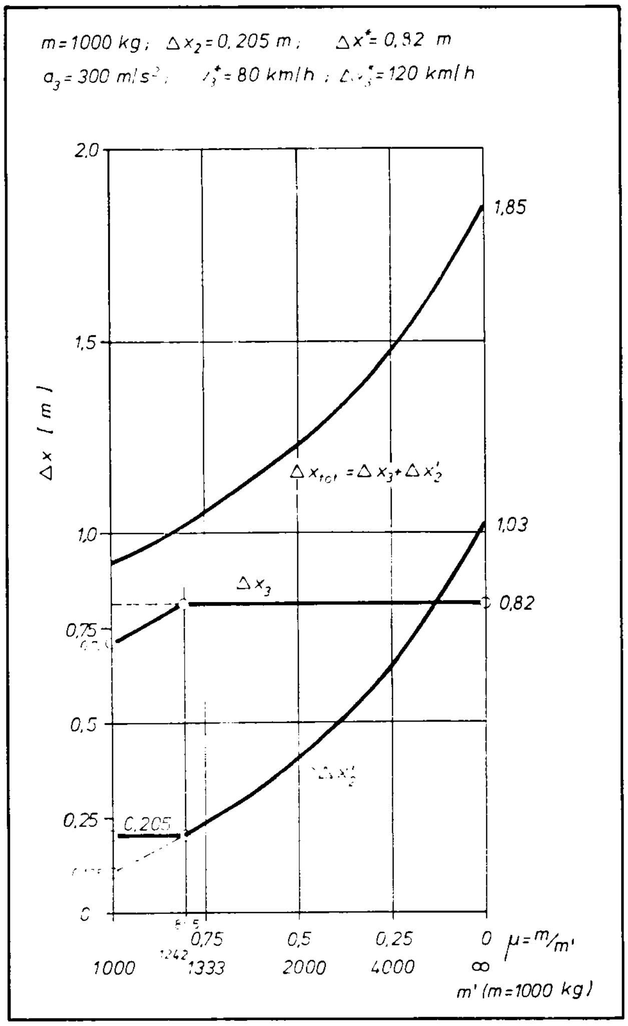


Figure 20

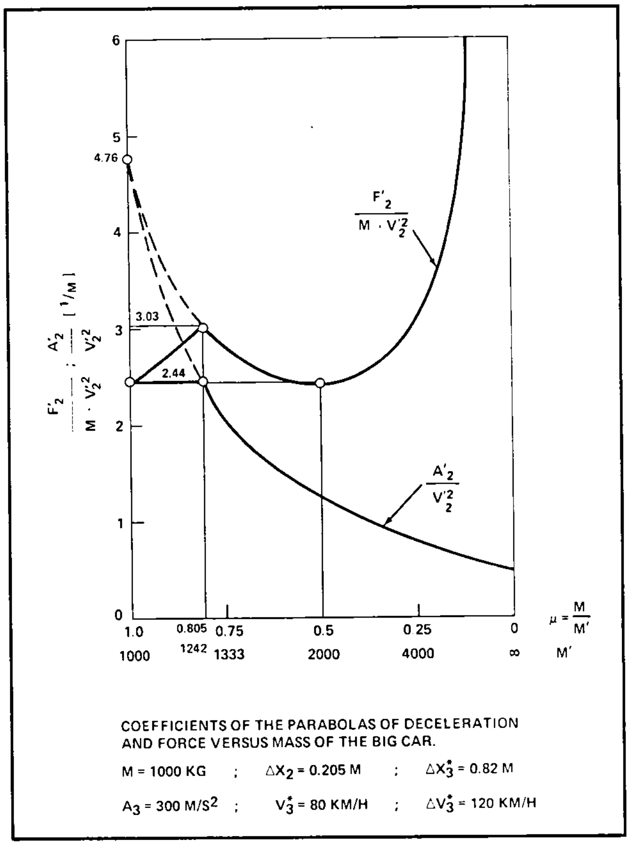


Figure 21

It can be shown that in the median range of the speed-dependent characteristics the coefficients of the parabolas for forces and decelerations proceed as shown in Figure 21. For the decelerations the results are slopes which are monotonously decreasing with larger masses, for the accelerations the minimum of slope is at m = 2,000 kg.

After determining the required deformations in the median range of the characteristics for all masses above 1,000 kg come the pertinent parabolas of deceleration (deceleration as function of the impact speed against a fixed barrier) from

$$a_2' = \frac{v_2'^2}{2 \cdot \Delta x_2'}$$

The transition to the higher range is made at the intersection with the 300 m/s²-level. At lower speeds the parabolas are either entering the zero point (disadvantage: deformations Δx_2 also at v→0) or they are entering a constant course selected in such a manner that the forces will be uniform for all masses. The last-named variant has been selected here in view of a distributed energy absorption during soft vehicle-to-vehicle collisions (refer to Fig. 22).

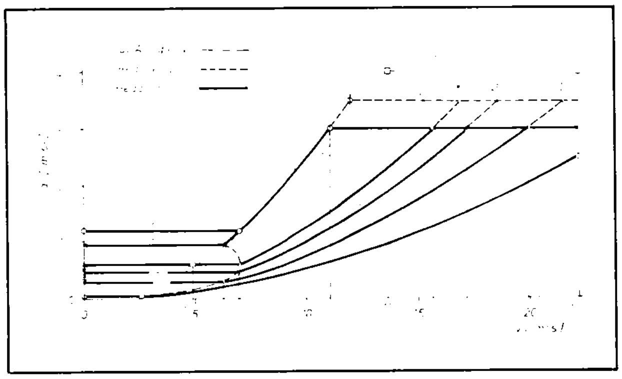


Figure 22

The forces and deformations as a function of the impact speed against a fixed barrier come from

$$F = m \cdot a \quad \text{or} \quad \Delta x = \frac{v^2}{2a}$$

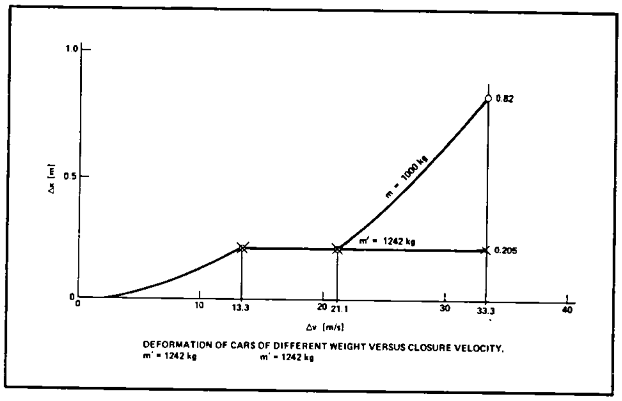


Figure 28

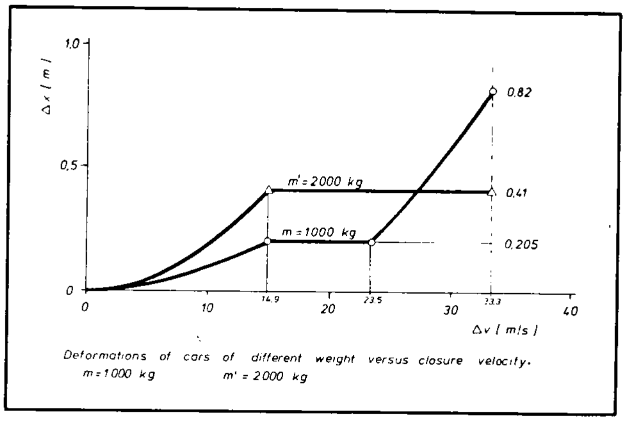


Figure 29

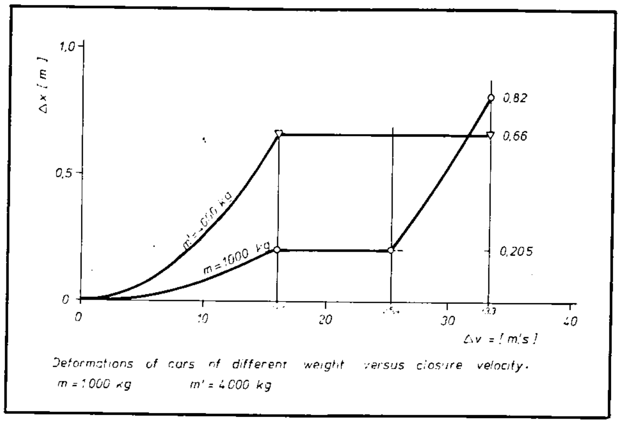


Figure 30

4. Rear End Structure

In consideration of the 75 mph rear impact test of a vehicle of any given weight against the 1,000 kg vehicle and assuming that at the rear the deformations path is shorter than at the front, there is only the possibility of designing the rear and "harder" for maximum acceleration of 350 m/s^2 than the front structure. For an impact

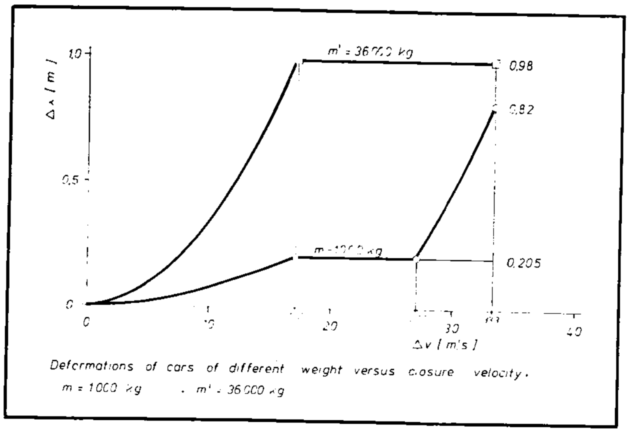


Figure 31

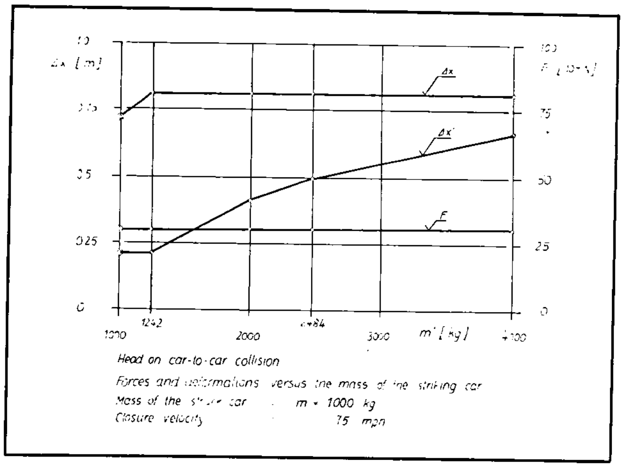


Figure 32

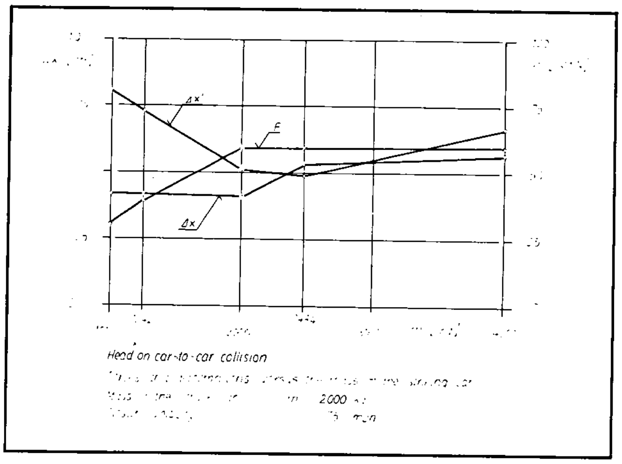


Figure 33

against a fixed barrier, the decelerations, forces and deformations are shown in Figures 22, 23 and 24.

For a vehicle of 1,242 kg mass Figure 34 shows the rear end deformations when hit by a moving barrier at 50 mph or by a vehicle at 75 mph in a mass range between 1,000 and 4,000 kg. The maximum rear deformation will be 0.56 m.

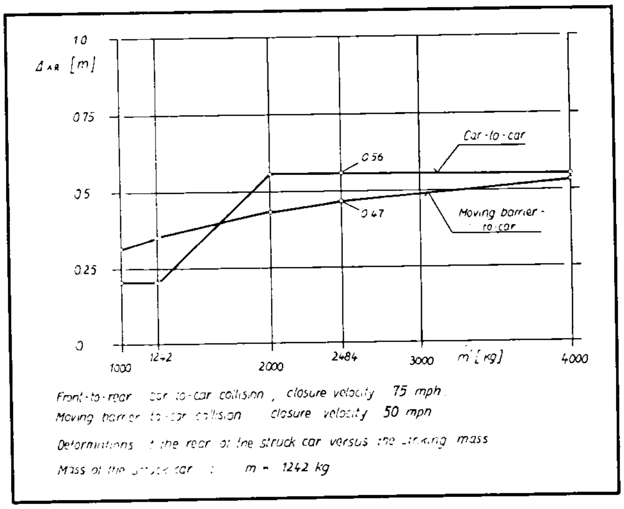


Figure 34

5. Side Impact

The design for the side structure is based on the fact that the side deformation during a 15 mph pole impact is twice as large as for the 30 mph side impact of 2 vehicles of pertinently similar weight (local forces, distributed forces). No further assumptions are required.

Figure 35 shows the forces and deformations during a 15 mph pole impact for vehicles in the range between 1,000 and 4,000 kg. The deformations increase from 0.14 to 0.40 m, the forces are at approximately 20 Mp.

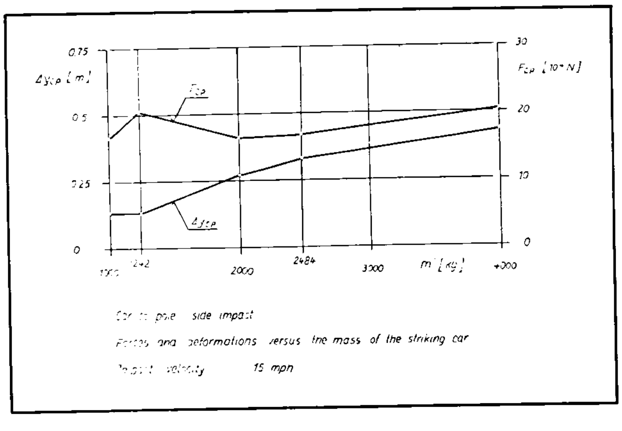


Figure 35

During a 30 mph side impact and at constantly increasing mass, the impacting vehicle absorbs more energy and the side deformation in the impacted vehicle will decrease (refer to Fig. 36).

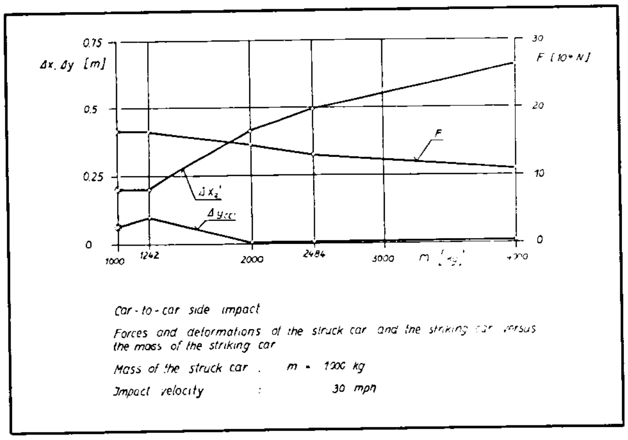


Figure 36

6. Summary of Results

Starting from the permissible decelerations-impact speed-curve of the USA Specifications the weight-adjusted characteristics of the proposed front and rear

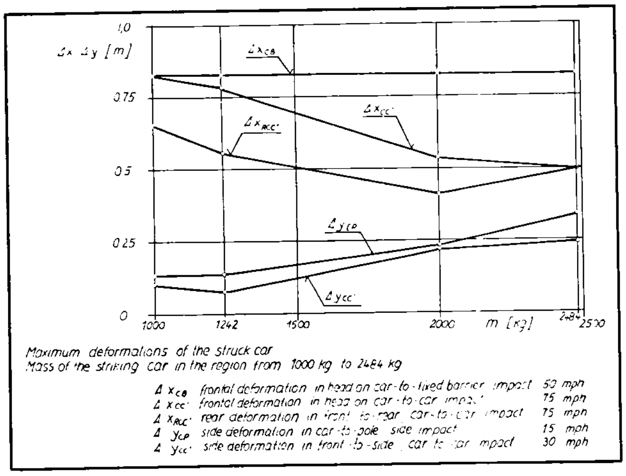


Figure 37

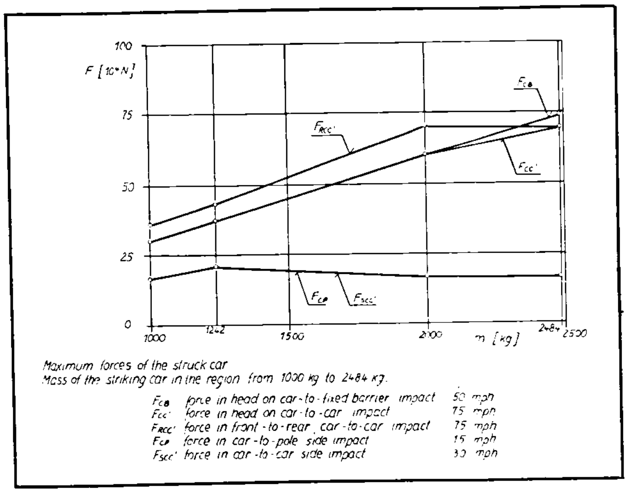


Figure 38

structure may solve the problem of intervehicular compatibility in mixed traffic. The speed dependent characteristics permit designing the heavy vehicle, on the one hand, "soft" enough that it will absorb a considerable share of the energy in the event of collisions with smaller vehicles while, on the other hand, designing the vehicle "hard" enough that in the event of collisions with fixed obstacles the deformations will not become too large. So the heavy car has lost the aggressiveness inherent to heavy cars today.

	Small Vehicle	Large Vehicle
Front deformation force	0.82 m 37 Mp	0.82 m 74 Mp
Rear deformation force	0.56 m 43 Mp	0.41 m 69 Mp
Side deformation force	0.14 m 21 Mp	0.33 m 16 Mp

The design proposed here covers a mass range of 1,000 kg to infinite. When a light vehicle of 1,242 kg and a heavy vehicle of 2,484 kg are considered within the scope of the ESV, the structures should be designed for the following deformations and forces (refer to Figs. 37 and 38):

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SECTION 3

PART 3 RESTRAINTS AND OCCUPANT SIMULATION

INFLATORS FOR AUTOMOTIVE OCCUPANT RESTRAINT SYSTEMS

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Introduction And Background

The Experimental Safety Vehicles being developed are directed toward the use of passive, occupant restraint systems. The inflatable cushion is a major consideration in achieving the goals of these programs.

For over two years, Rocket Research Corporation (RRC) has carried on an intensive program to apply its inflation system technology to the occupant restraint problem. In cooperation with Eaton Corporation, a program to develop advanced crash restraint systems using RRC inflators was initiated. This work has been progressing well, and RRC is currently producing several models of prototype hardware for a variety of sled and barrier tests by Eaton Corporation and others. This hardware is based on an all-solid propellant system in contrast to the first generation high-pressure "augmented" designs or high-pressure stored gas used in earlier work.

Rocket Research Corporation made use of standard N-5 double-base propellant in early gas generator hardware in order to conduct system tests while new propellants were being developed at RRC to meet the critical toxicity and high temperature/life requirements. These double-base propellants were used in combination with a Freon coolant to yield a low temperature gaseous exhaust. These "second generation" Freon-cooled gas generators were an outgrowth of related generators developed by RRC and currently in service on the Boeing 747 airplane for inflation of the emergency escape slides. One shipset of these inflation systems is shown in Figure 1. In the 747 installation, these generators provide the primary gas flow for driving high-performance air aspirators which in turn inflate the

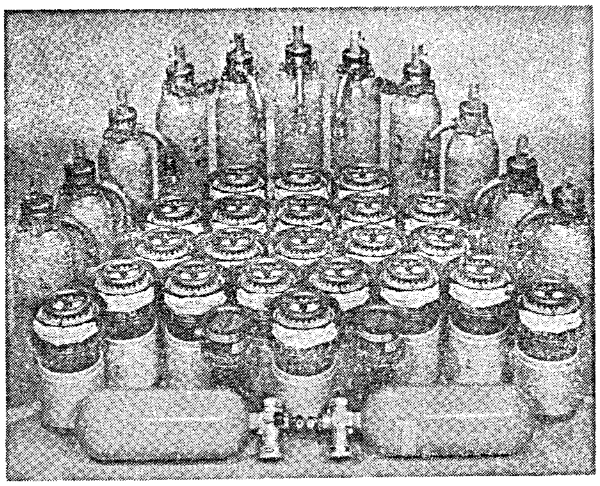


Figure 1

slide over a 5- to 7-second interval. The final gas mixture in the inflated slide is composed of approximately 40 percent cool gas genrator products and 60 percent ambient air. In the 747 airplane these systems were chosen because of the weight and volume advantage over high-pressure stored gas.

As an outgrowth of the 747 technology, several forms of Freon-cooled gas generators for passive restraint systems with operating times of 20 to 40 milliseconds have been developed and are in various stages of production. Inflators of this type have been provided to Wayne State University for use in a steering wheel air cushion test program being conducted for the National Highway Traffic Safety Administration. Several of these units are shown in Figure 2. The Eaton/RRC team also won the contracts to supply occupant restraint systems to both AMF and Fairchild for use in the Experimental Safety Vehicles. The RRC inflators for these programs are Freon-cooled units and are discussed later in this paper.

The Freon-cooled gas generator for the inflatable occupant restraint application has now been replaced by a third generation design – the all-solid cool gas generator. This advanced inflator was made possible by the development of new propellants and a unique gas generator design.

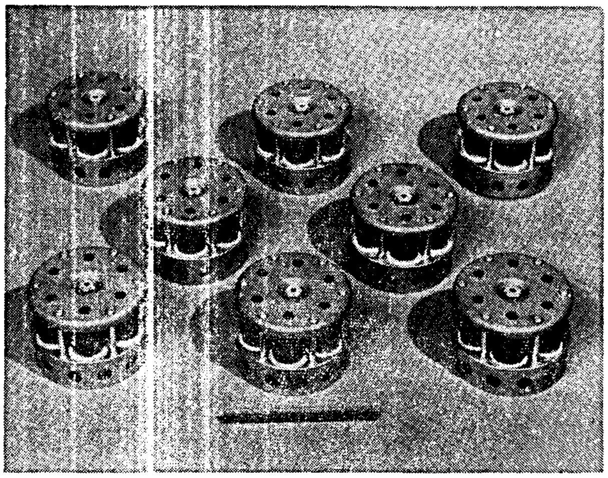


Figure 2

From the very beginning of its occupant restraint program, RRC has emphasized the aspect of toxicity in this work. Analysis of the exhaust products of the gas generators is routine in almost every test conducted. Chemical analysis is often supplemented with studies of the physiological effects of generator exhaust products, including animal exposure tests both at RRC and by outside laboratories. Details of the toxicity evaluation program at RRC are presented in this paper.

For relatively small inflatable volumes, 1 to 2 ft^3, the all-solid inflator provides significant advantages compared to pressurized gas or liquid-cooled systems. For large inflatable volumes, a unique aspirator system, which uses an all-solid generator (or other gas source) as the source of primary working fluid, offers major additional advantages. The aspirator system described below is a proprietary RRC development, also growing out of the 747 technology noted above.

Rocket Research Corporation Inflation Systems

In general, RRC inflator development has fallen in three main categories:

1. Freon-cooled gas generators
2. All-solid gas generators
3. Aspirating systems

Other work has included research on "air induction" cushions, rocket- or jet-deployed cushions, and cartridges for augmented gas systems using RRC propellants. The initial work on gas generators was conducted with Freon as the coolant. Considerable effort went into the selection of the coolant with major factors being thermal stability, boiling point, molecular weight, cost, and toxicity. Design of the generator is equally important to prevent the thermal breakdown of Freon with the generation of highly toxic species such as phosgene, perfluoroisobutylene (PFIB) and others. Cardiac sensitization became the major factor leading to selection of Freon C-318 for use in the ESV inflators.

In the following paragraphs, each of the principal inflators that have been developed is briefly described.

Inflators For The Experimental Safety Vehicle (ESV) Programs

Each ESV is equipped with three independent systems to protect the driver, the front passenger, and the rear seat passengers from injury in the event of a frontal impact. The driver cushion/gas generator system is located within the steering wheel. The front passenger system is mounted integral with the instrument panel, while the rear passenger system may be either roof mounted or mounted adjacent to the rear of the front seat.

The gas generator systems (inflators) developed by RRC for the ESV applications are based on a modular Freon-cooled gas generator concept. By proper combinations of the gas generator modules and sequential firing, the gas volume output and dynamic characteristics of the inflator may be tailored to the requirements of each of the three system installations. Each gas generator module (see Figures 3 and 4) consists of a compart-

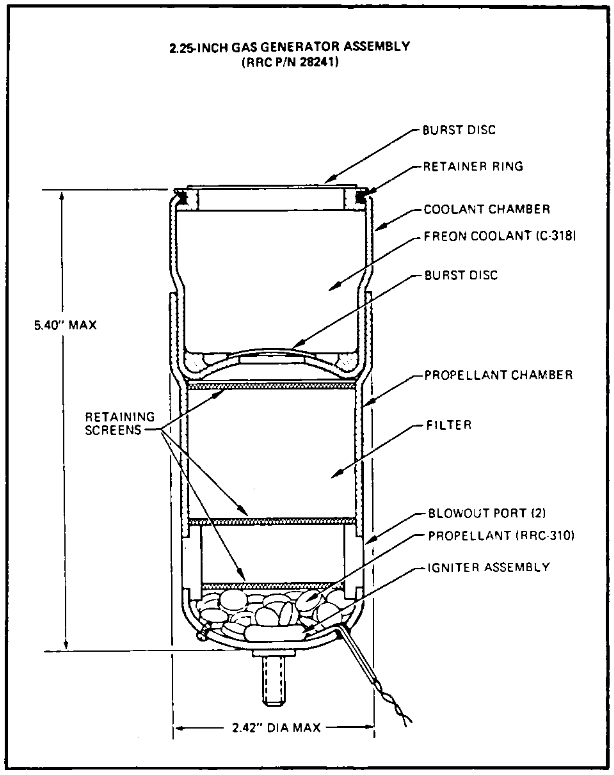


Figure 3

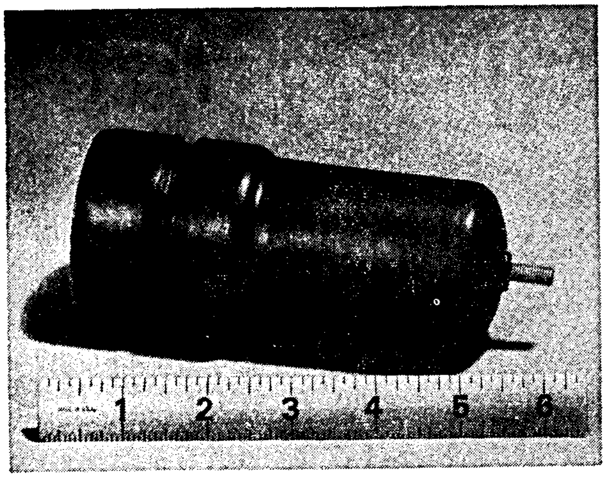


Figure 4

mented steel housing containing an RRC-developed solid propellant (RRC-310) and a liquid coolant (Freon C-318). When ignited, the solid propellant gas mixes with and vaporizes the coolant, thus supplying a cool gas to inflate the occupant restraint cushion. Each module produces 2.4 cubic feet of gas measured at exit temperature (150°C = 300°F) and 1 atmosphere.

As indicated, proper combinations of the gas generator module are required for each of the three vehicular system locations. The driver, or steering wheel system (Figure 5), consists of four modules mounted in

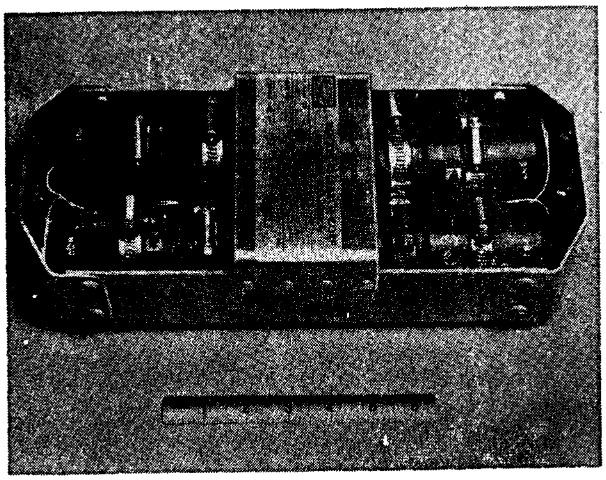


Figure 5

opposing pairs beneath a deflector plate. The front passenger system, Figure 6, is made up of seven to nine modules mounted side by side in series fashion. A diffuser plate is mounted over this series arrangement to insure proper cushion inflation characteristics. The rear seat system, Figure 7, consists of three identical assemblies, each containing four gas generator modules. The modules in each rear seat assembly are located side by side but are rotated 180 degrees form each other.

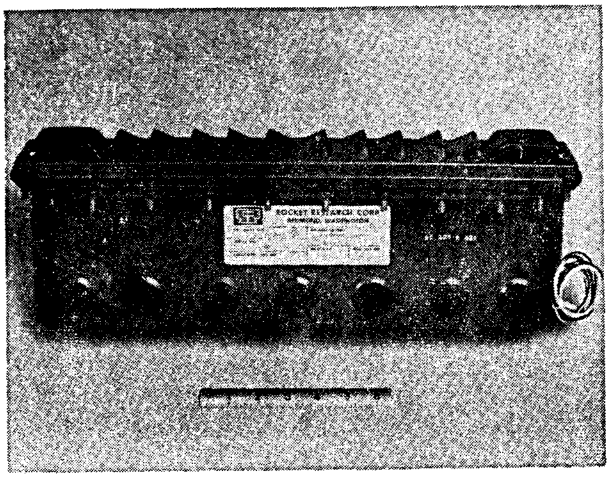


Figure 6

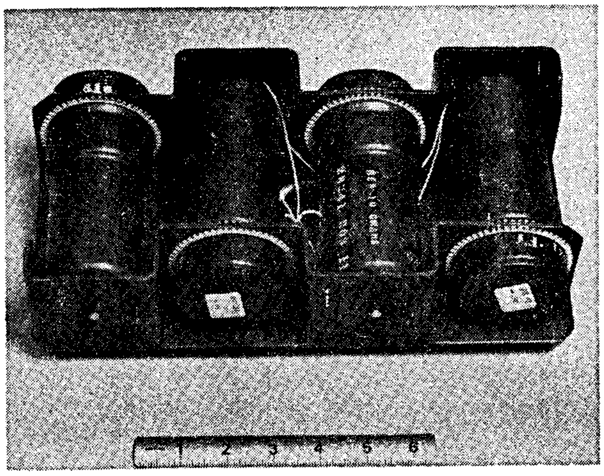


Figure 7

Model 28300 All-Solid Steering Wheel Inflator

The RRC Model 28300 all-solid "air generator" for mounting within the steering wheel is shown in Figures 8 and 9. This experimental prototype has been under development for several months; and, as of October 15, 1971, over 180 tests of the radial flow design had been conducted, including over 50 tests of the Model 28300 plus approximately 40 tests by Eaton Corporation. Delivery of 115 units has been made to the Eaton Corporation for integration into occupant restraint systems and subsequent tests which, to date, have included 18 sled and/or barrier tests. The Model 28300 has also been used in manned air cushion demonstrations under "static" conditions.

The Model 28300 inflator is shown in cross-section in Figure 10, and the characteristics are listed in Table 1. A summary of advantages is given in Table II. The clean,

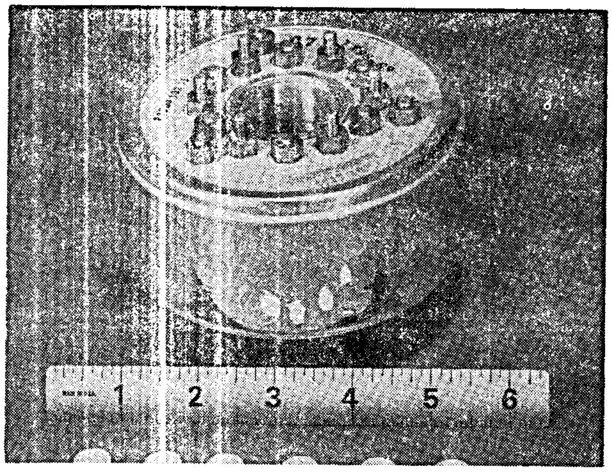


Figure 8

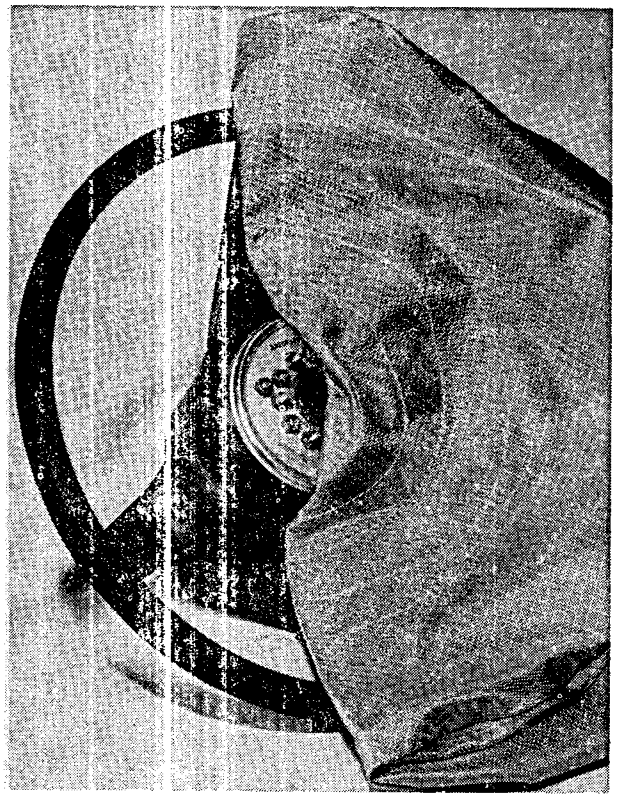


Figure 9

cool, nontoxic exhaust products are a result of the unique characteristics of the RRC-310 propellant and the design of the generator. The unique coolant bed not only acts as a heat sink, but as a filter which reduces particulate output to negligible levels. One feature of this design is that it is nonpropulsive when fired without a cushion attached. This can be a distinct advantage from the standpoint of safety during final assembly, shipping, and installation into an occupant restraint system. When fired in this condition, untethered, there is virtually no movement of the inflator.

The Model 28300 is presently equipped with a Holex squib (P/N 9676), a dual bridgewire unit with a resistance of 2.5 ± 0.3 ohms. The all-fire current is 1 amp and the no-fire current is 0.1 amp. Squibs with other characteristics can be obtained.

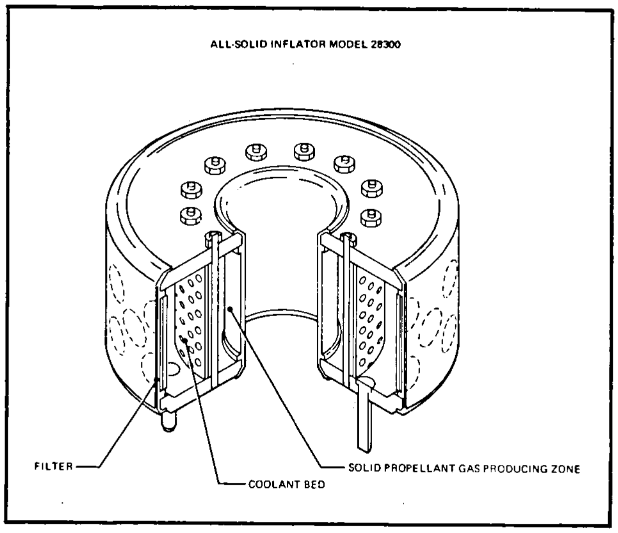


Figure 10

Table I
CHARACTERISTICS OF MODEL 28300 INFLATOR

Diameter, inches	4.68 maximum
Height, inches	2.25 plus fittings
Center hole diameter, inches	1.25
Weight, lbm (nominal)	2.7
Material of construction (structural)	6061/7075 aluminum
Gas exhaust ports	Radial outward
Cushion mounting provisions	Base
Operating temperature range, ^{o}F	-20 to +220^{o}F
Gas temperature, ^{o}F (from 70^{o}F)	170^{o}F
Gas volume, ft^3 at temp and 1 atm	1.76
Noise, db (in car measurements)	<140
Ignition Delay, ms (nominal)	1.0 ms
Operating time, ms (nominal)	20 to 25
Present squib	Holex P/N 9676
Resistance, ohms	2.5 ± 0.3
All fire, amps	1.0
No fire, amps	0.100
Exhaust composition (nominal)	
Gases, percent by volume unless noted	
N_2	94.4
O_2	5.02
H_2O	0.38
H_2	0.13
CO_2	400 ppm
CO	300 ppm
NO_x	0 to 8 ppm
CH_4	100 ppm
NH_3	20 ppm
Total solids, milligrams	100

Table II
ALL-SOLID INFLATOR ADVANTAGES

Nontoxic exhaust
Low noise (<140 db)
No high pressure gas or liquified gas storage
Reduced number of readiness circuits – no pressure or liquid level sensing necessary
Meets all environmental requirements – propellant has met life requirements at 240°F
Low weight

The nominal ignition delay of the Model 28300 is 1 millisecond, and the inflator has an operating time of 20 to 25 milliseconds. The gas output, when fired at ambient temperature (70°F), is 1.76 ft^3 at 170°F and 1 atmosphere. The cushion temperature rise, using a 1.5 ft^3 cushion fabricated of 7.4-oz. coated nylon, is negligible.

The output characteristics of this inflator as a function of ambient temperature are listed in Table III.

Table III
MODEL 28300 OUTPUT VS AMBIENT TEMPERATURE

Ambient Temperature (°F)	Output at 1 Atmosphere and Gas Temperature (ft^3)	Output Gas Temperature (°F)
0	1.56	99
+30	1.65	131
+70	1.76	170
+100	1.85	202
+150	2.00	257
+180	2.14	306

Design and development of the production prototype, Model 28400, is underway.

Aspirator Inflation System

The RRC aspirator inflation system offers the most effective means of minimizing toxicity problems by using air from within the car as part of the inflation gas. In addition, lower noise levels are achieved; and by proper design, the problem of the out-of-position passenger can be significantly reduced. A list of advantages of the aspirator inflator is shown in Table IV.

Table IV
ASPIRATOR INFLATOR ADVANTAGES

Soft deployment – acceptably low forces to the passenger in any position
Smaller gas source – 2/3 to 3/4 of cushion filling gas is drawn from passenger compartment.
Less compartment overpressurization
Low thrust forces into mounting structure
Minimizes noise
Lower toxicity due to dilution with compartment air

Figures 11, 12, and 13 depict a deployment sequence of the RRC aspirator inflator. In tests to date, either a stored gas bottle (40 $in.^3$ for a 10-$ft.^3$ cushion) or an augmented gas source has been used as the "driver" for the aspirator. (An all-solid gas generator driver is being developed.) When the system is initiated, the cushion

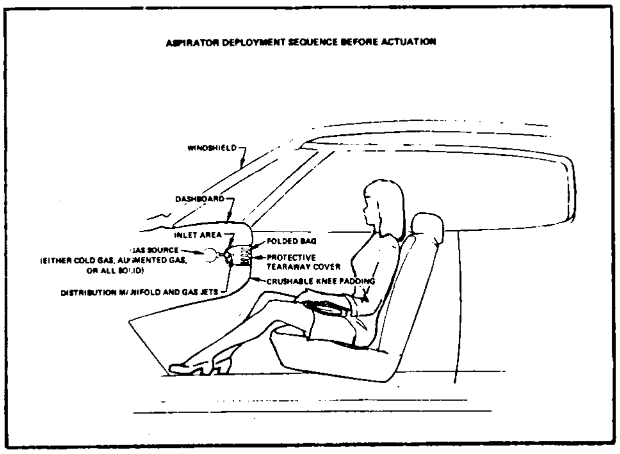


Figure 11

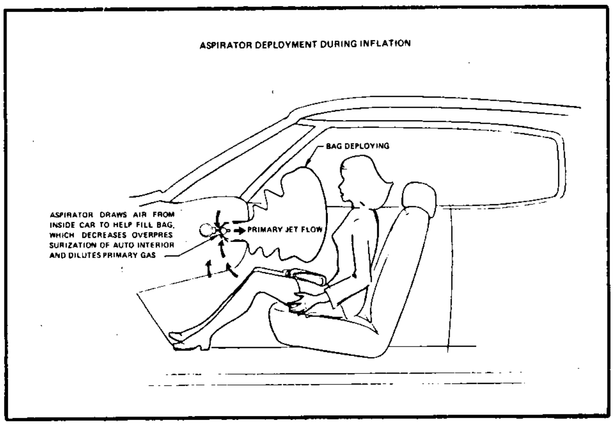


Figure 12

which is stored inside the aspirator housing is pressurized until the cover tears open. Buildup of pressure is possible because the check valves at the air inlet prevent excessive backflow. When the cover breaks, the cushion is ejected out of the aspirator and the check valves open, enabling air to be pumped or aspirated into the cushion. The aspirator is designed to "stall" or cease pumping at a chusion back pressure low enough to prevent excessive pressures from being developed if an obstruction is encountered (such as an out-of-position passenger). The system will, however, continue to fill around such an obstruction. The net result is that an out-of-position occupant is pushed back into the seat with acceptable forces. (Tests have shown that the rearward velocity imparted to a 50th-percentile, 3-year-old toddler will not exceed 10 mph). When the cushion is filled and begins to pressurize, the valves again close and cushion pressure is increased by blowdown from the gas source and/or the momentum of the passenger into the cushion. The check valves may also be designed to act as a vent for the gases. Check valve motion is 1 to 2 milliseconds to either open or close.

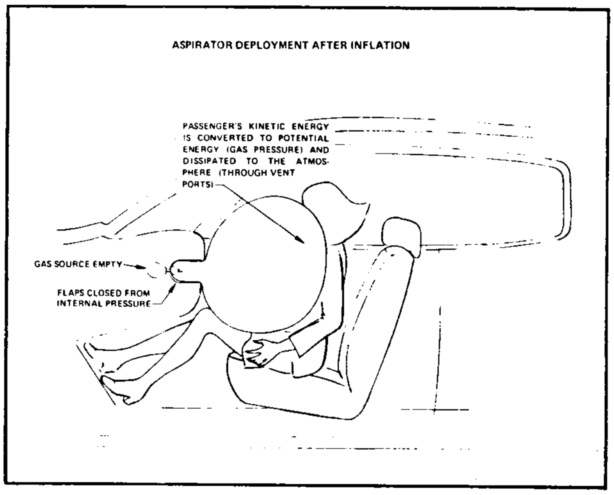


Figure 13

A general rule of thumb dictates that about 10 in.^{2} of aspirator cross-sectional area be allowed for each cubic foot of cushion. With this value, overall pumping ratios (volume of air/volume of primary gas) of approximately two are attained when using high-pressure stored nitrogen as the gas source. As a result, the gas source weight and volume are dramatically reduced. A 40-in.^{3} bottle at 3,000 psi is adequate for a 10-ft.^{3} cushion. With higher temperature gases, which will be generated by the all-solid driver under development, overall pumping ratios will approach 3.0, thus further reducing overpressure and hypoxia problems in the automobile as a result of deployment. Due to the dilution with induced air,

Table V
TYPICAL ASPIRATOR PERFORMANCE CHARACTERISTICS

Aspirator Area (in^2)	Cushion Volume	Aspirator Inlet Area Cushion Volume Ratio (in^2/ft^3)	Time To* Fill (msec)	Pumping Ratio
70	4.9	14.3	19	1.55
70	7.2	9.72	24	1.8
70	9.3	7.52	33	1.95

*Test series did not include tear-off cover. The presence of a cover or a deployment door will result in additional time required for deployment.

higher temperatures can be employed for the gas source exhaust than would otherwise be allowable.

Experimental data from a series of parametric sizing tests is shown in Table V. The gas source was 40 in.^{3} of GN_2 at 3,000 psig.

Dynamic tests have been conducted at the dynamic test facility of Eaton Corporation's Safety Systems Division. A sequence from one of these tests (simulating a 30-mph barrier impact) is shown in Figure 14. This test was conducted with a 50th-percentile male dummy and met all requirements of FMVSS 208. These and other tests have provided further indication that it is possible to provide protection to the out-of-position passenger (as well as one properly seated) without imparting injury as a result of the deployment itself.

The state of the art in aspirator design at RRC exists now to design and develop a production model aspirator inflator using pressurized gas or augmented gas as the driver. Because of the elimination of the high-pressure stored gas and the other advantages gained, the optimum inflator for the larger bags appears to be an all-solid driven aspirator. An illustration of an aspirator inflator is shown in Figure 15, and the characteristics are listed in Table VI.

30-MPH SLED TEST OF ASPIRATOR INFLATOR

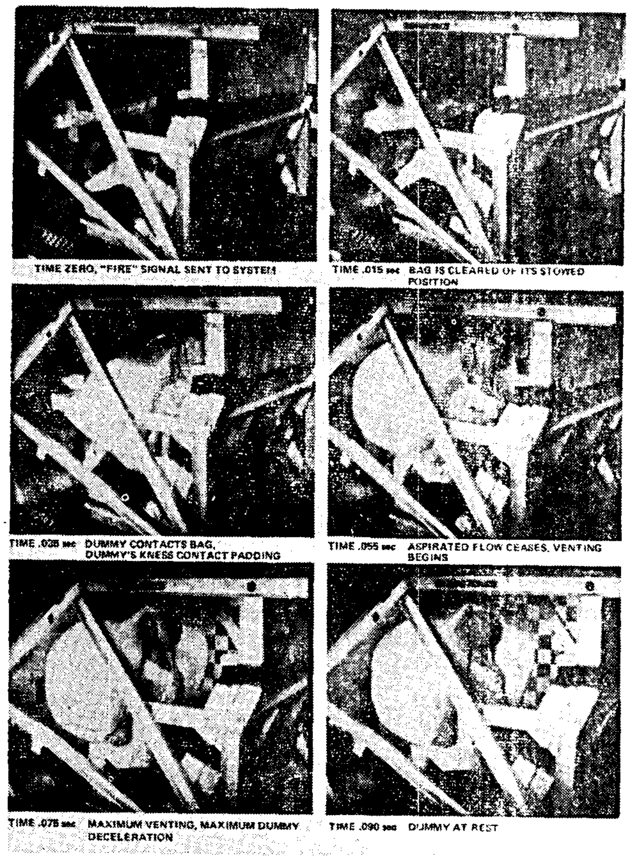


Figure 14

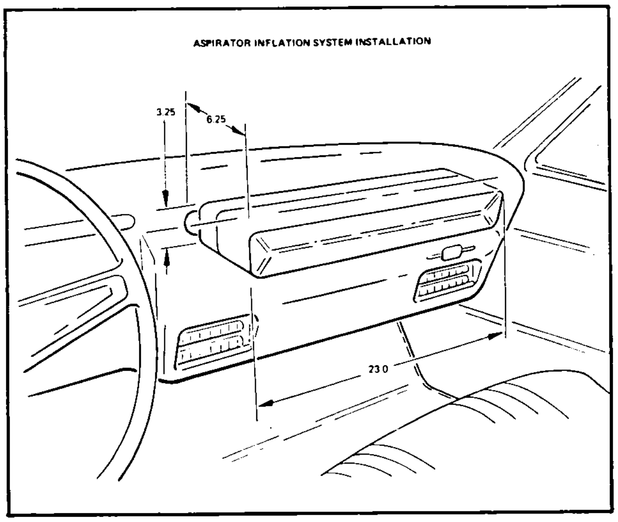


Figure 15

Table VI
CHARACTERISTICS OF ASPIRATOR INFLATOR

Parameter	Value
System length, inches	23 to 28
System height, inches	3.25
System thickness, inches	6.25
Cushion volume, ft^3	7 to 10
Predicted time to fillback, ms	35
Storage temperature range, °F	-40 to +220
Operation temperature range, °F	-20 to +220
System weight, lbm	12 to 14

System Requirements And Propellant Selection

While there are many approaches (and many propellants) that may be used to achieve the necessary ballistic performance, two requirements overshadow all other considerations; namely, elimination of toxic exhaust products, and the ability to withstand high environmental temperatures (240°F) for a long installed life (up to 10 years) in the automobile. Standard solid propellants and pyrotechnics were found to be generally unsuitable for this application due to either poor high temperature aging characteristics or toxic exhaust products, or both. Double-base propellants typically are limited to less than 500 hours at 170°F. For example, in tests conducted by RRC, N-5 propellant was marginal after 100 hours at 200°F, marginal after 200 hours at 185°F, and marginal after 500 hours at 165°F. After 500 hours at 185°F, N-5 propellant had deteriorated to the point where it no longer performed satisfactorily. These tests involved ballistic evaluation as well as weight loss measurements. One of the most obvious toxicity problems arising from the use of double-base propellants is the high carbon monoxide content of the exhaust (5 to 10 percent by volume in the cushion). Carbon monoxide is both toxic and flammable, and its concentration must be minimized in systems for crash restraint use. A listing of propellants that have been considered and the problems related to their use is given in Table VII. Conventional propellants may produce significant and unacceptable quantities of toxic gases such as CO, NH_3, HCN, NO_2, HCl, CO_2, or H_2O, which, while of no consequence in the usual military application, could present a definite hazard to automobile passengers in the event of an accident.

Table VII
PROPELLANT SYSTEM CONSIDERATIONS

Black powder	Very dirty – high NO_2 and SO_2
Double base	Unstable above 170°F, high NO_2, H_2O, and CO
Gun powder	Unstable above 170°F, high NO_2, H_2O, and CO
Single base	High NO_2, H_2O, and CO
RDX and HMX	Good thermal stability, high NO_2, H_2O, and CO
Ammonium nitrate	Poor ballistics, poor temperature cycling, high NO_2, H_2O
Potassium nitrate	High NO_2
Ammonium perchlorate	High H_2O and HCl
Ammonium chloride + sodium nitrite	High H_2O
High nitrogen organics	Poor stability, high CO and H_2O
Organic binders	High CO and H_2O

Rocket Research Corporation has developed and characterized three new families of solid propellants with high thermal stability that lend themselves readily to mass production. Both the nature and form of these new propellants provide basic building blocks for a number of different gas generator requirements. The resulting gas generator is a new approach to gas generation using solid propellants and results in a unit that produces clean, relatively cool "air." It is possible to adjust the O_2/N_2 ratio as desired over a range from zero percent oxygen to as high as 20 percent oxygen. Over 98 percent of the exhaust gases are nitrogen and oxygen with water constituting from 0.5 to about 1.5 percent. Remaining gases detected are in trace quantities only (refer to Table I). Carbon monoxide content is typically less than 300 ppm with a further reduction planned by eliminating, in the production design, some organic adhesives now being used in the assembly of the preprototype units.

Rocket Research Corporation propellants for this application have already exceeded 5,000 hours storage at 240°F with no effects on ballistics or physical properties. The propellants have been classified Class B by the Bureau of Explosives. These propellants pelletize readily to form a material easily adaptable to mass production and one which also provides unusual flexibility to adjust ballistic performance in the gas generator. Some of the pellets of RRC-310 propellant are shown in Figure 8.

TOXICITY EVALUATION PROGRAM*

The importance of the toxicity requirement cannot be overemphasized, and this factor has been absolutely dominant in all of RRC's work. The RRC gas analysis techniques are well documented, including sampling techniques as well as analytical procedures. In addition to gas sampling, RRC inflators are evaluated for aerosol (dust) production. The considerations that have guided RRC toxicity studies are presented in this section together with a summary of some of the more important test results. Sources of information are discussed in the appendix.

Physiological effects

The adverse effects acting on the occupant of an automobile during and after an accident are extremely complex in their relation to each other. The purpose of this section is to emphasize and clarify the more pronounced effects in relation to gas generator exhaust.

Thermal Effects

The effect of high temperature gases on the skin and respiratory tract is a potential problem of chemical gas generators. The effect of hot gases on the exposed parts of the body and respiratory tract is a function of their heat content (heat capacity) as becomes evident in the extreme case of water steam. While the transient temperature of exhaust gases is not easy to measure, specifications must be established within which the gas generator is to perform.

Water is a common combustion product of many gas generator propellants. It was also considered as a coolant to absorb excess heat from gas generator propellants and contribute to the gas volume delivered to the inflatable cushion. In these cases, hot water vapor can cause scalding of exposed skin and eyes as well as produce damage to the respiratory tract when inhaled.

The thermal damage by hot gases is mainly a function of their water content and heat capacity (including the heat of condensation of water). Dry air can be tolerated at higher temperatures than steam-saturated air. It is desirable to keep the temperature of the gas generator effluent and its water content as low as possible to avoid thermal damage.

Physiometrics, Inc., under contract to RRC, prepared a literature search to define the maximum safe water vapor content of hot gas for inflation of automobile occupant restraint cushions (Ref. 1). Most of the information cited in this section is taken from that report.

To assess the potential damage by steam inhalation and impingement on the skin, the following assumptions were made:

a. The maximum environmental temperature at which the system has to perform safely is 82°C (180°F).
b. Inhalation of one full breath of undiluted, hot, humid nitrogen or air in the range of 121 to 260°C (250 to 500°F) with water concentrations from 0 to 30 percent by volume.
c. Inhalation of mixture (b) for 30 seconds after dilution with an equal volume of warm (82°C = 180°F) air.
d. Inhalation of mixture (b) for 1 hour after dilution by a factor of 4 with warm air.

The survey (Ref. 1) cites work conducted by Moritz et. al. (Ref. 2) with dogs, where dry and moist hot air was introduced below the pharynx through an insulated cannula. The number of inhalations ranged from 22 to 106. Injury in the upper trachea was only mild in most cases and moderate in one. The conclusion seems warranted that harm produced by a single inhalation of dry air up to at least 260°C (500°F) would be very slight.

However, when an equal mixture of air and steam was used in the experiments conducted by Moritz et. al., severe injury to the upper trachea was observed after 10 to 27 inhalations. Even with only 10 inhalations, the upper tracheal injury was severe.

Although the Moritz study was primarily concerned with thermal damage produced deep in the pulmonary system, some preliminary experiments studied the effects of hot gases in the pharyngeal area. There is indication of the hazard of development of edema which could cause obstructive asphyxia and death. These experiments showed that even with only a few breaths of dry air delivered to the pharynx at 300°C (575°F), or of steam delivered at 100°C (212°F), severe local edema developed within a few hours, resulting in asphyxial death. The upper airways appear to be more susceptible to heat and steam damage than the bronchi and alveoli themselves.

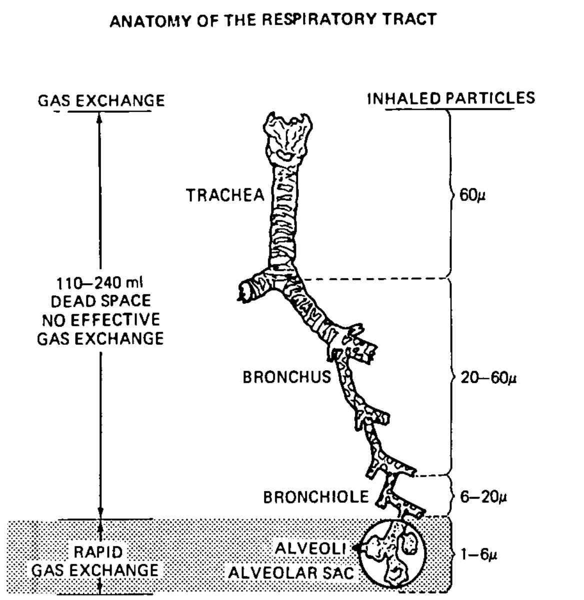
*This section was extracted in part from RRC 71-ES-73, *Toxicity Evaluation of Gas Generator Effluents for Crash Restraint Bag Inflation*, by Dr. E. W. Schmidt, Manager, Chemical Research, Rocket Research Corporation

Because of the high heat content of water steam (due of the heat of vaporization), RRC has chosen to minimize the water content of the gas generator exhaust.

Respiratory Effects

The main concern in the toxicity area is that of respiratory damage. This damage may be caused by both gases and/or aerosols. To more clearly illustrate the various terms used in this study, Figure 16 is reproduced from Ref. 3. The illustration shows that no effective exchange between blood and gas occurs in the respiratory tract until the gases reach the alveoli. However, corrosive gases act on mucous membranes and epithelium all the way down into the lungs and are absorbed by surface moisture. Certain high boiling compounds such as perfluorodimethylcyclobutane (halocarbon C 51-12), which are otherwise physiologically inert and noncorrosive, cause respiratory irritation due to condensation of solvent vapor in the respiratory system.

Aerosols are retained in their order of particle size, the larger ones in the nose and mouth, smaller ones in the bronchi and alveoli, and significant fractions of the smallest ones (in the submicron range) are actually exhaled unabsorbed (example: cigarette smoke).



ELIMINATION OF SMALL PARTICLES (<5μ)

NUMBER PER ml	ELIMINATION
<10	COMPLETE
~1,000	90%
~1,000,000	INADEQUATE

SOURCE: REF. 3

This chart gives the approximate dimensions of the breathing tract in adult males, together with details of the size of particles commonly found there. Particles larger than 5μ are usually eliminated, but smaller particles are deposited and cause irritation and inflamation. The table indicates what proportion of small particles are normally eliminated; thus, if the dust count is 100 particles per ml, 90% are eliminated and 10% are deposited. It is particularly important to reduce airborne dust particles less than 2μ in size.

Figure 16

Table VIII
LUNG VOLUMES

Respiratory Volumes	Definition	Mean Values		Standard Deviation	
		Feet3	Liters	Feet3	Liters
Inspiratory reserve volume	Maximal volume that can be inspired from end tidal inspiration.	0.118*	3.344	–	–
Tidal volume	Volume of gas expired or inspired during each respiratory cycle.	0.134*	0.45**–3.80*	–	–
Expiratory reserve volume***	Maximal volume that can be expired from resting expiratory level.	0.035	0.98	0.009	0.26
Residual volume***	Volume of gas in lungs at end of maximal expiration.	0.042	1.19	0.012	0.35
Inspiratory capacity***	Maximal volume that can be inspired from resting expiratory level.	0.134	3.79	0.018	0.52
Functional residual capacity***	Volume of gas in lungs at resting expiratory level.	0.077	2.18	0.018	0.50
Vital capacity***	Maximal volume that can be expired after maximal inspiration	0.169	4.78	0.021	0.59
Total lung capacity***	Volume of gas in lungs at end of maximal inspiration.	0.204	5.97	0.028	0.81

*Maximum
**Minimum
***Data from Kaltreider, 50 young men, 22.9 ± 3.3 years

Data Source: Reference 3

The tidal volume of a normal and excited breathing person may be of importance in calculating the amount of contaminant absorbed during the first few seconds of a quickly changing concentration profile. A summary of mean lung volumes is given in Table VIII and Figure 17. Breathing rates at various levels of activity are summarized in Table IX.

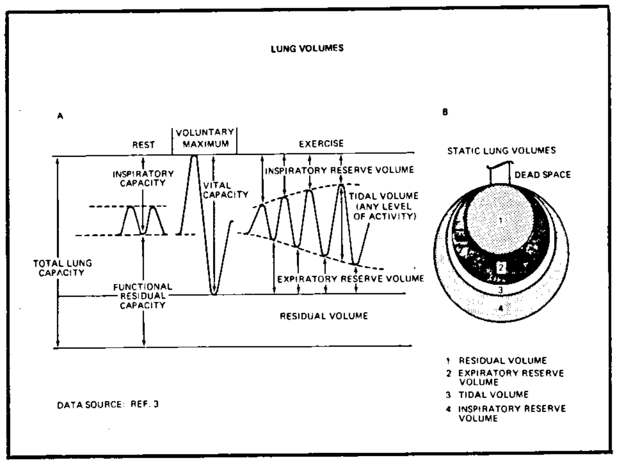


Figure 17

Table IX
VOLUMES OF AIR BREATHED

Position or Action	Liters per minute		
	Henderson and Haggard[a]	Ferguson[b]	Jennings[c]
Lying down	6	6	–
Sitting	7	7	6–7
Standing	8	–	8
Walking, 2 mph	14	–	–
Walking	–	20	–
Walking, 4 mph	28	–	–
Walking to running	–	–	14–40
Slow run	43	–	–
Working	–	48	–
Hard work	–	72	–
Intense exertion	65–100	–	60–100

[a]Henderson, Y. and Haggard, H. W., *Noxious Gases*, 2nd ed., Reinhold, New York, 1943.
[b]Ferguson, C., personal communication, 1956.
[c]Jennings, B. H., *Hazardous Vapors and Dust in Industry*, Ventilating and Air Conditioning Contractors Assoc., Chicago, 1957.

Narcotic Effects

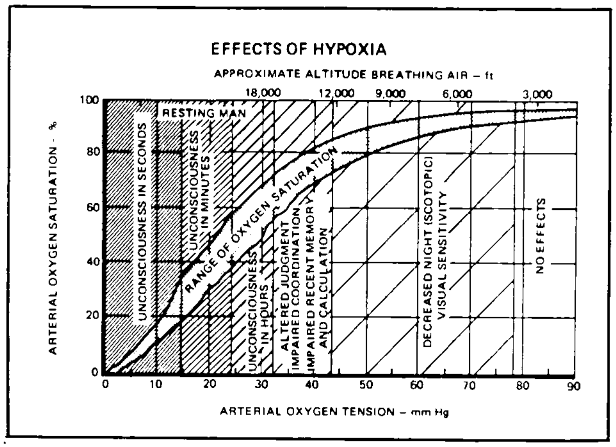
Another adverse effect is the potential narcotic action of certain components of gas generator exhaust. Halocarbon-12 and other halogenated hydrocarbons exhibit this property. Narcosis is the state of profound unconsciousness produced by a drug. Progressive inhalation causes narcosis of various depths, ranging from dizziness to, under extreme conditions, respiratory paralysis. While narcosis can be survived without permanent damage, the exhaust must not cause the occupants to become unconscious. In any case, the occupants must be able to help themselves and leave the vehicle without being intoxicated by the gas generator exhaust.

Hypoxia and Suffocation

Hypoxia (synonym: anoxia, lack of oxygen) may occur if the oxygen concentration in the car falls below its normal level due to dilution with an otherwise inert gas (nitrogen). Short periods of moderate hypoxia may be survived without permanent damage, but psychological response and physical ability are impaired due to lack of oxygen. Severe hypoxia may cause permanent brain damage or ultimately suffocation.

Progressively more severe states of hypoxia are observed as the oxygen concentration is decreased below the normal 21 percent in air. Little change is observed until the oxygen content drops to 12 to 14 percent. The effect in this range is comparable to that of high altitude with reduced oxygen pressure. The rate of breathing is increased 1½ times at 10 percent oxygen, doubled at 9 percent, and tripled at 5 percent oxygen. Rocket Research Corporation has conducted a thorough literature search on hypoxia and associated effects, in particular with respect to post-accident stress and physical exertion (Ref. 4).

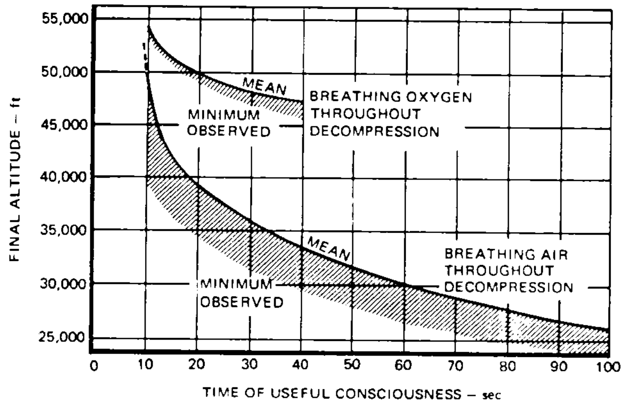
The stress on the cardiovascular system under conditions of an accident is extremely high, and only healthy individuals can survive prolonged exposure to less than 10 percent oxygen. The various symptoms observed as the oxygen content or partial pressure is decreased are illustrated in Figure 18 (Ref. 3). For a resting man,



As arterial oxygen tension falls, progressive impairment occurs in the central nervous system, as indicated on the chart by zones of increasing density. These changes occur in resting men who are not fatigued or otherwise stressed. The oxygen saturation of arterial blood for resting men is also shown as a function of oxygen tension (the hemoglobin dissociation curve). A range of saturations for each value of tension is shown, because temperature and pH influence the saturation values also. Individual variability and time dependency are characteristics of these data.

Figure 18A

Sources: USAF Flight Surgeon's Manual, McFarland and Boothby, ed.



This figure indicates minimum and average duration of effective consciousness in human subjects following rapid decompression breathing air (lower curve) and oxygen (upper curve). At altitudes above 20,000 to 23,000 feet, unacclimatized subjects breathing air will lose consciousness after a variable period of time. Individual susceptibility varies widely except at the highest altitudes.

Source: Blockley and Hanifan.

Figure 18B

unconsciousness occurs after several hours at 5 percent oxygen. However, these numbers are not representative for a person who just barely survived an accident and may struggle desperately to get out of the car.

Cardiac arrest may occur within a minute when the oxygen content drops below 5 percent (Refs. 5, 6, 7). Curiously enough, man would survive under those conditions many seconds longer if he could hold his last breath with normal air rather than inhale the less than 5 percent oxygen mixture. At least as significant as cardiac arrest at these low oxygen concentrations are permanent brain damage and irreversible degenerative changes in the nervous system.

Consideration of hypoxia very much limits the use of compressed nitrogen or other inert gases in crash restraint applications. If all seats were equipped with compressed nitrogen systems, the oxygen concentration in the car could drop below critical levels. Further attention must be given to the problem of an immobile passenger, possibly a child, who may be near or actually enveloped by a large air cushion containing such inert gases which could create a persistent zone of low oxygen concentration. Hypoxia is an extremely fast developing phenomenon, and it takes only a few deep breaths to fully develop.

In case of hypoxia conditions, all other toxic constituents acting on the pulmonary and cardiovascular system will show an increased or even potentiating activity. This is very definitely true for carbon monoxide and hydrocyanic acid. Also, carbon dioxide has a very pronounced effect if the oxygen concentration is decreased below normal. It must be kept in mind that all TLV data are established for normal air, not an oxygen-deficient environment. Looking at analysis data of chemical gas generators, stored gas cylinders, or augmented devices, and assessing the potential toxicity, one is inclined to disregard the nitrogen even if it is the major constituent. This may not be done if the crash restraint system is to function safely in a closed, tight vehicle.

Cardiac Effects

Another area of adverse effects which has received considerable attention by RRC during the process of man-rating crash restraint gas generators is that of cardiac sensitization. It has been known for a long time that certain solvent vapors and some anesthetic agents sensitize the heart toward injection or endogeneous release of epinephrine (adrenalin). The effects are (in increasing order of severity) multiple ventricular beats, cardiac arrhythmia, ventricular fibrillation, or cardiac arrest. It was discovered recently that many fluorinated halocarbons, thought to be physiologically completely inert, exhibit this effect if epinephrine is simultaneously present (Ref. 8). Epinephrine is released by the adrenal gland in situations of shock, stress, and lack of oxygen to speed up the heart rate and to constrict the outer blood vessels, thus directing the main oxygenated blood supply to the brain and the heart.

The most active cardiac sensitizer is dibromotetrafluoroethane, halocarbon 114B2, which was the cause of a fatal accident during volunteer tests in Italy. Of all the fluorocarbons that meet the various requirements for use in gas generators, octafluorocyclobutane (halocarbon C-318) is the least active with respect to cardiac sensitization. This is the coolant selected for the ESV systems described above. Additional tests were performed by RRC to assess the hazard potential of fluorocarbon gas generator exhaust for crash restraint application (see animal exposure tests).

Adverse Effects of Aerosols

The effects of aerosols differ depending on their solubility in body fluids. Many aerosols are readily soluble and may exhibit a more pronounced effect than insoluble aerosols, such as aluminum oxide. Insoluble materials with the exception of silicates and, in particular, asbestos do not generally cause adverse effects until they build up to a level where they constitute a nuisance to respiration and vision. These compounds are generally referred to as nuisance particles. The American Conference of Governmental Industrial Hygienists Committee on Threshold Limits (Ref. 10) states:

> A number of dusts or particulates that occur in the working environment ordinarily produce no specific effects upon prolonged inhalation. Some insoluble substances are classed as inert (e.g., iron and steel dusts, cement, silicon carbide, titanium dioxide, cellulose); others may be soluble (starch, soluble oils, calcium carbonate) but are of such a low order of activity that in concentrations ordinarily encountered do not cause physiologic impairment; still others may be rapidly eliminated or destroyed by the body (vegetable oils, glycerine, sucrose). In the case of the insoluble substances, there may be some accumulation in the respiratory passages. In the case of the soluble substances, this accumulation will ordinarily be temporary but may interfere to some extent with respiratory processes. Hence, it is desirable to control the concentrations of such particulates in the air breathed by any individual, in keeping with good industrial hygiene practice.
>
> A threshold limit of 15 mg/m^3, or 50 mppcf, of total dust with less than 1% SiO_2, whichever is less, is recommended for substances in these

categories and for which no specific threshold limits have been assigned. This limit, for a normal workday, does not apply to brief exposures at higher concentrations. Neither does it apply to those substances which may cause physiologic impairment at lower concentrations but for which a threshold limit has not yet been adopted.

In a notice of intended changes (1969), a more specific definition of allowable dust is given for coal dust and quartz. As indicated in Figure 16, a fraction of the total aerosol in the small particle size range may be exhaled unabsorbed (Ref. 9). Correspondingly, only the retained dust shall count in the TLV determination.

For aerosol determination, a size selector with the characteristics shown in Table X is recommended (Ref. 10):

Table X
PARTICLE SIZE RETENTION CHARACTERISTICS
ACGIH-TLV SIZE SELECTOR

Aerodynamic Diameter (Unit Density Sphere), μm	% Passing Selector
2	90
2.5	75
3.5	50
5.0	25
10.0	0

Short-term limits for nuisance particles, unless otherwise specified, may be calculated by accumulating the 8-hour TLV in periods of no less than 15 minutes as time weighted average values. For a 30-minute exposure, the STL would be 16 times TLV equal to 240 mg/m^3. In this range, however, one must consider that some individuals with asthma may be hypersensitive to dust.

Other Adverse Effects

Exhaust gases from a gas generator should not irritate the skin or mucous membranes (eye) when directly impinging on them. This condition is already superseded by the requirement that the exhaust shall not contain respiratory irritants. Any contaminant present in large enough concentration to cause skin and eye irritation could also cause respiratory irritation. Eye irritation would be highly dangerous if the gas generator discharged inadvertently while driving and the driver's vision was hampered by lacrimation. Also, the gas generator shall not produce smoke which might obscure the vision below the point where directional control of the vehicle cannot be safely maintained.

Sampling And Analytical Methods

It is of extreme importance that the sample sent to a chemistry laboratory for analysis is representative of the actual exposure conditions in the car during or immediately following a crash. Some chemical changes may occur in the sample, and potentially hazardous species may disappear before the analysis is completed. This is especially true of phosgene and perfluoroisobutylene, which hydrolyze rapidly with moisture usually present.

In recognition of this fact. RRC has established standard sampling procedures for crash restraint gas generator effluents (Table XI). The time elapsed between the test and the analysis is recorded along with the results and very rarely exceeds 30 minutes.

Table XI
RRC ANALYSIS METHODS, LISTING OF DOCUMENTS

Title	RRC Document Number
Crash restraing bag gas sampling procedure	TP-0175
Analysis of nitrogen dioxide and nitric oxide	PS-0087
Analysis of carbonyl halogenides	PS-0088
Analysis of gas generator aerosol effluents	PS-0089
Freon C-318 thruster gas analysis by gas chromatography	PS-0090
Analysis of boric oxide	PS-0092
In-car Freon analysis test procedure	TP-0169
Analysis of zirconium compounds	PS-0099
Analysis of ammonia	PS-0100
Analysis of hydrogen cyanide	PS-0101

Basically, two sampling methods are used. For development and quality assurance tests, gas generators are mounted in a stainless steel tank. The tank is evacuated and backfilled with helium to ambient pressure. The valve is then closed and the gas generator is fired into the helium atmosphere. Helium is used because it does not interfere with the gas chromatograph (GC) analysis. The other method, used when cushions are inflated, samples the gases into an evacuated stainless steel tank and allows the gas sample to achieve at least ambient pressure. The tank is then repressurized with helium to 20 psia. In either case a correction factor has to be applied for the helium dilution if analysis other than GC is performed on the sample.

In order to determine aerosol emission, the tank into which a gas generator has been fired is rinsed with distilled water, and analysis is performed as described in Table XI. Aerosols from inflated cushions or interiors of cars should be sampled using millipore filters.

In addition to standard methods of gas analysis, RRC has developed specific methods of analysis for suspected contaminants in gas samples. These methods were adopted from the scientific literature; and after testing several possible methods, the most reliable and most sensitive method was selected for crash restraint application. A summary of RRC documents describing these analysis procedures is given in Table XI. In addition to specific procedures listed therein, the following instruments are currently used by RRC to identify and to analyze contaminants:

- Gas chromatograph in combination with infrared spectrophotometer
- Gas chromatograph in combination with mass spectrometer
- Infrared spectrophotometer
- Ultraviolet-visible spectrophotometer
- Atomic absorption spectrophotometer
- Flame emission spectrophotometer
- Scanning electron microscope

Animal Exposure Tests

Rocket Research Corporation toxicity studies have examined the physiological consequence of generator exhaust products. This work has taken the form of literature surveys and animal exposure testing, both at RRC and by outside laboratories. Animal exposure tests conducted in our laboratories have been carried out in conjunction with veterinary diagnosis and pathological consultants from the University of Washington, School of Medicine. Based on their advice, CD strain COBS rats, conventionally used in medical analysis, have been used in our in-house tests under special handling conditions. These tests have included both chamber and in-car tests, under worst-case conditions of gaseous concentrations and location, to identify the physiological or pathological result of such exposure.

For in-car tests, cushion deployment barriers are utilized to force-vent the gases into the car in much the same manner as an occupant's body would do under actual crash conditions. Gas concentrations may then be continuously monitored by infrared spectrophotometer as a function of time at a number of locations in the car following cushion deployment. Typically, this monitoring continues up to 30 minutes in the sealed car, thus establishing concentration-time-location profiles for supplementary chamber testing. The animal witnesses are then euthanized and necropsies performed for a variety of gross, microscopic, and microbiological examinations. Chamber tests are being conducted on each RRC inflator design as it becomes available. For example, the RRC Model 28300 inflator has been tested using 18 rats. These tests were conducted in a closed chamber to which a deflated plastic balloon was attached (see Figure 19). The animals were placed in the chamber and the inflator fired within the chamber. The plastic balloon prevents loss of gases without a severe overpressure occurring in the chamber. A nominal 1:1 or less dilution with air in the chamber occurs. The animals are left in

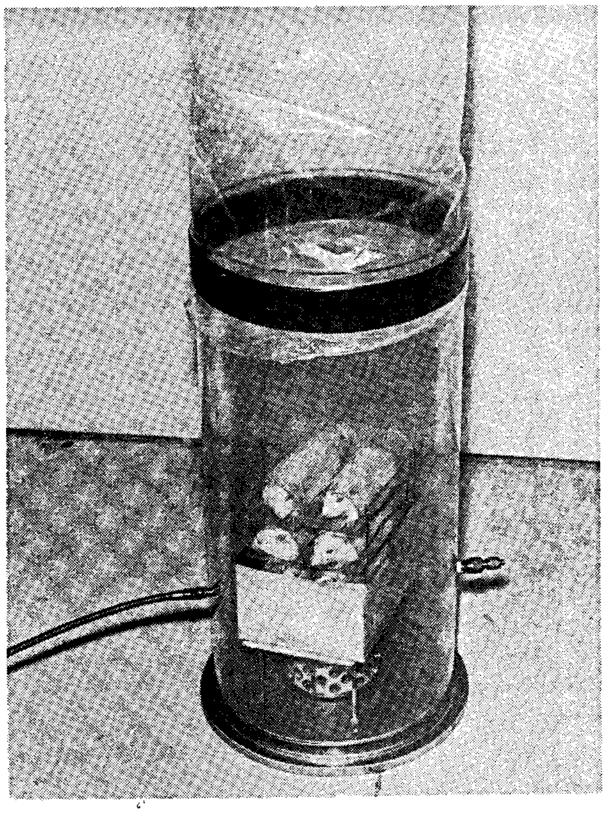


Figure 19

the chamber for 30 minutes before removal. They are then divided into groups with the first group being euthanized immediately, a second group after two days, and a third group after seven days. One group of six unexposed control animals are also euthanized, part with each exposed group. In this test series with the Model 28300, three tests were conducted, (three inflators) each with six animals in the test chamber.

No damage to any of the animals has been detected to date. All tests indicate the gases from the RRC Model 28300 inflator to be quite breathable and noninjurious to humans.

Special Cardiac Studies

Rocket Research Corporation has worked with the Haskell Laboratory for Toxicology and Industrial Medicine, of E.I. du Pont de Nemours and Company on an RRC-funded evaluation of the Freon C-318 used as a coolant in our Freon-cooled gas generators (Ref. 11). The objective of this study was to assess the cardiac sensitization potential of Freon C-318, which effect has been observed for a variety of halogenated compounds at varying concentrations for each. When present, this effect is manifested by a cardiac arrhythmia ranging from a few sequential ventricular beats to complete cardiac arrest. This can occur when such compounds are breathed at or above the threshold concentration in air in conjunction with high blood levels of endogenous or injected epinephrine (i.e., adrenalin) as would result from fright or exertion. (This effect has also been noted under conditions of hypoxia in the presence of epinephrine where no halogenated compounds are breathed.) The tests series conducted by Haskell involved 12 dogs, based on previous good correlation between dog and human cardiac responses to anesthetics. The test or exposure profile included one breath of undiluted cushion gas (nominally 35 percent Freon C-318 and 65 percent nitrogen), 30 seconds of inhalation of cushion gas diluted 1:1 with air followed by 29.5 minutes with the concentration of cushion gas following a dilution curve (as an e-function with a half life of 30 minutes). This is presented in Figure 20. This profile has been

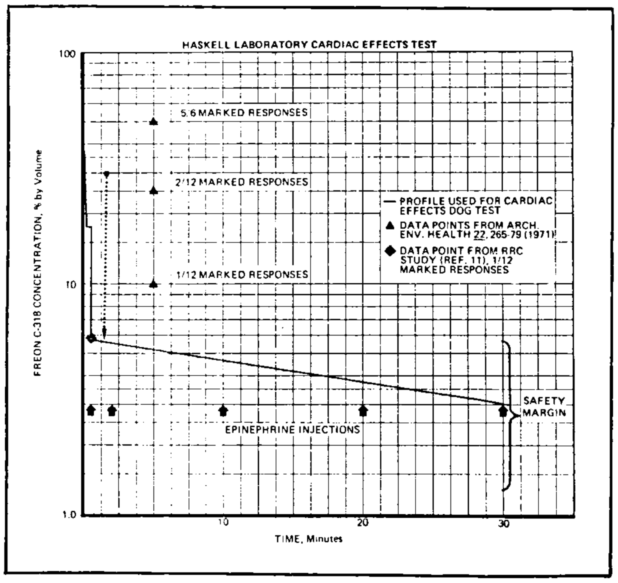


Figure 20

determined to be a good approximation based on actual in-car measurements. The 6:1 dilution shown was chosen based on the assumption that Freon-cooled inflators would be used for both the driver and passenger positions in the front seat. Figure 20 also shows the time when epinephrine injections were administered to stimulate the heart (challenge injection).

Under the conditions of the test, one of the dogs exhibited a "marked response," a series of consecutive ventricular beats. The test was repeated with the same animal with the same result. One conclusion is that this animal was sensitive to the conditions of the test. This would indicate that there is a possibility some people would also be sensitive and in a similar situation (in a crash) could suffer ventricular arrhythmia and possible cardiac arrest. This was a factor in RRC's decision to place the all-solid generator and aspirator systems as the primary choices for automobile occupant restraint inflators.

The sensitive animal from the above test series was subjected to another test in which he breathed undiluted cushion gas for five full seconds, followed by exposure to air. Challenge injections of epinephrine were made such that the effects of both the inhaled gas and the epinephrine would reach a maximum level in the heart at the same time. No response was noted, even in repeat experiments.

Based on these tests it was concluded that Freon C-318 could be used in controlled tests where personnel would be exposed to the exhaust gases for not more than a few seconds with a Freon C-318 concentration in the cushion of 35 percent by volume.

There are other factors that rule out the use of Freons or other liquid coolants, the principal one being the cost and difficulty of providing a liquid level sensor to indicate system readiness.

Summary And Conclusions

Advanced "third generation" inflators for automotive passive restraint systems have been developed by RRC which provide major advantages over earlier high pressure gas-cooled and fluid-cooled designs. These new devices include an all-solid "air" generator for use with inflatables of relatively low volume (e.g., 1 to 2 cubic feet steering wheel cushion), and an aspirator inflator that may be driven with a small stored gas cylinder, an augmented gas source, or an all-solid generator for relatively large inflatables (e.g., 10-cubic-feet passenger cushion).

The primary emphasis in the RRC program has been on the development of propellants and inflators which can meet the extremely stringent toxicity and storage requirements for proposed automotive passive restraint systems. The all-solid air generator and the aspirator inflator (which utilizes the air already in the car) have been demonstrated through sled and barrier tests to be capable of producing effective inflation characteristics while significantly reducing overall hazards.

A summary of the RRC research program on the toxic hazards of inflator gases and aerosols suggests that considerable attention must be devoted to test and measurement techniques to obtain meaningful results. Also, normally benign constituents, such as N_2 or H_2O, may be hazardous under certain conditions. Therefore, the use of maximum amounts of dry air in the inflatable is indicated.

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APPENDIX*

Guidelines From Sources Of Information On Toxicity And Adverse Effects

Numerous agencies and institutions have compiled information on toxicology and industrial hygiene. Several of these agencies have established threshold limits for places of employment. As such, they establish limits which occasionally may be used with jurisdictional power in case of labor disputes or damage claims against employers. Similar limits should be established for the conditions of crash restraint exhaust exposure in order to avoid or at least to provide guidelines in liability suits resulting from post-accident damages.

This appendix lists institutions and agencies as sources of information. A thorough compilation of information resources on general toxicology in the United States is given in Ref. A-1. In addition to sources listed in this directory, the National Library of Medicine provides a computerized literature search service to universities and hospitals (Ref. A-2). Rocket Research Corporation is using the above services as well as the Automatic Subject Citation Alert (ASCA) of the Institute for Scientific Information (Ref. A-3) to maintain an up-to-date file on all toxicity questions with respect to gas generator exhausts.

American Conference Of Governmental Industrial Hygienists

The most widely accepted Threshold Limit Values (TLV) are the ones adopted by the American Conference of Governmental Industrial Hygienists (ACGIH). The ACGIH Committee on Threshold Limits reviews these limits annually in view of additional information which has become available during the past year. Revisions of the TLV list are issued every two years. This list is usually published in the Industrial Hygiene Digest (Ref. A-4). Preprints may be obtained from the ACGIH office of the Secretary-Treasurer (Ref. A-5).

In addition to the listing of the TLV's, a more detailed *Documentation of Threshold Limit Values* issued by the same institution is available (Ref. A-6). This document gives the pertinent scientific information and references upon which the selection of TLV's was based.

Because TLV's are subject to revision, it is advisable to reference the year along with any TLV data to make sure that a comparative discussion is based on the same set of data.

Rationale In Establishing Threshold Limit Values

The following sections are copied from Reference A-4 to illustrate the logic of considerations leading to a given TLV and to point out the margin for safety if 8-hour/day, 40-hour/week TLV's are applied to a 30-minute/once-a-lifetime exposure.

*Appendix extracted from Rocket Research Corporation Engineering Study 71-ES-73, entitled *Toxicity Evaluation of Gas Generator Effluents for Crash Restraint Bag Inflation,* August 31, 1971.

Threshold limit values refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. Because of wide variations in individual susceptibility, however, a small percentage of workers may experience some discomfort from some substances at concentrations at or below the threshold limit, a smaller percentage may be affected more seriously by aggravation of pre-existing condition or by development of an occupational illness.

Threshold limit values refer to time-weighted concentrations for a seven or eight hour workday and forty-hour workweek. They should be used as guides in the control of health hazards and should not be used as fine lines between safe and dangerous concentrations.

Time-weighted averages permit excursions above the limit provided they are compensated by equivalent excursions below the limit during the workday. In some instances it may be permissible to calculate the average concentration for a work-week rather than for a workday. The degree of permissible excursion is related to the magnitude of the threshold limit value of a particular substance. The relationship between threshold limit and permissible excursion is a rule of thumb and in certain cases may not apply. The amount by which threshold limits may be exceeded for short periods without injury to health depends upon a number of factors such as the nature of the contaminant, whether very high concentrations – even for short periods – produce acute poisoning, whether the effects are cumulative, the frequency with which high concentrations occur, and the duration of such periods. All factors must be taken into consideration in arriving at decision as to whether a hazardous condition exists.

Threshold limits are based on the best available information from industrial experience, from experimental human and animal studies, and when possible, from a combination of the three. The basis on which the values are established may differ from substance to substance; protection against impairment of health may be a guiding factor for some, whereas reasonable freedom from irritation, narcosis, nuisance, or other forms of stress may form the basis for others.

The committee holds to the opinion that limits based on physical irritation should be considered no less binding than those based on physical impairment. There is increasing evidence that physical irritation may initiate, promote, or accelerate physical impairment through interaction with other chemical or biologic agents.

In spite of the fact that serious injury is not believed likely as a result of exposure to the threshold limit concentrations, the best practice is to maintain concentrations of all atmospheric contaminants as low as is practical.

These limits are intended for use in the practice of industrial hygiene and should be interpreted and applied only by a person trained in this discipline. They are not intended for use, or for modification for use, (1) as a relative index of hazard or toxicity, (2) in the evaluation or control of community air pollutions or air pollution nuisances, (3) in estimating the toxic potential of continuous uninterrupted exposure, (4) as proof or disproof of an existing disease or physical condition, or (5) for adoption by countries whose working conditions differ from those in the United States of America and where substances and processes differ.

Ceiling Versus Time-Weighted Average Limits

Although the time-wieghted average concentration provides the most satisfactory, practical way of monitoring airborne agents for compliance with the limits, there are certain substances for which it is inappropriate. In the latter group are substances which are predominantly fast acting and whose threshold limit is more appropriately based on this particular response. Substances with this type of response are best controlled by a ceiling "C" limit that should not be exceeded. It is implicit in these definitions that the manner of sampling to determine compliance with the limits for each group must differ; a single brief sample, that is applicable to a "C" limit, is not appropriate to the time-weighted limit; here, a sufficient number of samples are needed to permit a time-weighted average concentration throughout a complete cycle of operations or throughout the work shift. Whereas the ceiling limit places a definite boundary which concentrations should not be permitted to exceed, the time-weighted average limit requires an explicit limit to the excursions that are permissible above the listed values. The magnitude of these excursions may be pegged to the magnitude of the threshold limit by an appropriate factor.

These factors range from 3 to 1.25 for 15 minutes/once a day excursions above TLV depending on seriousness of permanent effects expected. They may not be applied to species which have a "C" notation.

Mixtures

Only in rare instances will the exhaust contain only one contaminant, and in most cases the exhaust will contain several contaminants. In dealing with mixtures, the ACGIH recommends the following method (Ref. A-4):

> When two or more hazardous substances are present, their combined effect, rather than that of either individually, should be given primary consideration. In the absence of information to the contrary, the effects of the different hazards should be considered as additive. That is, if the sum of all the following fractions
>
> $$\sum_{1}^{n} \frac{C_i}{TLV_i} = \frac{C_1}{TLV_1} + \frac{C_2}{TLV_2} + \ldots\ldots + \frac{C_n}{TLV_n}$$
>
> exceeds unit, then the threshold limit of the mixture should be considered as being exceeded. C_i indicates the observed atmospheric concentration of the species i, and TLV_i the corresponding threshold limit.
>
> Antagonistic action or potentiation may occur with some combinations of atmospheric contaminants. Potentiation is characteristically exhibited at high concentrations, less probably at low.

If the adverse effect of a contaminant is on different parts of the body, the TLV's may be treated individually, e.g., dichlorotetrafluoroethane (Halocarbon-114) would be a cardiac sensitizer, but hydrogen chloride would be a respiratory irritant. The rule of additive behavior does not apply to this example.

National Research Council, Advisory Center On Toxicology

The National Research Council, Advisory Center on Toxicology has established Emergency Exposure Limits (EEL) for various atmospheric contaminants (Ref. A-7 and A-8). The need for individual EEL's arose from the fact that actual exposures are not always as uniform as constant level occupational exposures (TLV). Converting established TLV's to EEL's is not merely a question of applying an identical factor to all of them. The EEL committee report (Ref. A-8) says:

> Experience has proven that this rationale is wrong and cautions that reliance upon it may result in serious injury.
>
> For these reasons, any standards for exposure patterns differing from the industrial pattern must be promulgated independently of the threshold limit, after detailed study of the conditions of exposure and of the toxicological data, and should represent the consensus of a body of experienced toxicologists. Each substance requires individual study.

Definition of Emergency Exposure Limits

The National Research Council, Advisory Center on Toxicology takes the following position:

> It is the opinion of the committee that the sensory comfort of the exposed person is not a necessary concern in determining an Emergency Exposure Limit Value.
>
> The Emergency Exposure Limit (EEL) for short-term exposure to an airborne contaminant is a concentration which, when inhaled for a specified single brief period, rare in the lifetime of an individual, is believed not to result in a period of disability or interfere with the performance of his assigned task. In no event shall the value so selected produce danger from flammability of combustible aerosols, or result in substantial impairment of vision or visibility, or the ability to breathe.

The definition above is very similar to that of the American Industrial Hygienist Association (AIHA) (Ref. A-9). The NRC Advisory Center on Toxicology was mainly concerned with new chemicals for military and space applications, whereas the AIHA studied mostly industrial contaminants. The NRC EEL's are established for young healthy male adults under close medical supervision. They are not intended to be used in situations where the general public may be exposed.

Table A-1

RELATION BETWEEN TLV's AND NRC COMMITTEE ON TOXICOLOGY EEL's

Compound	TLV (1969) ppm	EEL 30 Minute ppm	Ratio EEL/TLV
Fluorine	0.1	2	20
Monomethylhydrazine	0.2 T	7	35
Hydrogen fluoride	3	10	3.3
Hydrogen chloride	5 C	20	4
Nitrogen dioxide	5 C	20	4
Sulphur dioxide	5	20	4
UDMH	0.5	50	100
Hydrogen sulfide	10 T	100	10
Carbon Monoxide	50 T	800	16

T = Tentative
C = Ceiling

Extrapolation Of Emergency Exposure Limits From TLV or CT Factors

It was previously stated that the EEL may not be extrapolated from TLV data, Still, it is interesting to study the ratio between the two for some chemicals where both TLV and EEL are established (Ref. A-10). Some data are listed in Table A-1.

Emergency exposure limits data must always be listed along with the time of exposure for which they were calculated. Emergency exposure limits data are usually calculated for 10, 30, and 60 minute exposures. The concentration x time (CT) product for these numbers is not constant. The CT value for nitrogen dioxide is shown in Figure A-1 as an example. Toxicological experience has shown that the severity of adverse effects of fast-acting poisons is proportional to the C x T product. This is true only for long durations of exposure exceeding 30 minutes. In this range, the CT plot versus time is a horizontal line. In some cases, the CT may be used to interpolate between established values. However, extrapolation in the direction of shorter durations of exposure is not justified. This is illustrated in Figure A-1, where CT decreases for very short periods of exposure.

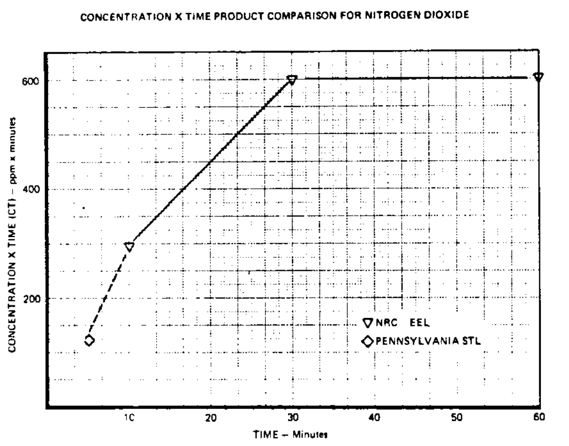

Figure A-1

Pennsylvania Department Of Health Standards

The Commonwealth of Pennsylvania is one of the few states which has adopted individual regulations establishing threshold limits in places of employment (Ref. A-11). "The prupose of these regulations and standards is to prescribe minimum requirements and standards for the maintenance of occupational health in places of employment in Pennsylvania."

In contrast to the TLV data established by the ACGIH, the Pennsylvania regulations also include short-term limits. The short-term limits are established for durations of exposure from 5 to 30 minutes.

Pennsylvania Threshold Limit Values

The Pennsylvania TLV's are established as maximum average values for 8-hour/day exposure. The rationale in defining these limits is the same as those used by the ACGIH.

Pennsylvania Short-Term Limits

The Pennsylvania short-term limits (STL) are established for times of exposure ranging from 5 to 30 minutes. For example, a nitrogen dioxide short-term limit is given as 25 ppm for 5 minutes. This limit was also entered as a diamond in Figure A-1 and follows the trend of the EEL curve established by the NRC.

United States Standards Institute

The United States of America Standards Institute (Ref. A-12) issues summaries of available information on allowable concentrations of toxic dusts and gases. A limited number of these summaries are available to date, and only a few contain information relevant to crash restraint toxicity problems.

Environmental Protection Agency

The Air Pollution Control Office of the Environmental Protection Agency (EPA) has issued a series of documents on air quality criteria (Refs. A-13 and A-14). In contrast to the previously listed agencies, which are mainly concerned with exposure occurring at places of employment, the EPA is concerned with exposure of the general public to possibly toxic industrial, domestic, and automobile emissions in the general environment for life-long time periods.

The standards issued by the EPA would be more applicable to the general public than the NRC – EEL's which were established for a small fraction of the overall population only. However, the EPA standards apply for life-long exposure, 24 hours/day and thus bear an immense margin for safety. The difference in effects observed in exposures "rare in the lifetime of an individual, not exceeding 30 minutes" and "life-long, 24 hours/day" must be significant enough to take precedence over the EPA standards as a requirement for crash restraint applications. In many instances the EPA standards would require the air inside a car after bag inflation to be of better quality than is available outside the car.

The EPA documents are very valuable compilations of information on toxicity, in particular of nitrogen oxides, over a wide range of concentrations.

U. S. Navy

The U. S. Navy has issued very strict toxicity standards for the atmosphere in submarines (Ref. A-15).

The exposure in confined spaces such as a submarine is somewhat similar to an in-car exposure, the major difference being continuous exposure in the submarine for periods of up to 90 days.

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PROBLEMS ASSOCIATED WITH RESTRAINT SYSTEMS

Dr. H. P. Willumeit, VW

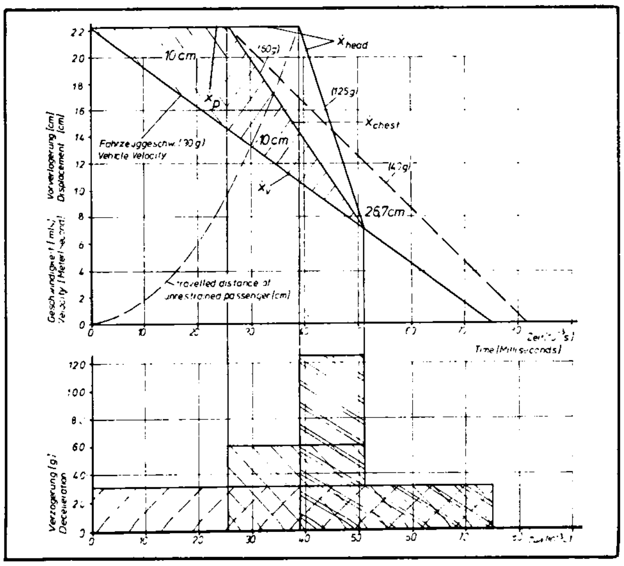
One of the main points in the development of the VW safety vehicle was the restraint system for the vehicle occupants.

The criteria which should be used in the assessment of restraint systems are:

1. The passivity of the system;
2. The occupant must not be hindered by the restraint system when driving normally.
3. In a crash the occupant must be protected from injury by minimum forward movement and retardation.
4. The system itself must not be capable of causing injury to the occupants.

Figure 1

This picture shows the actual retardation and speed in relation to time after the crash has begun. In the upper



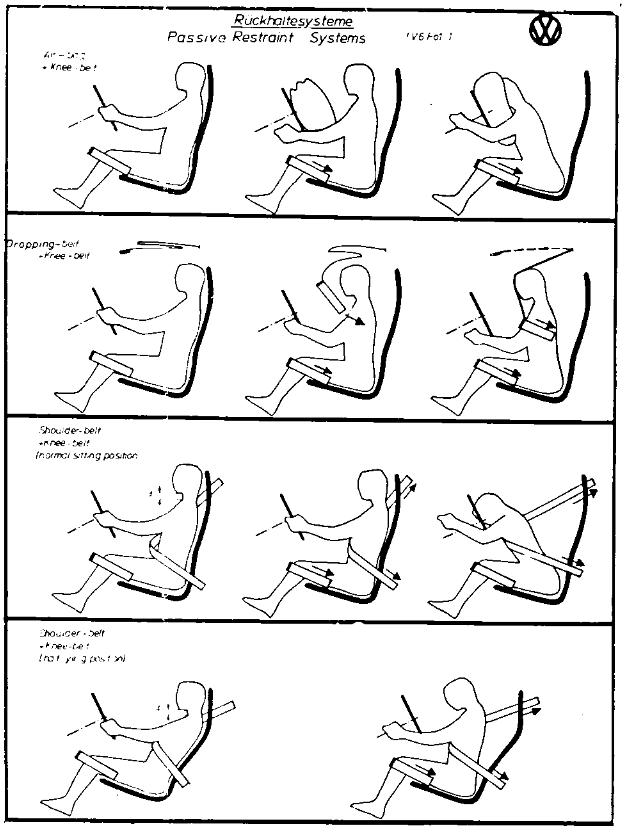
picture the degree of retardation is shown by the angle of the speed curves and furthermore the distance travelled after the crash begins is shown by the area under the speed curve. In particular the area between the occupant speed curve (x chest) and the vehicle speed curve is a direct dimension for the forward displacement of the chest of the occupant.

It is easy to see that the occupant acceleration and displacement during the crash will remain small if occupant retardation starts as nearly as possible at the beginning of the crash. This means that the restraint system which is most effective is the one which enables the occupants to take part in vehicle deceleration right at the beginning of the crash.

Figure 2

This picture illustrates the principles of the restraint systems which we at VW have been working on.

1. *Airbag and knee belt*
When driving normally, the knee belt is integrated in the lower part of the instrument panel. At crash begin it is placed automatically over the knees of the occupant so that it holds the lower part of the body and prevents the occupant from dipping. The knee belt has a limiter which keeps the force from exceeding what can be withstood by the human thigh.
The upper body of the occupant is held in position by a high pressure air bag (filling pressure approximately 1.5 kg/cm^2).



2. *Drop belt and knee belt*

A belt which is stowed in the roof when driving normally moves down over the occupant's chest when crash begins. At the same time a net or cloth is tensioned between belt and vehicle roof to hold the head in position on impact. The knee belt is also part of this combination.

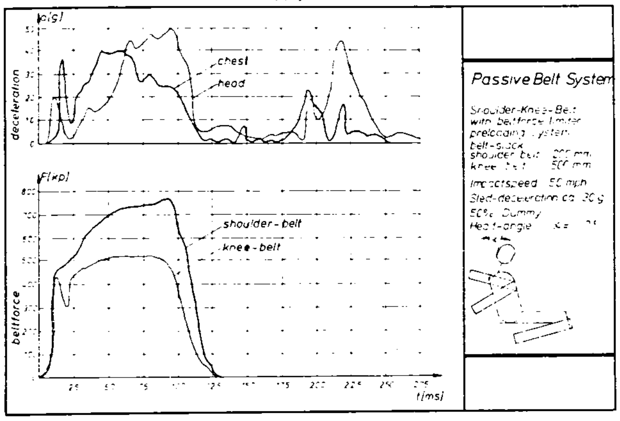
3. *Diagonal shoulder belt and knee belt*
This belt combination is the favourite in the development of the safety car at VW.
The shoulder belt which is round in section and fairly stiff is so slack that it offers the occupant so much freedom when driving normally that he does not feel hampered in any way. Due to the large amount of slack in the belt it does not have to be adjusted to suit persons of different sizes. At crash begin the slack is taken up by hydraulic means or a small gas motor together with the knee belt, and tensioned. This means that the occupant takes part in vehicle retardation shortly after the crash has commenced. Both knee and shoulder belts have limiters which ensure a controlled amount of occupant forward displacement.

4. *Diagonal shoulder belt and knee belt with inclined seat*
In order to increase the forward displacement distance for the occupant, he can be given a more reclining seating position when driving normally.

Figure 3

A typical diagram of head and chest retardation as well as belt forces for the passive belt system with belt tensioning and force limiters in a frontal collision at an impact speed of 80 kph is shown here. This shows clearly the forces on application of the belts about 12 milli-seconds after crash begin. They appear as peaks in the chest acceleration, and a little later, in the head acceleration. The maximum figures for the head and chest acceleration (50 g and 40 g) are within a safe tolerance of the permissible values.

The belt slack before crash begin was 200 mm in the shoulder belt and 500 mm in the knee belt. The belt tensioning appliance was actuated at the beginning of the crash. With the aid of this appliance the occupants

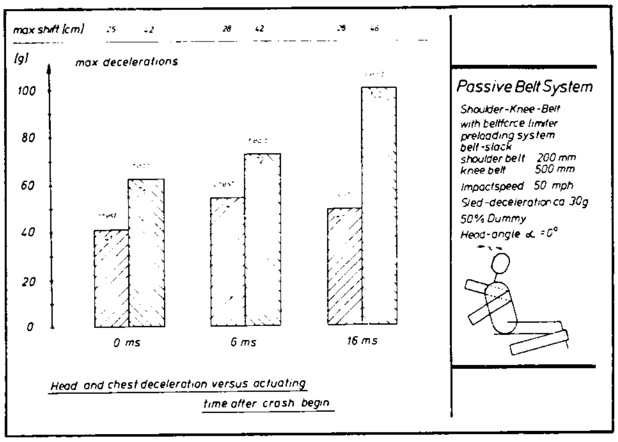


are restrained 12 milli-seconds after the crash begins. The relative forward displacement of the head in this test was about 380 mm.

As there are practical problems connected with the actuation of restraint systems at crash begin in a vehicle collision, the influence of the retarded actuation of the restraint system on the occupant retardation was investigated (Fig. 4).

Figure 4

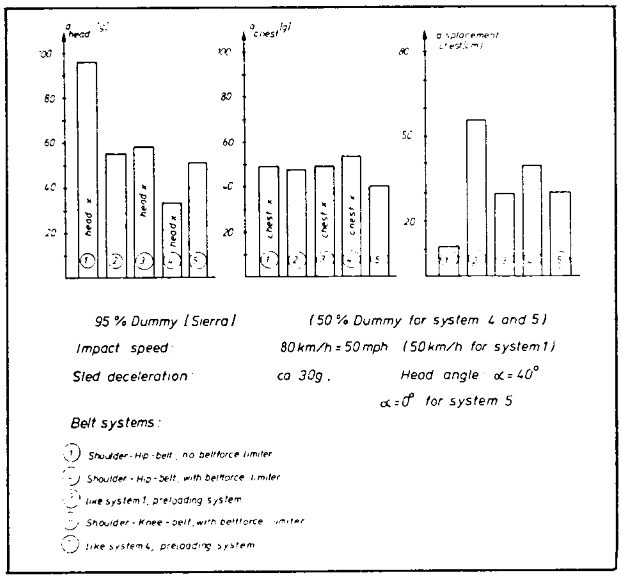
The tests were carried out with a different dummy to the one shown in Figure 3 and slightly different results were obtained for the retardation. A large increase in



head retardation was obtained in these investigations with increasingly retarded release whereas the chest retardation only increased slightly.

Figure 5

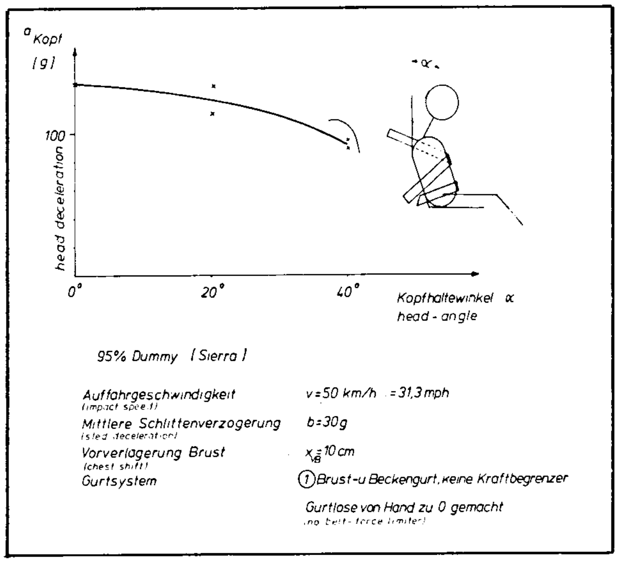
Figure 5 shows a summary of chest and head retardations as well as the relative forward displacement for a series of different belt combinations with and without force limiters and with and without belt tensioners.



It appears to us that the head angle before crash begin has a considerable influence on head acceleration. An investigation of this problem showed that this influence (Fig. 6) only existed with a belt system which did not permit forward displacement of the chest.

Figure 6

In order to avoid unnecessary strain on the dummy the tests were only carried out at an impact speed of 50



kph. The head acceleration in these tests increased more rapidly the more vertical the head was, in other words, the smaller the head angle was, before the crash started. The cause was found in the evaluation to be the impact of the chin on the chest.

Figure 7

We could only eliminate the influence of head angle by having a force limiter in the shoulder belt which permits forward displacement of the dummy's chest.

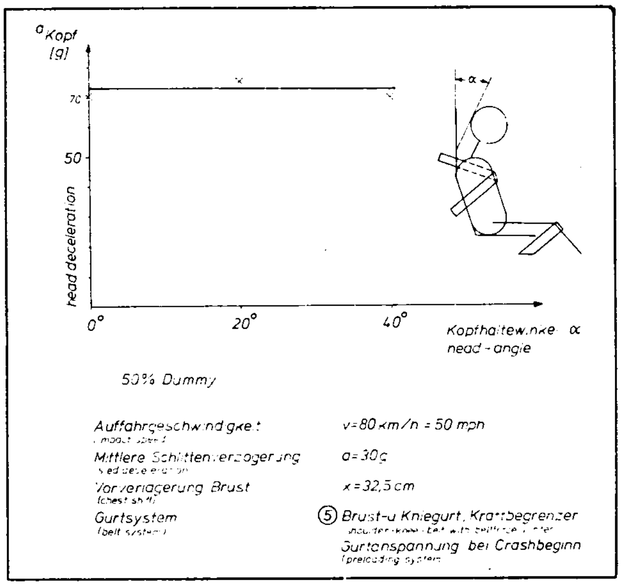
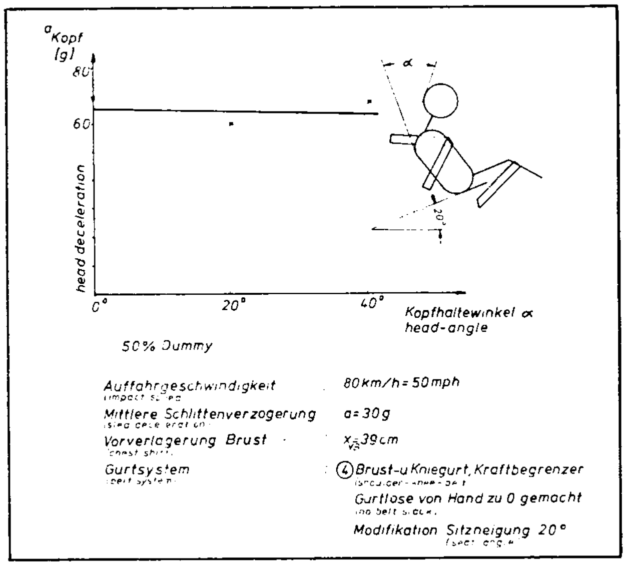


Figure 8

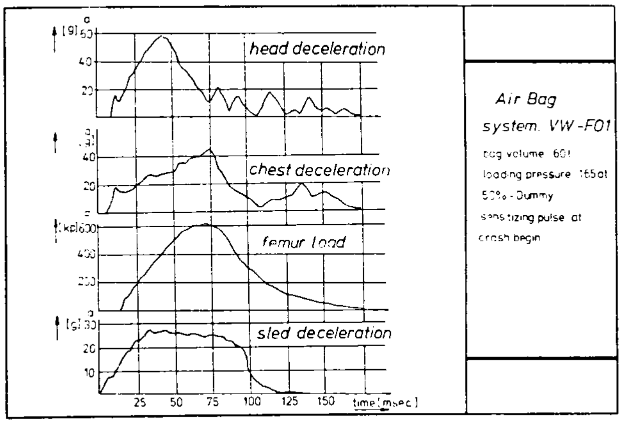
This test was carried out at an impact speed of 80 kph but not with an optimized belt system so that the



head retardation was relatively high. Even with the seat inclined the influence of the head angle on the head acceleration was no longer apparent.

Figure 9

In addition to the belt system we also developed an



airbag which was especially designed for the high impact speed of 80 kph. The object of this development was, above all, to keep the time between crash begin and full operation of the sack as small as possible and thus – as already mentioned – to reduce the forward displacement of the occupants. The result was the so-called high pressure bag which has a bag volume of 50 liters and is filled to a pressure of more than 1 kg/cm². This bag restrains only the upper part of the body and the head of the occupant whereas the lower part of the body must be held by a knee belt. A diagram of occupant retardation with this restraint system in an 80 kph frontal crash is shown in Figure 9.

After about 13 milli-seconds the reaction of the inflating bag can be seen in the chest and head acceleration.

The maximum resultant head acceleration is 60 g and the chest acceleration 40 g.

To conclude my talk I should like to show you a short film which shows how the passive belt is applied when entering and leaving the vehicle and followed by two scenes from a high speed film of an 80 kph impact test with a sled on which a dummy is held by a pretensioned and force limited knee-shoulder belt system. You will then see a high speed film of a frontal vehicle crash against a fixed barrier at an impact speed of 80 kph. Both dummies seated at the front were retained with the knee-shoulder belt system. The specifications for occupant loading were sufficiently far from the permissible values.

SOME FEATURES ABOUT AIR-BAG RESTRAINT CAPACITY

Mr. Jean Leroy *O.N.S.E.R., France*

One of the aims of the Laboratoire des Chocs de l'Organisme National de Securite Routiere is the knowledge of the passive safety devices, which would protect passengers of vehicles during collisions.

For that purpose, two studies have been undertaken in the Laboratory and are being carried out simultaneously.

1. Development Of An Experimental Air-Bag Provided With An Air Storage Reservoir For Pressure-Fed Air Supply

This item has been subjected to thorough investigation, which led to better knowledge of the many problems concerning the air storage reservoir and its opening process, the diffuser, the composition of the bag material regarding its inflating ability as well as its strength. This device now allows us to preform retaining tests on the crash simulator, at 50 km per hour, and on the proving ground, inside the vehicle, in simulated crashes.

2. A More Fundamental Study Bearing On The Retaining Action Proper

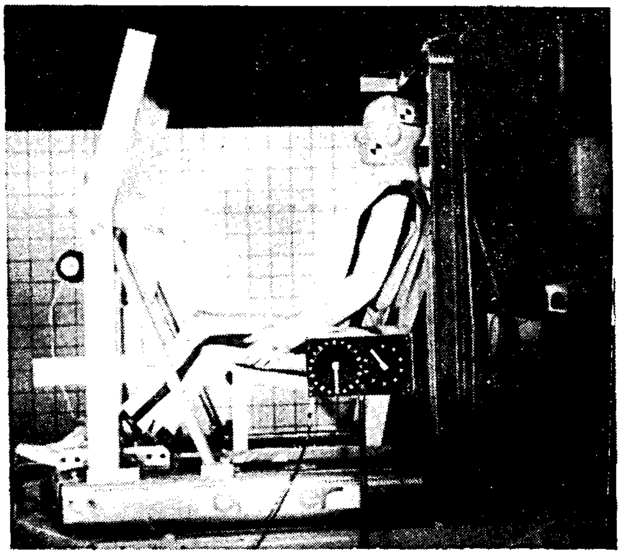
This investigation is carried out using *pre-inflated bags* so as to eliminate the parameters introduced by the gas generator and the inflating procedure.

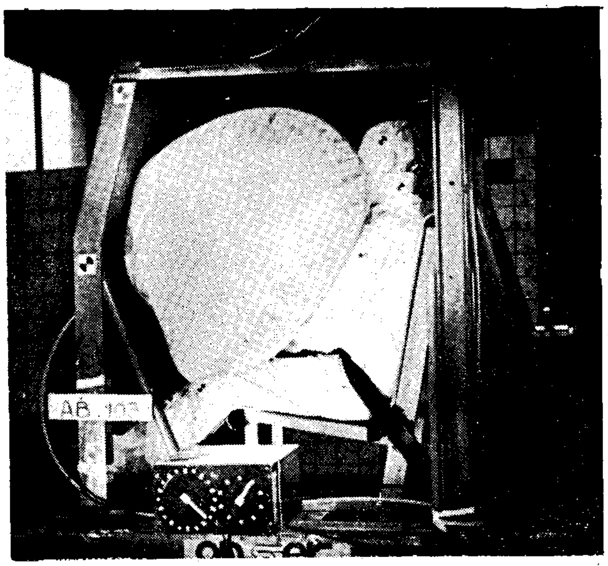
Our report is mainly intended to deal with the air-bag restraint capacity, taking this type of investigation as a basis. This study is conducted on the dynamic sled during frontal collisions at 50 km per hour, with conventional trapezoidal deceleration, using a specifically designed mechanical model of test carriage body.

Test Carriage And Its Simulated Body

A 50th percentile dummy is placed in a normal position and restrained either with a lap belt or with the cushion.

The bag inflated before the test must be maintained under pressure. It is placed and positioned between the dummy and model carriage body. It belongs to the passenger type and has an approximate volume of 0.2 m3.





Bag Pre-Inflated And Positioned Before The Test

In this short statement, which is to be discussed afterwards, we shall mention the observations that have mostly attracted our attention and that we shall comment upon during the picture show which is to follow.

Tests Performed With Pre-Inflated Bags – Behavior Of The Dummy

When the collision occurs and when the dummy is moving forward, we can notice two types of behavior, which offer similar features.

- *Without a seat belt*: the dummy will move forward sliding along the seat.

- *With a seat belt*: the dummy will start sliding forward till the belt tightens. Then, as the retaining forces are higher at the pelvis level, the whole body will be induced to rotate.

During this first stage, the seat belt does not seem to be required for the retaining action proper. However, it allows the movements of the back part of the body to be slightly restricted, which is likely to prove interesting in many cases (impact of the knees against the car dashboard).

After this forward motion stage:

- *With a seat belt*: the dummy will move backwards, towards the back of the seat, more slowly than for the preceding motion and approximately in the reverse direction. It will then encounter the back of the seat and, if no conveniently designed device is used, its head will be flung back in strongly marked hyperextension.

- *Without a seat belt*: the pelvic portion of the trunk will remain in its forward position and the dummy upper part (chest and head) will be flung back and round. The head will then strike against the back of the seat within a limited area. This impact appears to be difficult to control and may have detrimental consequences which are still to be investigated.

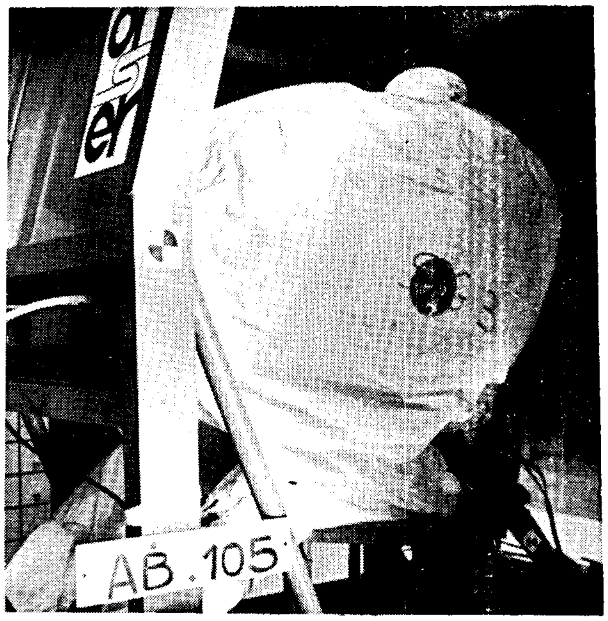
Part Played By The Exhaust Process In The Bag Retaining Action

As we were proceeding to our tests we could notice that the way in which the bag was deflated had a great importance. In particular, the valves must open to prevent the passenger from being thrown back against the seat at a speed approaching the speed of impact.

The ideal system should prevent every rebound, which therefore implies that a zero level of pressure inside the bag at the ultimate limit of the movement.

Conventional valves, fitted with low-strength pressure-operated lids, should be located in such a way as to enable them to open and, then, release the gas, a process which does not look obvious considering the actual operating conditions prevailing inside a vehicle.

In fact, it has been shown that air exhaust could become impossible owing to certain locations of the valves brought into contact with a flat hard surface after inflating the bag, which emphasizes the part played by their arrangement in compliance with the type of vehicle and the advantage that could be derived from choosing more sophisticated exhaust solutions.



Exhaust Valves Located On The Bag Side-Faces

Deceleration Incurred In The Collision

As these tests progressed it has been found that the deceleration effects recorded on the dummy were lower than those obtained under identical conditions with a three-point safety belt restraint system (without air-bag). This difference is mainly noticeable at the head level.

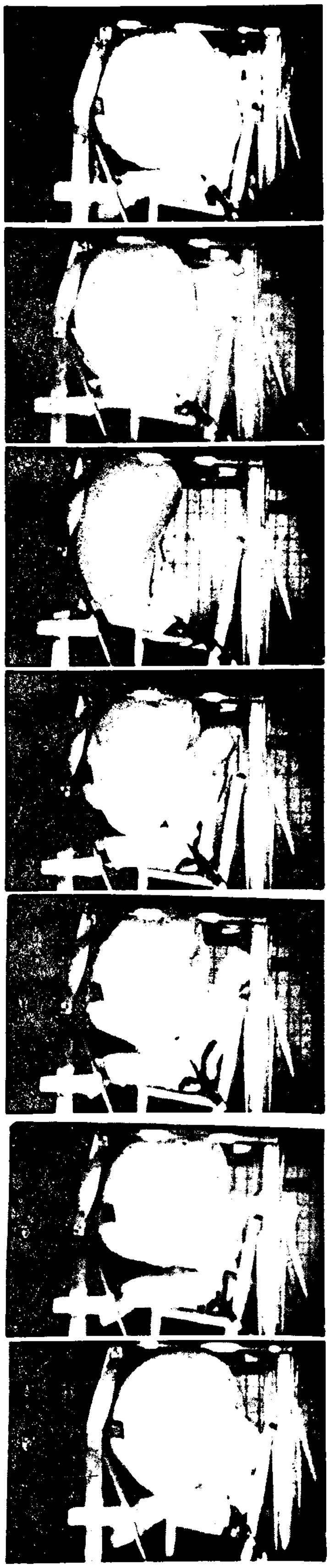
As for the comparisons drawn between various dummies, restrained by a pre-inflated bag jointly used or not with a seat lap belt, the differences are far less important and will be subjected to special investigation.

(Projection of the film with comments)

In conclusion, these tests we have just described show us the restraint capacity of the air-bags. Many questions are still too precise, particularly those about the backward movement. It seems that on this point, the seat lap belt could have an important action. Furthermore, it offers the advantage to maintain the initial positions, which should prove highly important in case of oblique collisions, vehicle overturning or multiple impacts – collision conditions for which the efficiency of these devices is still to prove.

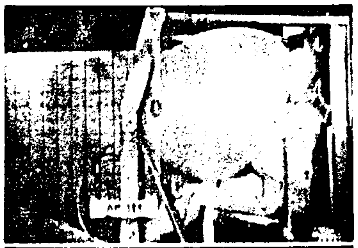
APPENDIX 1

First Test – Pre-Inflated Bag With Lap Belt, No Exhaust Valve – Speed: 50 KM Per Hour



t=0	First Collision Impact. Dummy and air-bag initial positions.
t=30ms	The dummy encounters the air-bag.
t=70ms	Ultimate position of the dummy into the air-bag.
t=100ms	The dummy is flung back in the reverse direction as compared to its forward movement.
t=115ms	The dummy encounters the seat. The impact speed is approximately 40 km per hour.
t=150ms	Ultimate position of the dummy after it has been flung back against the seat.
t=400ms	Final position.

Second Test – Pre-Inflated Bag Without Lap Belt, No Exhaust Valve – Speed: 50 KM Per Hour

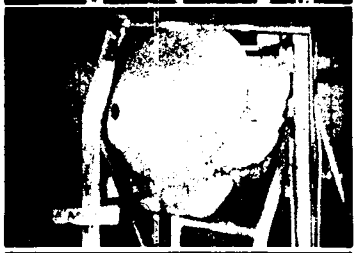


t=0 First collision impact.

t=30ms The dummy encounters the air-bag.

t=70ms Forward ultimate position.
We can notice the perfect translation of the chest of the dummy.

t=90ms The dummy is flung back in a rotative movement around the lap.



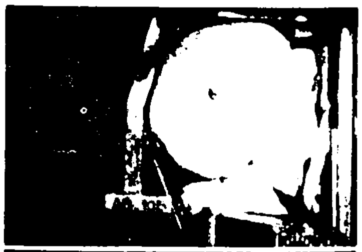
t=115ms The dummy encounters the seat.

t=150ms Ultimate backward position.

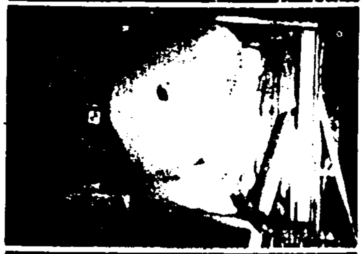
t=400ms Final position.

APPENDIX 3

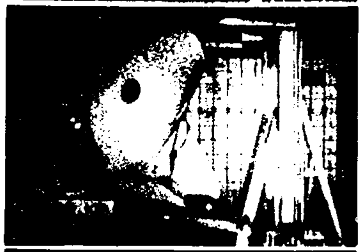
Third Test – Pre-Inflated Bag with Lap Belt
With Exhaust Valve – Speed: 50 KM Per Hour



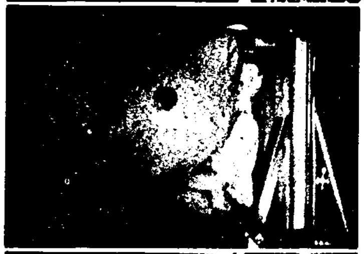
t=0 First collision impact.



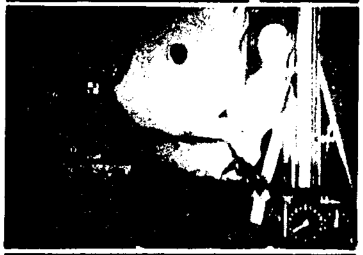
t=30ms The dummy encounters the air-bag.
Opening of the exhaust valves.



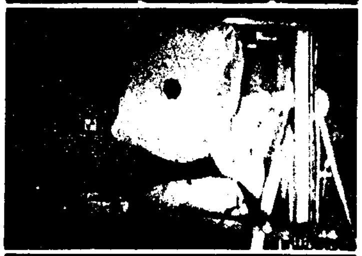
t=65ms Ultimate forward position of the dummy into the air-bag.



t=115ms The dummy is flung back.

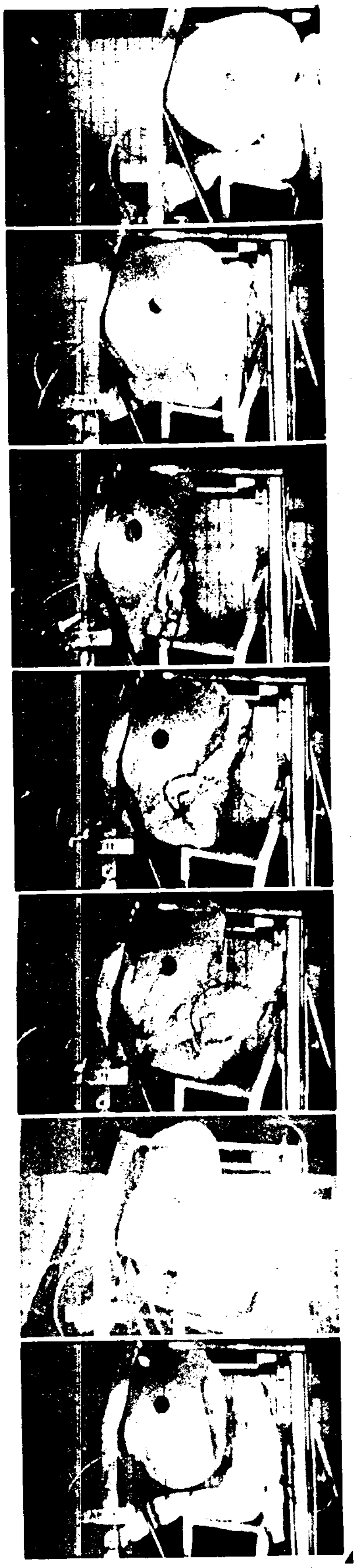


t=160ms The dummy encounters the seat.
The speed of impact = approximately 15 km per hour.



t=230ms Ultimate backward position.

t=600ms Final position.



Fourth Test – Pre-Inflated Bag Without Lap Belt With Exhaust Valve – Speed: 50 KM Per Hour

t=0 First collision impact.

t=30ms The dummy encounters the air-bag. Opening of the exhaust valves.

t=80ms Ultimate forward position.

t=110ms The dummy is flung back.

t=155ms The dummy encounters the seat.

t=200ms Ultimate backward position of the dummy.

t=600ms Final position.

THE SHORTCOMINGS OF ANTHROPOMORPHIC TEST DEVICES (DUMMIES)

Dr.-Ing Willi Reidelbach

DAIMLER-BENZ A.G.

Motor vehicle safety standard 208 and ESV specifications evaluate the occupant protection on the basis of physical quantities measured during certain typical crash tests by means of dummies. The dummies shall simulate the living car occupants. Desired are measurements of accelerations of the head, chest and pelvis, forces in the thighs and – as soon as technically feasible – also pressures. The measured values shall be smaller than the so called injury criteria.

This principle would be satisfactory, if the dummies were reliable measuring devices. Unfortunatley they are not as hundreds of tests have shown during the last years. The following shortcomings have been assessed:

1. One and the same dummy supplies different values in spite of equal test conditions. Chandler[1] reports that for instance seat belts forces grew continuously during a long test series although the dummy was inspected and readjusted before each test (Fig. 1). Only

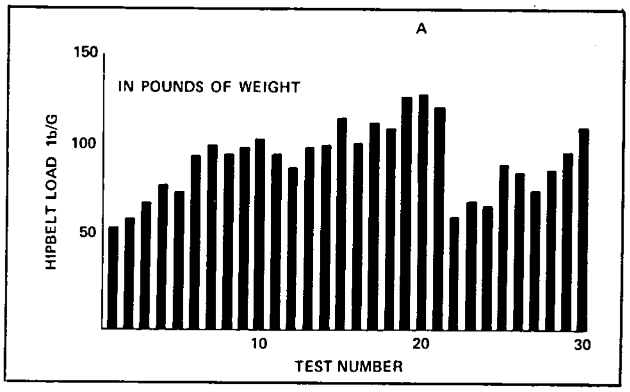


Figure 1

after the dummy was completely disassembled and then reassembled partly using new spare parts did the tests again give the original results which again were followed by increases. Other test series from Terry[2 3], for instance impact of the same dummy against a larger number of equal windscreens (Fig. 2) or impact of the same dummy against a series of equal steering columns (Fig 3), achieved values scattering in similarly broad patterns. Also a test sequence which we performed using equal or most similar instrument panels confirms this observation (Fig. 4). The deviation amounts to ± 30 to 40%, in extreme cases ± 50 %.

2. Different dummies produce different results from equal tests both with regard to the mean value and

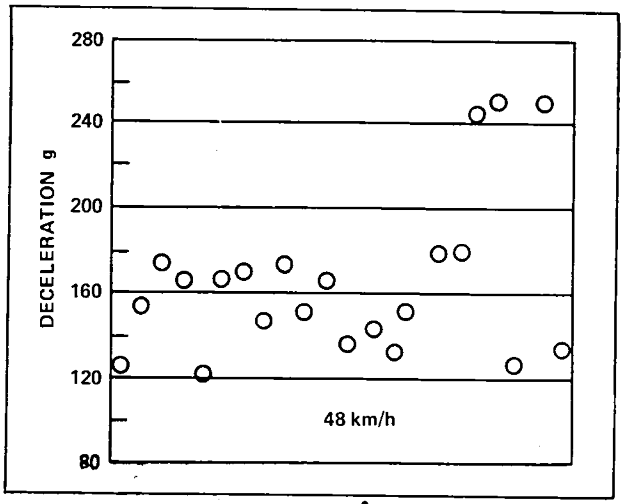


Figure 2

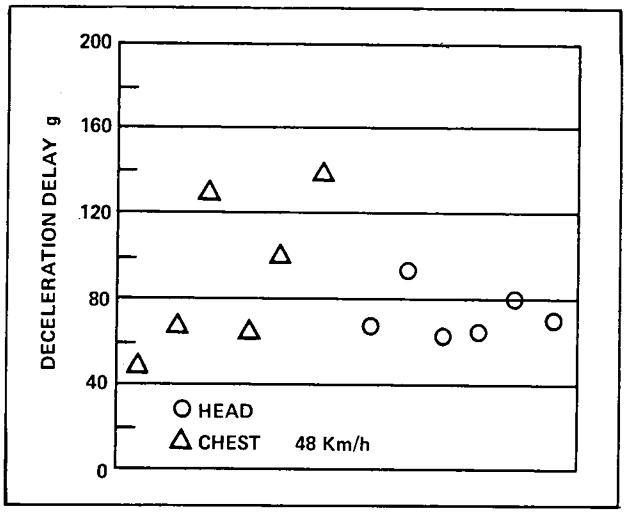


Figure 3

to the deviation. Terry reports on tests with four dummies of rather similar design all of them impacting equal blocks of honeycomb metal (Fig. 5). The mean values of the head deceleration vary between 130 g and 175 g thus being in a ratio of 1 to 1.35, the deviation amounts to ± 25 %. Corresponding results are valid for the chest deceleration. Chandler compared five different dummies and realized the probably not surprising result that the simplest dummy – composed only of a few wooden blocks and rubber parts – showed the smallest scattering of measurements.

Based on these observations the question arises whether the complicated mechanical system of a dummy with many degrees of motional freedom can respond otherwise under any circumstances. The possibilities of uncontrolled changes or abrasion of its parts are numerous. Small variations of the start position before impact have large effects on the measurements as experiences prove. Probably the living human body would also

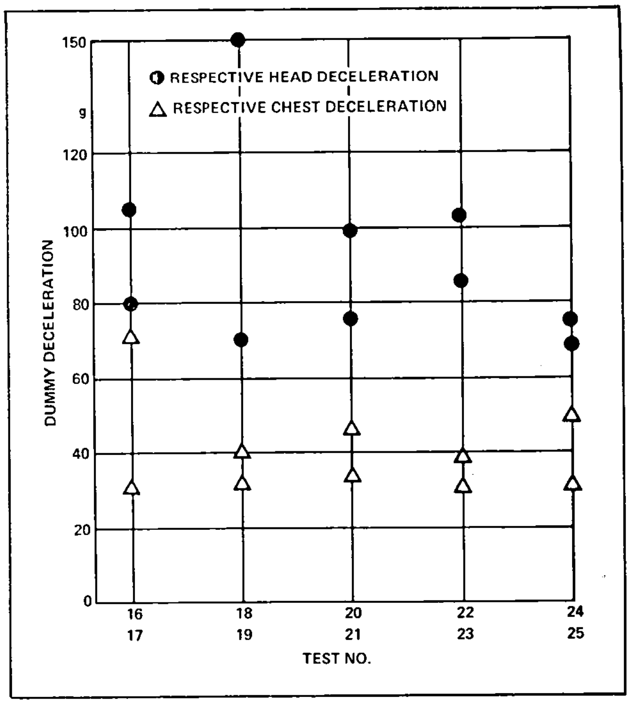


Figure 4

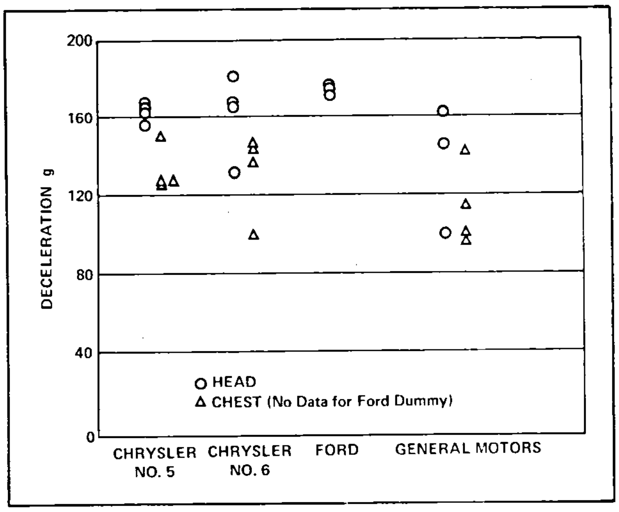


Figure 5

provide varying results if it could be used as a measuring device. It seems that the overcomplicated dummy ("Super Sophisticated Sam") is not suitable for the purposes discussed here. Instead a test device is needed as simple and sturdy as possible which withstands a large number of tests without changing its kinematic behavior and its measuring characteristics.

3. The decisive deficiency is the lack of knowledge on the correlation between dummy and a human body. Too few data were discovered as to support a definition of such a correlation. But what is yet known points toward a certain direction: dummies are more rigid than humans. They must be so to withstand numerous tests without damage. They then respond to impact pulses with higher accelerations respectively with higher forces.

Patrick[4] has measured under equivalent test conditions the head decelerations of a volunteer, a cadaver, and a dummy. The deceleration quantities differ in the ratios of 1.0 to 2.3 to 7.0. Also investigations by Fiala[5] resulted partly in nearly equal and partly in values several times larger. The ratios varying between 1.2 and 3.5. To these figures could probably be added the results of other comparative evaluations, which are not known to us at the moment. Nevertheless it seems justified to assume that the decelerations and forces measured with dummies are greater – under certain conditions several times greater – than those which would be measured with living human bodies. Reliable factors of correlation can not be provided at the time being. One should accept that they will depend upon the type of loading and the loaded part of the human body. It is a very urgent task to clarify this disputed correlation between dummies and human beings.

The comparative evaluations just described lead strictly to the following conclusion: If the injury criteria defined up to now represent the tolerable loading limits of the living human body then the corresponding tolerable loads on a dummy must be greater – under certain conditions appreciably greater. This means: Rules or specifications, the compliance with which shall be proven by means of dummies. must set higher injury criteria than they do today.

Aside from this unresolved problem additional doubts arise: The physical quantities measured today are probably not sufficient to evaluate the total injury risk. It seems extremely necessary to develop a device capable of measuring clearly and reproducibly the pressure on the surface of a human body or dummy.

Completely unknown are the means of discovering interior injuries by dummy tests. It has been attempted to simulate internal organs. The English Motor Industry Research Association recently reported on a new dummy in the thoracic cavity of which so called mechanical equivalents of the internal organs are placed. It is maintained that the stresses on these organs are indicated and thereby measurable. We hesitate to assume that this additional complication will improve the repeatability of the results. On the other hand the trauma indicating dummy can in fact be a useful device if applied where a most complete and comprehensive simulation of human tolerance is needed, i.e. in the field of basic biomechanical research. We would appreciate detailed information on the new English dummy or on any other of this kind. But we don't believe that these complicated dummies are suitable to step into the existing breach in the measuring techniques.

In conclusion it must once again be emphasized that there is the particularly urgent task to standardize a most simple and sturdy dummy as a test device. In this case we voluntarily depart from our request for pure performance standards. Here, quite detailed design standards appear necessary to assure that the automobile engineer in product engineering, as well as the test engineer of a compliance laboratory or governmental authority, works with the same measuring devices. No effort should be spared to reach this aim.

We approach in particular the International Standardization Organisation with the request to accelerate the work of the Subkommittee 12 in the Technical Committee 22 and to coordinate these efforts with those of the Crash Test Dummy Subcommittee of the SAE as well as those arising through research contracts of NHTSA.

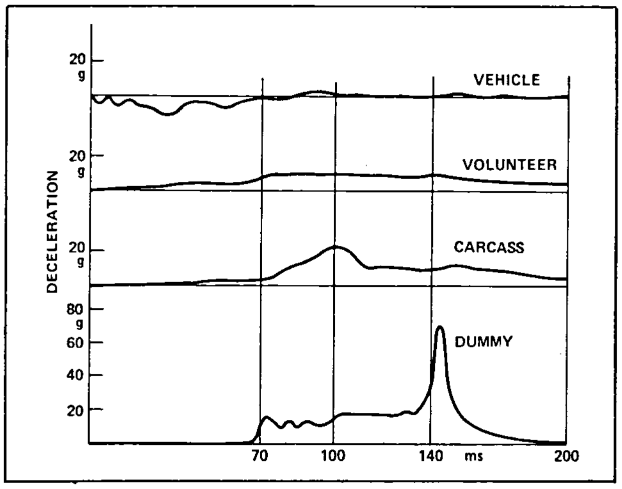


Figure 6

Notes

1. R. F. Chandler, Comparative Evaluation of Dummy Performance, under $-G_X$ Impact, SAE-Paper 690 798.

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THE DYNAMICS OF DUMMIES

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UNITED KINGDOM

Present crash test dummies are almost unusable because they do not give repeatable measurements and because most of the measurements which they do give are misleading. I shall return briefly to lack of repeatability at the end but I shall concentrate mainly on the misleading results. In fact I shall concentrate on only one problem – that of chest simulation. This is sufficiently complex to illustrate the type of problem involved in simulation but without being so complex that only experts will know what I am talking about.

Correct representation of the chest is important for three reasons. Firstly, chests made to the present SAE specification J963 overestimate impact forces by up to 100%. This not only upsets the plans of vehicle manufacturers trying to meet compliance specifications, it also upsets the calculations of people who try to improve these compliance specifications by feedback from accidents. Secondly, the top of the chest is often struck by the chin when a seatbelt is used and, as the J963 specification includes an excessively stiff chest, this can contribute towards the unrealistically high head decelerations which are obtained in tests. Thirdly, the shoulders which are ignored at present are in fact quite heavy and when represented correctly they assist in retaining shoulder belts in place.

Impact tests have been carried out on dead bodies for many years but the dynamics of chest impact have not been understood. This is surprising because they are not excessively difficult. Static compression tests on human chests are reported in the literature to give a range of stiffnesses between 50 and 300 pounds per inch.

Values at the higher end of the range were obtained by Professor Patrick with embalmed bodies and values at the lower end were obtained by Dr. Nahum with fresh bodies. Experiments on living volunteers confirm Dr. Nahum's figures so we can assume a static chest stiffness of something under 200 pounds per inch. Dummies made to the present J963 specification have a static chest stiffness of around 600 pounds per inch which is a factor of 3 high.

The reason why these dummies have such stiff chests is to correspond with the supposed dynamic stiffness of the chest. In Figure 1 are the force/time histories for the chests of three embalmed bodies tested by Professor Patrick. As these were embalmed they had the higher static chest stiffness of around 300 pounds per inch. They were stopped by a rigid plate from 16.5 mph and the forces shown in Figure 1 were measured on this plate. The peak loads are about 1,700 pounds and the measured deflections of the chests at this load were about two inches. Dividing the load by the deflection we get an apparent dynamic stiffness of about 850 pounds per inch giving us the required factor of 3. Where does it come from?

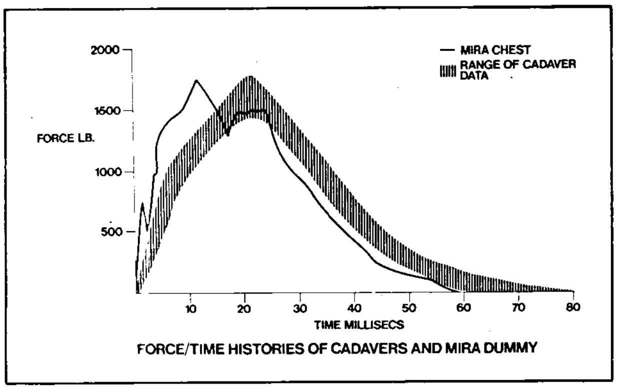

Figure 1

Well, like other materials bone is stiffer when loaded dynamically than when loaded statically but at the speeds we are considering this would give an increase of only 20 to 30 percent which is a tenth of the change we are looking for. The explanation must be looked for elsewhere in the construction of the human chest.

In talking about dynamic stiffness we have implicitly assumed a very simple model of the chest as shown on the left of Figure 2. In fact, the chest is more like the right of Figure 2 where in addition to the mass of the

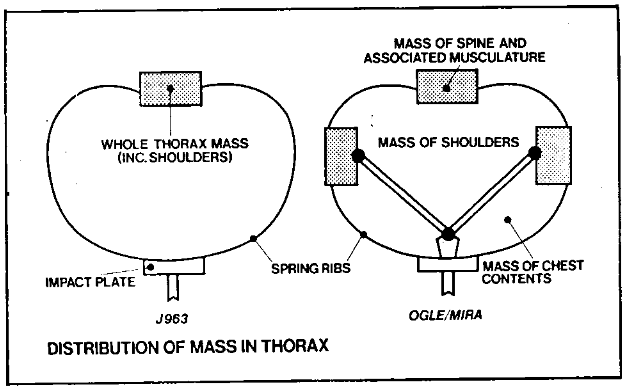

Figure 2

spine and its musculature which is decelerated by the spring action of the ribs we also have the masses of the shoulders and the chest contents which are not decelerated in this way. Also, we have the various appendages which are hung on the torso, that is, the head and neck and two arms. It is in fact the effects of the distributed masses of the shoulders and chest contents together with the effects of the head and arms which give rise to the differences between static and dynamic results and not any variation in the elastic properties of the rib cage itself.

The largest single contribution to the load does come from the compression of the rib cage; as the spring rate is about 300 pounds per inch and the weight behind it is 19 pounds, the frequency of this system is about 11 or 12 Hz and the force which it exerts on the plate is shown as thorax in Figure 3.

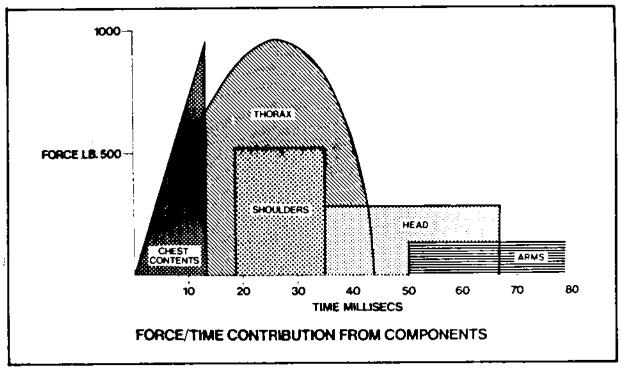

Figure 3

An additional contribution to the force on the plate comes from the chest contents. These move forward under impact and press upon the inside of the chest wall which is in contact with the plate. The inertia of the chest contents therefore adds to the force on the plate and a simple calculation based upon the mass of the chest contents and how far they can move shows that the additional force is as shown in Figure 3.

Thirdly, a contribution to the force on the plate is made by the shoulders. These also load the plate directly through the force transmitted down the clavicle with some extra force transmitted through the rib cage. The contribution of the shoulders does not start immediately contact is made between the chest and the plate but is delayed by about 20 milliseconds since the shoulders can move forward by four or five inches relative to the chest without appreciable resistance. When they reach the end of their travel however, they make a contribution to the force on the plate as shown in the figure.

Finally, contributions are made by the head and arms. Owing to the large amount of forward movement which each of these has, their contributions to the plate force are very late in the impact. The contribution of the head is very complicated as the force is transmitted down the nect to the back of the rib cage but as an approximation we may ignore this and represent the contribution of the head by the shape shown in the figure.

When all these contributions are put together, they give a predicted result which is shown in Figure 4. If we now compare this with the force/time histories recorded

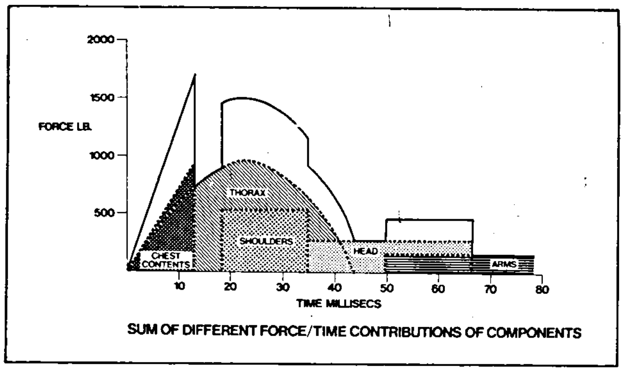

Figure 4

by Professor Patrick we have quite reasonable agreement (see Figure 5).

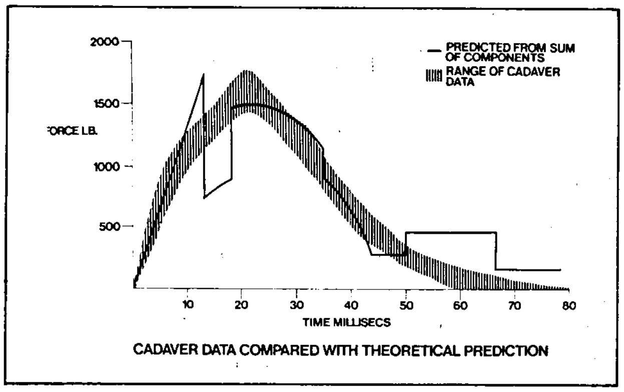

Figure 5

When this stage of theoretical prediction was reached there was a simple way of checking. A model chest was built with a rib cage stiffness of 300 pounds per inch, and correct representations of the shoulders and chest contents. Professor Patrick's tests were repeated with this model and the result obtained is very close (see Figure 1).

It is interesting at this point to look at the performance of a dummy built to current J963 chest requirements. The static stiffness of this chest was found to be 600 pounds per inch, it had no chest contents and very low shoulder weight. The predicted contributions of the components of this chest are shown in Figure 6. The actual performance agrees very well with the sum of these components but is nothing like the performance of cadavers. As you can see, in Figure 7 the peak load is too high by a factor of about 2. It is in fact, impossible to model the behaviour of the chest when the effects of shoulders and chest contents are omitted, no matter what spring rate is used.

Figure 8 shows Patrick's results, the MIRA results, results for the complete dummy to SAE J963 and even worse, the results for the Blak Tufy dummy which go

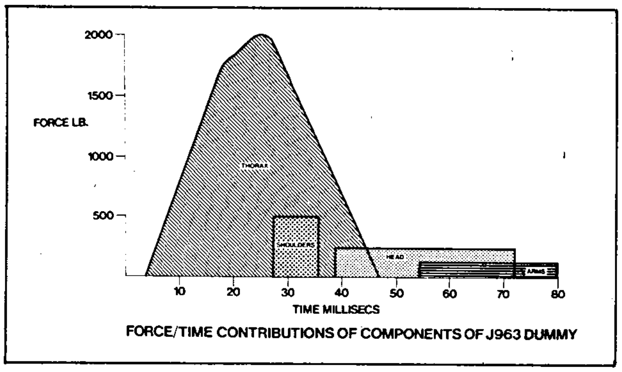

Figure 6

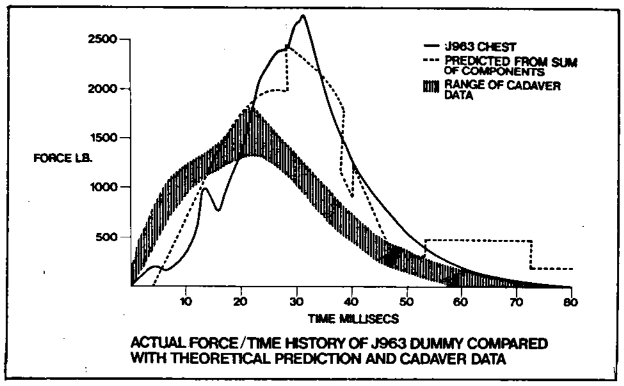

Figure 7

off the top of the graph. Remember as well that Patrick used embalmed bodies which have stiffer chests than live people.

Having carried out this exercise, we returned to a more representative chest stiffness.

Finally, I should like to add that this chest construction is only the most obvious way of simulating the action of the human chest on impact; it is constructed as a direct copy of the chest and it has got rid of many of the misleading results. It also improves the repeatability by paying attention to detail design and using closely

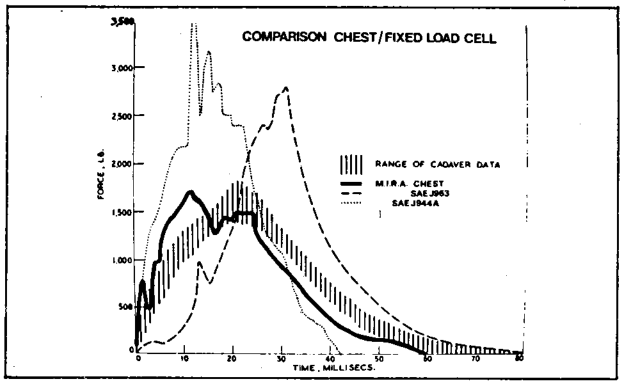

Figure 8

defined setting-up procedures. At present with dummy skeleton the chest is good, the pelvis and thighs are good, the spine, neck and head are much like any other dummy at the moment, and in present work we have to bear this in mind. In particular, we have to remember that all dummies, including this one, give misleadingly high head accelerations when the dummy wears a 3-point seat belt. We are working on this.

If we wish to improve the repeatability much further we shall need to make the device much less like a man. For instance, the contribution of the shoulders to chest load is high but that of the lower arms is low. Perhaps we can discard these lower arms and some other components in course of time but this must only be done in the light of clear understanding of relevant biomechanics and after full consultation.

SECTION 3

PART 4 SUBSYSTEMS, TESTING AND OTHER CONSIDERATIONS

HYDRAULIC ENERGY ABSORPTION SYSTEMS FOR HIGH-ENERGY COLLISIONS

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Abstract

In conjunction with the Department of Transportation's Experimental Safety Vehicle program, hydraulic energy absorption systems have been designed, built, and tested successfully in various front and rear impact geometries at velocities up to 50 mph. The front and rear energy absorption systems each consist of two variable stroke hydraulic buffers which are loaded by a highly rigid bumper through connections which permit the two buffer pistons to move at different rates in the case of an asymmetric impact. The buffers absorb essentially all the required energy, the vehicle structure undergoing minimal deformation. Vehicle behavior and system loads for asymmetric impacts were predicted using a computer simulation. Test results were largely in accord with the simulation, except in certain impact configurations in which the actual peak transverse loads were much lower than occurred in the simulation.

It was concluded that the energy absorption requirements implied by the ESV crashworthiness goals can be met or exceeded using purely hydraulic absorption systems. The total weight of the systems delivered on the ESV will be about 800 lbs. A significant reduction in this weight will probably require a change in design concept to one in which energy absorption also takes place in the vehicle structure.

Introduction

Under the U.S. Department of Transportation Experimental Safety Vehicle (ESV) program, AMF Incorporated has been under contract to design and build a vehicle with a very high level of crashworthiness. This vehicle utilizes hydraulic energy absorption systems in both front and rear ends in conjunction with a rigid passenger cage to meet the crashworthiness requirements for front and rear end collisions.

The purpose of this paper is to report on the design and performance of the energy absorpition systems. In order to restrict it to a convenient size, the discussion has been confined to the functional design, development and testing of the systems as entities; the details of component designs have been discussed only when they are relevant to an understanding of system operation. Consequently, such facets of the program as the development of the hydraulic energy absorbers themselves have been omitted.

The paper conforms to custom in that the design is presented as if a perfectly straightforward and logical route was taken from the performance objectives to the final design, rather than the actual succession of design iterations.

Objectives

DOT performance requirements for the front and rear bumper and vehicle structure subsystems were translated into the following set of working performance objectives for the energy absorption systems themselves:

1. For frontal impacts with a fixed, rigid barrier or pole, the force transmitted by the front energy absorption system to the vehicle frame should be low enough so that the frame acceleration does not exceed the boundary shown in Figure 1. The same applies to rear impacts with a movable rigid barrier weighing approximately 4,000 lbs. Acceleration peaks of less than 5 milliseconds duration can be ignored. The acceleration versus time trace should be as close to a square pulse as possible (again, filtering out peaks of less than 5 milliseconds duration).
2. The stroke of the energy absorption systems at impacts below 10 mph should not cause body or other component damage.
3. The structural stability of the energy absorption systems should be such that they perform their function throughout a wide range of impact geometries; in particular for those shown in Figures 2 and 3.

System Description

A schematic of the front energy absorption system is shown in Figure 4, with the basic component functions summarized in Table 1. The rear system is identical except for the use of shorter stroke buffers and only one accumulator instead of two. In both front and rear systems, the buffer cylinders are mounted rigidly within the vehicle frame. The basic energy absorption task is handled by the hydraulic buffers; the bumper and bumper/buffer connections may be regarded as devices for transferring load to the buffers so they can perform their basic task throughout a wide range of impact geometries. The vehicle frame itself is regarded as being rigid and not contributing any energy absorption capability. The accumulators receive the oil displaced during an impact, provide a reserve of oil in case of minor leakage, and, being pressurized, permit the buffers to re-extend following low velocity impacts.

The stroke of both front and rear systems is an increasing function of impact velocity. This is necessary to satisfy both the maximum acceleration requirement

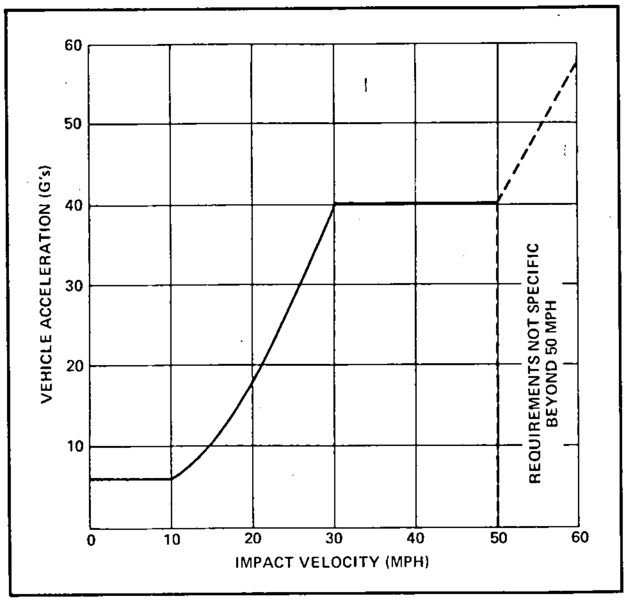


Figure 1

at 50 mph and the damage-free requirement below 10 mph. (A stroke in excess of 25 inches is required for the front system in a 50 mph barrier collision to keep the maximum acceleration below 40 g's, and the use of a fixed stroke system with that stroke would have meant an excessively long vehicle.) The stroke variation is achieved by changing the hydraulic flow area of the buffers as a function of impact velocity. This is done in each buffer by shifting the position of a sleeve, which carries the flow orifices, in response to the hydraulic pressure developed in the buffer.

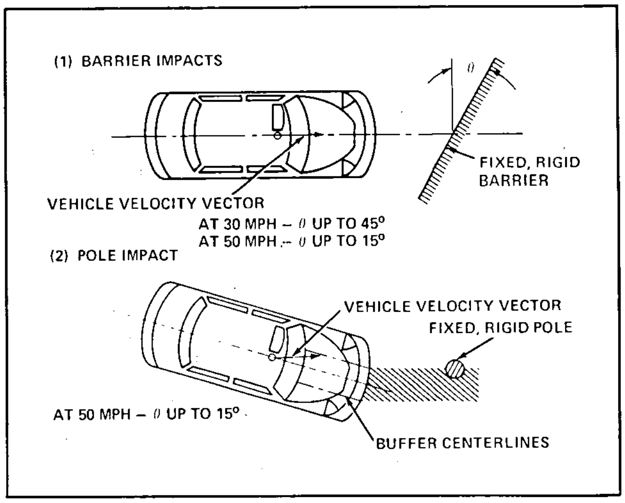


Figure 2

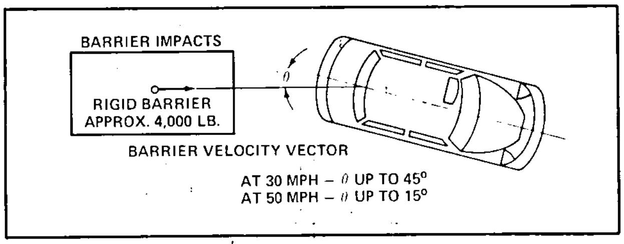


Figure 3

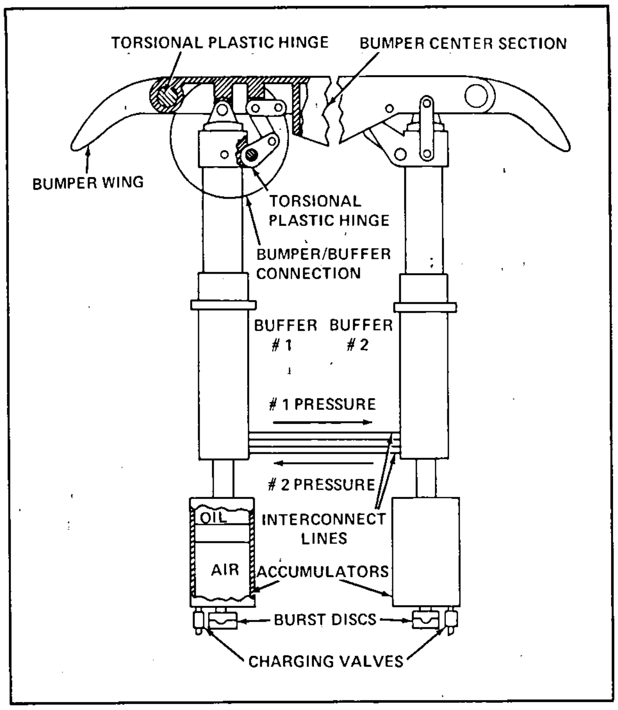


Figure 4

Sufficient clearance with respect to body and chassis parts is provided to accommodate 9 inches of bumper stroke front and rear. In 0° barrier impacts, this value is not exceeded until the impact velocity exceeds about 13 mph for frontal impacts, and 29 mph for rear impacts.

TABLE 1
Summary of Component Functions

Component	Primary Functions
Buffers	Absorb the kinetic energy of the vehicle, the energy absorption process being such that: (i) Stroke increases with impact velocity. (ii) Force increases with impact velocity. (iii) Force vs. stroke profile is approxi- a square pulse for each impact velocity. (iv) Obliquity of impact has a minimal effect on the energy absorption capability.
Bumper Center Section	Absorbs kinetic energy of bumper, buffer pistons, and connection hardware. Transmits load from the impact area to the buffer pistons.
Bumper/Buffer Connections	Maintain constant distance between buffer centerlines when buffers stroke unequally. Transmit longitudinal and transverse loads from the bumper to the buffer pistons. Limit the moments transmitted from the bumper to the buffer pistons.
Bumper Wing	Transfers load application point inboard while absorbing energy in oblique impacts to limit peak transverse loads and facilitate buffer stroking.
Accumulators	Receive hydraulic fluid displaced during impact. Return buffer pistons to fully-exptended position following a low velocity impact. Supply make-up oil in the event of minor leakage.

The damage-free requirement below 10 mph is thus met. The maximum stroke for the front system is 30 inches, and for the rear 14 inches, these occurring at impact velocities of 50 mph and above.

Both the front and rear systems operate at the same force levels in 50 mph barrier impacts. The ultimate energy absorption capability of the rear system is, however, only about half that of the front, as is reflected in the maximum strokes of the two systems. This is due to the fact that the rear impacts involve a barrier of finite (4000 pounds) mass which is free to move rather than a fixed barrier as in the front. During such an impact, about half the initial vehicle kinetic energy (based on its initial velocity relative to the barrier) is dissipated, the remainder appearing after the impact as kinetic energy of both the vehicle and the barrier. In a frontal impact, since the barrier is fixed and undergoes no velocity change during impact, the initial vehicle kinetic energy must be entirely dissipated.

If the only impact configurations to be dealt with were 0° impacts with flat barriers, the system design problems would be, if not trivial, at least straightforward. However, the problem becomes somewhat complicated when consideration is given to oblique and off-center impacts.

Consider, as a canonical example, a 0° 50 mph impact with a pole whose center lies along one of the buffer centerlines (Figure 5a). An obvious design approach would be to make the connections between the buffer pistons and bumper sufficiently rigid so that, except for elastic deflections, the buffers stroke simultaneously and energy absorption occurs as if the impact were central. In fact, as far as energy absorption is concerned, no distinction would need to be made among various impact configurations at the same velocity. This scenario has the appeal of simplicity, at least until the bending loads on the buffer pistons are considered. Figure 5b shows the forces acting on the free body consisting of the buffer pistons and bumper for a rigid configuration. To handle the indicated moments, if 200,000 psi yield material were used, something like a 5 inch OD tube with 9/16-inch wall thickness weighing 26.7 lb/ft would be required for the pistons. Consideration of the fact that a total of about 12 feet of pistons is required for the two systems leads one to conclude that this approach means a heavy system. There are also severe packaging problems, due to the large piston and cylinder diameters, and to the length required so that the piston supports are sufficiently far apart to handle these moments without binding.

Abandonment of the rigid connection idea, while necessary from a weight and packaging standpoint, means that the buffers must be allowed to stroke unequally, and this gives rise to a new set of problems:

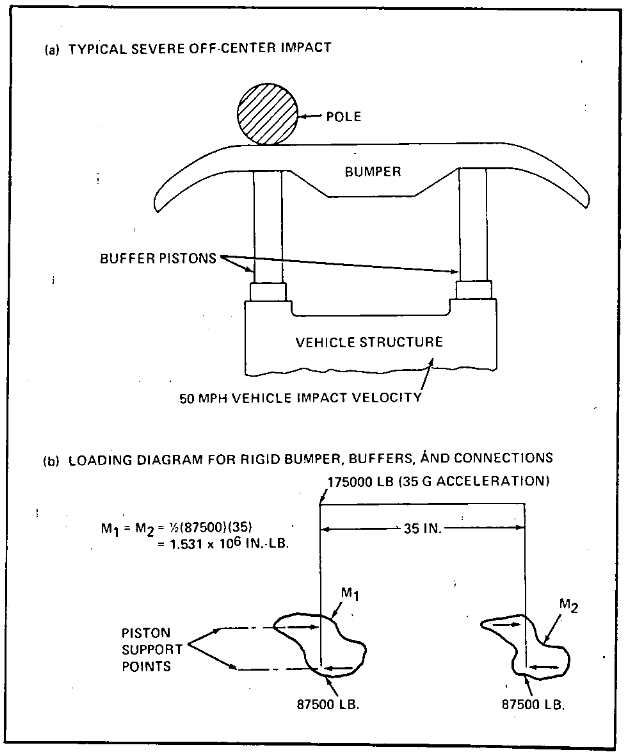


Figure 5

1. The connection between the bumper and buffers must be able to accommodate the increase in the distance between the outer ends of the two buffers which occurs when the buffers stroke unequally. Otherwise, excessive bending moments would be induced in the buffers.
2. The buffers must have the same combined energy absorption capability in oblique or off-center impacts as they have in a 0° centered impact despite the fact that the one remote from the impact operates at a lower pressure and is unable to achieve full stroke.

It is evident that the larger the stroke differential between the two buffers, the worse these problems become, both from the standpoint of a reasonable mechanism design to accomplish (1), and from the standpoint of the buffer design required for (2). The primary problem thus becomes one of minimizing the required stroke differential while keeping the bending moments on the buffer pistons down to reasonable values.

The amount of stroke differential required is a function of the load application point, the relative hydraulic resistances of the two buffers, and the amount of moment which can be transmitted by the connections between the bumper and buffers. In the case of oblique barrier impacts in which the initial contact point is outside the buffer centerlines, the bumper wing is allowed to fold back (by yielding a torsional plastic hinge) at a relatively low load value; this transfers the load application point inboard close to one of the buffer centerlines for most of the impact duration. Now, if the load application point is not outside the buffer centerlines, and if the relative buffer resistances could be adjusted to precisely the right values, it would be possible in a frictionless world for the buffers to stroke equally with no moment transmitted by the connections. In the case shown in Figure 5a, the buffer on the impact side would need just twice the resistance it has in a centered impact, while the resistance of the buffer remote from the impact point would have to be zero.

Although the developed system does not approach this level of refinement, it is possible, with no change in the basic variable-stroke buffer design, to modify the hydraulic resistance of each buffer so that, during an oblique impact, the buffer on the impact side offers more resistance throughout its stroke than it would in a centered impact. It is necessary to use the pressure in the opposite buffer to accomplish this, in effect, letting the left hand know what the right is doing, and conversely. The transmission of these pressure signals from one buffer to the other is the function of the interconnect lines shown in Figure 4. This increase in resistance of the impact-side buffer tends to minimize the stroke differential and also makes up for the loss in energy absorption capability of the other buffer.

Since the resistance of the buffer opposite the impact side cannot be decreased to arbitrarily small values, the stroke differential can be further minimized by having the bumper/buffer connections transmit the maximum moment compatible with a reasonable size and weight for the buffers. The value used is 400,000 in-lb each; the buffer pistons themselves have a capacity of 500,000 in-lb.

The question of how much stroke differential is required with this amount of moment transmitted was investigated with a computer simulation of the vehicle and energy absorption systems. This model was also used to investigate two other questions involved in the design of the energy absorption system: First, to what extent should the pressure in one buffer be used to modify the hydraulic resistance of the other (degree of "interconnectedness")?; and second, what are the magnitudes of the moments induced at the cylinder ends of the buffer pistons?

The results of the computer analysis can be summarized as follows:

1. The pressures from both buffers should have equal weight in setting the hydraulic resistance of either of the two buffers (i.e., the resistance is determined by the average of the buffer pressures).
2. For 400,000 in-lb moment capacity of the bumper/buffer connections, the maximum required stroke differential is about 11 inches (in a 50 mph impact with the configuration shown in Figure 5a).
3. The moments at the cylinder ends of the buffer pistons did not exceed those at the outer ends (400-000 in-lb) with the following exception: at the beginning of those impacts for which the initial relative velocity between the vehicle and impacted object was not parallel to the buffer centerlines, a very short duration, high magnitude spike occurred in the cylinder end moment and transverse load traces. ["Transverse" = horizontal and normal to vehicle longitudinal centerline.] It was reasoned that this spike would be considerably smoothed in the real case due to the elasticity in the buffers and the cushioning effect of the bumper wing, both of which were neglected in the model. As a consequence, it was for the most part ignored in the system design. It did, however, induce a certain conservatism in the original design of the bumper/buffer connection for the transverse loads. Since the peak transverse loads remained somewhat of an unknown quantity, it was necessary to get a good measure of these in the course of the test program. These were measured by appropriate strain gauges on the linkage, and it was necessary to insure that the strain-gauged components

remained within the elastic range; hence the conservatism.

Since the variable stroke buffer is the key factor in setting requirements for the other components and in determining the energy absorption characteristics of the system in various impact geometries, it is pertinent now to examine its design in more detail.

A schematic is shown in Figure 6. Energy is absorbed by forcing hydraulic oil out through orifices in the concentric fixed and regulating sleeves, with most of the

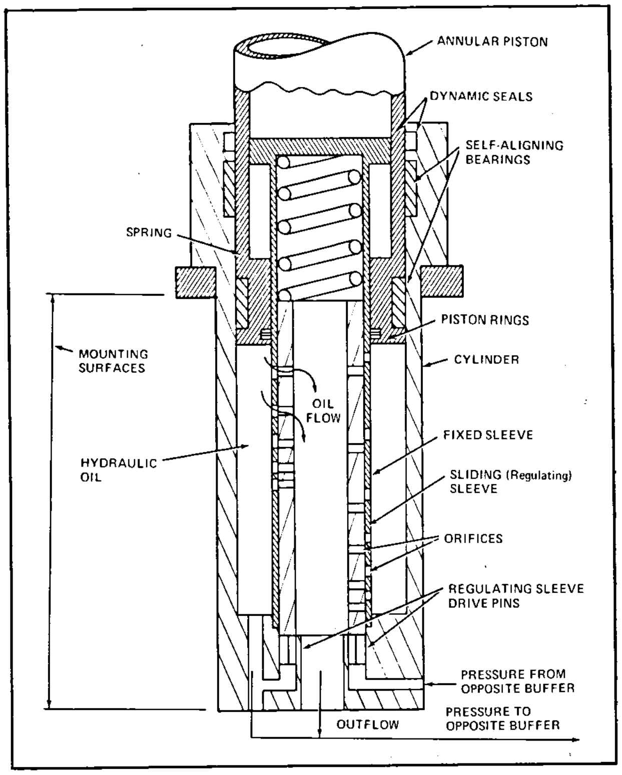


Figure 6

pressure drop occurring across the regulating sleeve. There are several orifice patterns in each sleeve, located according to the scheme shown in Figure 7. Each orifice pattern corresponds to a different impact velocity, and the distribution of orifices in it is such as to produce a theoretically square pressure (hence, acceleration) pulse. The length S of the orifice pattern is equal to the desired stroke at the given impact velocity. Initially, the sleeves are positioned as shown with the shortest (low velocity) orifice patterns aligned. To align one of the longer (higher velocity) patterns, it is necessary to move the regulating sleeve against the resistance of the spring (which is actually a stack of Belleville washers) a certain integral number of fixed sleeve hole diameters D. The force necessary to do this is applied by the regulating sleeve drive pins, which in turn are acted on by cylinder pressure.

The spring has a preload on it, so that a significant pressure is required to start the sleeve moving. For impacts at velocities insufficient to exceed this pressure, the regulating sleeve remains in its initial position as shown. The set of orifices aligned in this position are operational throughout the damage-free range of impact velocities discussed previously.

For impacts in which the velocity is high enough to generate a pressure sufficient of overcome the spring preload, during the pressure buildup transient at the start of the impact the regulating sleeve shifts to a position determined by the impact velocity and remains in approximately that position for the duration of the

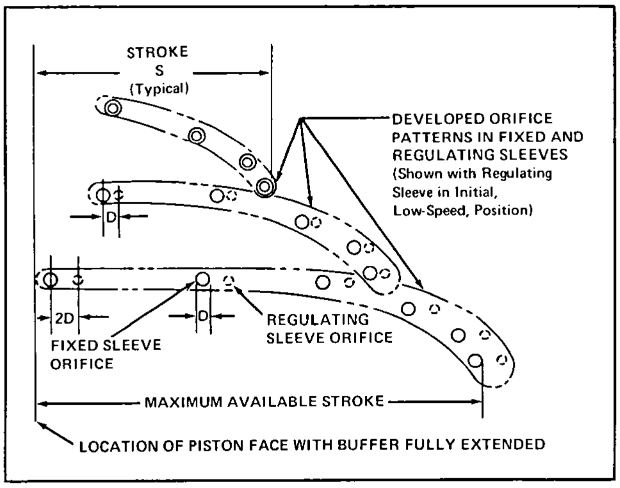


Figure 7

impact (at least for 0° impacts with the standard barriers). Sufficient damping on the regulating sleeve's motion is supplied by the losses involved in moving oil in and out of the region in which the Belleville washers reside, by viscous and coulomb friction between the Belleville washers and between the fixed and regulating sleeves, and by other miscellaneous energy sinks.

If the impact velocity falls between two of the specific velocities to which the orifice patterns correspond, the regulating sleeve moves to an intermediate position in which flow occurs through both orifice patterns. (Due to the relation between the diameter of the fixed sleeve orifices and the offset of the patterns in the regulating sleeve as shown in Figure 7, as one pattern is covered, the next is uncovered so there are no "dead" spaces; the variation of orifice area at intermediate positions is fairly smooth.)

The force/velocity/stroke characteristics selected for the front and rear buffers are shown in Figure 8. Outside of the low-speed (damage-free) range, both force and stroke are roughly linear with impact velocity for impacts with the standard barriers.

The fact that the hydraulic resistance of the buffer can be changed by changing the position of the regulating sleeve has a definite advantage in this system. As mentioned previously, in impacts for which the buffers stroke unequally, the resistance of the buffers is

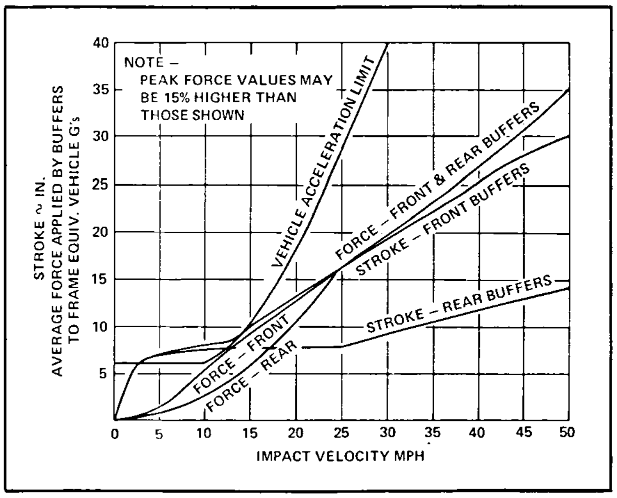


Figure 8

modified so that the buffer on the impact side absorbs energy at a higher rate than it would in a centered impact, thereby making up for the lower energy absorption rate of the other buffer. This is accomplished as follows. The regulating sleeve is moved by eight drive pins on which pressure acts. Any number of these pins can be isolated from the rest (by appropriate manifolding) and driven by the pressure from the opposite buffer, while the remainder are driven by the pressure in their own buffer. Thus, calling the buffers #1 and #2, the position of the regulating sleeve (hence, the hydraulic resistance) of buffer #1 can be set by a weighted average of the pressure in buffer #1 and that in buffer #2. The respective weights can be 1 and 0, 7/8 and 1/8, ¾ and ¼, and so on to 0 and 1. [The first set of weights in this sequence corresponds to an independent, or unconnected, pair of buffers; the last, to a totally interconnected pair with the resistance of buffer #1 determined entirely by the pressure in #2 and conversely.] It turns out that, for this system, the best choice of weights is ½ and ½; i.e., a simple average of the two pressures determines the regulating sleeve position.

As compared to an independent system in which each buffer is unaware of what the other is doing, the interconnected system reacts in an oblique impact with greater resistance on the impact side and less on the side remote from the impact. The pressure on the remote side is, however, determined by the moment transmitted by the bumper/buffer connections; hence the decreased resistance on that side is manifested not in a lower force level but in a higher stroke rate. This not only minimizes the stroke differential, but it also means that the energy absorption rate is higher for both buffers than it would be if they were not interconnected. This energy absorption rate is close to what it is for a centered impact, which is necessary to avoid an extremely high pressure peak as the impact side buffer approaches the end of its stroke.

The problem of designing the bumper/buffer connections in such a way as to maintain parallelism between the buffers while allowing them to stroke unequally was a complex one. The solution eventually adopted was to connect the bumper and each buffer piston with a longitudinal and a transverse link. The kinematic behavior of this mechanism for unequal buffer strokes is shown in Figure 9. With the proper choice of lengths for the longitudinal and transverse links, this linkage approximates the ideal path of the bumper with enough accuracy so that the buffers are not forced to deflect more than about .060 in. total (relative to each other) over a differential stroke range of 0 to 11.6 inches. After enough layout work had been completed to provide a basis for selecting the length of the longitudinal link, the length of the transverse link was selected using a program which computed the variation with stroke differential of the distance between points "A" on the bumper and "B" on the buffer end with the center of the bumper kept on the vehicle centerline. The distance between these two points (hence, the length of the link) was selected to keep this di^tance variation to a minimum.

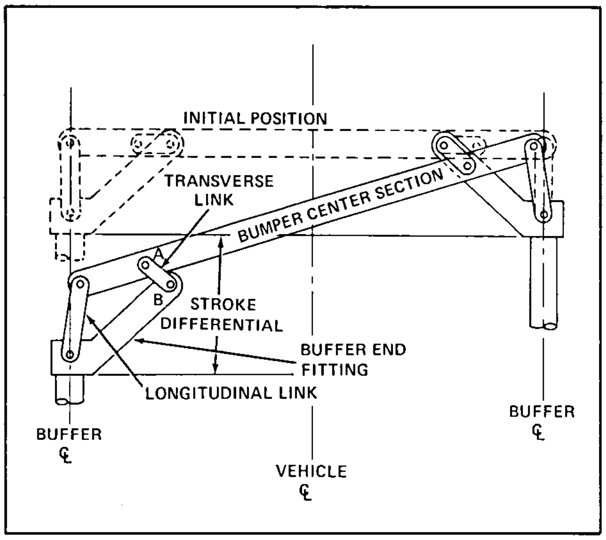


Figure 9

The linkage as shown in Figure 9 does not transmit any moment, although it is used to transmit transverse loads via the transverse links. Transmission of the 400,000 in-lb moment is accomplished separately with a torsional plastic hinge mounted to the buffer end fitting and connected by a lever arm and link to point "A" on the bumper (Figure 4). The torsional element is made of maraging steel which has (by test) an ultimate shear strain of approximately 15% and an ultimate shear stress of approximately 200,000 psi. The combination of high ultimate strain and ultimate strength not much greater than the yield strength gives a remarkably constant torque characteristic once the material starts to yield.

The bumper/buffer connections, together with the bumper and buffer pistons, constitute a group of components on the impact end of the vehicle whose kinetic energy cannot be absorbed hydraulically, which requires consideration of the factors in the bumper design. The most severe requirement on the bumper is that it must hang together during a 50 mph central impact with a rigid pole. Essentially, the bumper must play a dual role in such an impact. First, the initial phase of the impact consists in stopping the bumper, connections, and buffer pistons. For the front system, this is a mass weighing about 200 lbs. and possessing at 50 mph a kinetic energy of 200,000 in-lb which must be absorbed in deflection of the bumper. This deflection includes about 1 inch of permanent deformation. Second, with this portion of the system stopped, the bumper must yield no further while reacting the loads generated by the buffers (about 180,000 lbs.).

Since the bumper has a combined requirement of a minimum energy absorbing capability followed by a minimum static load capacity, a combination of high strength and ductility is required if a reasonably low weight is to be achieved. In addition, it must have sufficient rigidity locally to apply high, concentrated loads to the various links in the buffer/bumper connection. The material selected is a 7175-T66 aluminum forging, from which the center section is machined. Ultimate strength is 80,000 psi with 12% elongation in sections under ¾ in. thick. In order to maximize the energy absorbing capability, the bumper is designed essentially as a constant stress beam for a central load.

The bumper wings are also constructed of 7175-T66 aluminum; they are attached to the bumper center section with torsional plastic hinges of the same type used in the bumper/buffer connections. The hinge on the impact side yields in a high velocity oblique impact to allow the load application point to move inward, as previously discussed. Below 10 mph, for barrier impacts up to about 45°, it remains within the elastic range.

The hinge also absorbs a fairly significant amount of energy, about 125,000 in-lb before it fractures. This helps in reducing the magnitude of the transverse load spike which occurs in certain impact configurations.

Method Of Analysis

The primary analytical tool used during the functional design phase of the energy absorption systems was a computer simulation of the vehicle, energy absorption systems, and barrier (fixed or movable), shown schematically in Figure 10.

The following assumptions were made in formulating the model:

1. All motion is planar.
2. Both the vehicle and barrier are rigid.
3. The bumper frame (bumper, connections, and buffer pistons) is weightless, hence at the instant of impact, its velocity component normal to the barrier is zero.
4. The effect of those sections of the bumper outboard of the buffer centerlines is negligible.
5. The effects of geometry changes due to deflections of the buffer pistons are negligible.
6. Moments and transverse loads applied to the bumper frame are shared equally by the two buffer pistons.
7. The bearings supporting the buffer pistons in the cylinders are frictionless.
8. Tire forces are negligible.
9. Buffer regulating sleeve dynamics are negligible (position of regulating sleeve proportional to pressure).

The equations constituting the model were programmed for the G.E. Mark II Timeshare computer. Integration of the differential equations was performed by a 4th order Runge-Kutta routine available in the standard Mark II library. Input to the program consisted of mass and geometrical properties of the vehicle and barrier, buffer properties, and initial velocity and orientation of the vehicle with respect to the barrier. Program output consisted of a time history of the loads applied to the bumper frame (both by the vehicle and the barrier), buffer pressures, strokes, and stroke velocities, and the position and velocity of the vehicle relative to the barrier.

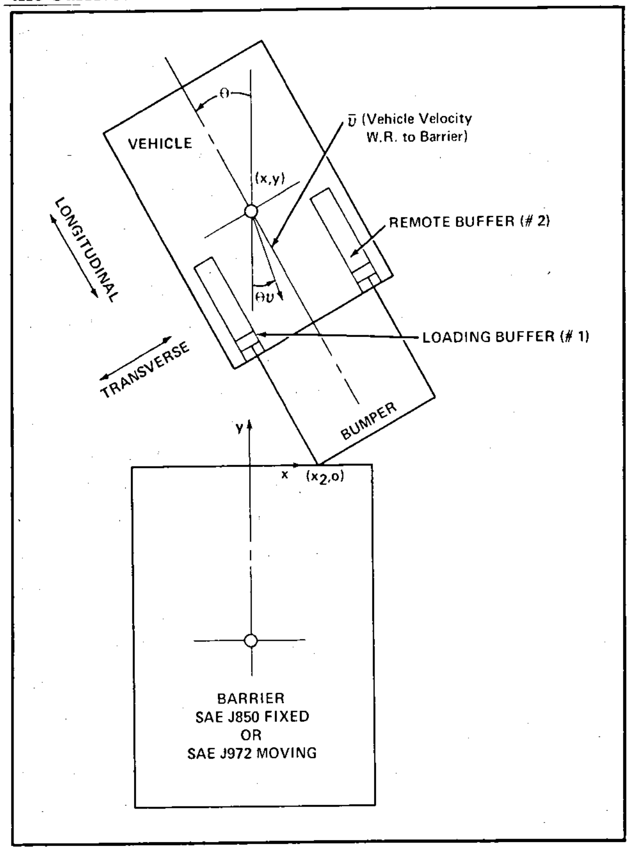
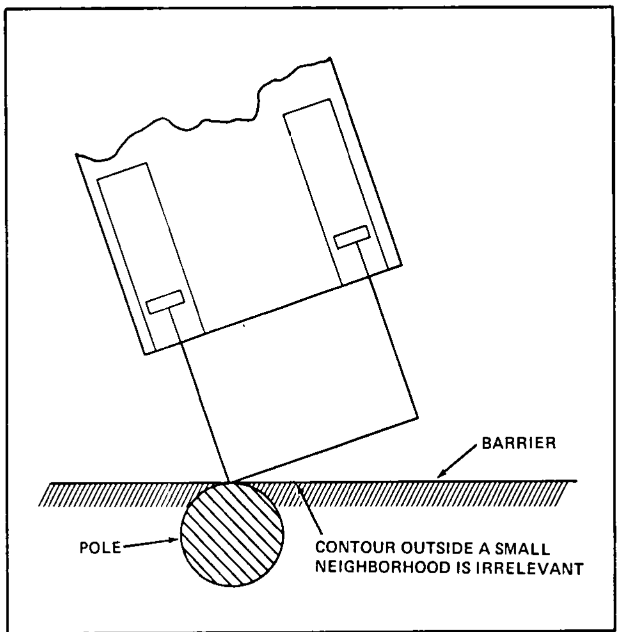


Figure 10.

Note that, although the model was formulated for a barrier impact, under certain conditions it provides a reasonable simulation of a pole impact at the leading buffer centerline. Specifically, if the vehicle does not slide along the barrier, and if the bumper face is not too far from being parallel to the barrier, then the difference between a barrier and pole impact is small. This is simply due to the fact that under these conditions, the vehicle behavior depends only on the geometry in a small neighborhood of the contact point and in such small neighborhoods, the geometry of a pole and barrier are similar as shown in the following sketch.

Once the model was checked out, the general approach to the problem of determining the characteristics of the bumper system was simply to change the appropriate characteristics in the direction indicated by the results of previous computer runs until a configuration was obtained which appeared to satisfy all the ESV criteria.



The primary limitations of the model were due to the rigidity assumptions on buffers and supporting structure and the non-existence assumption on the bumper wing. As a consequence of these assumptions, the magnitude of the loads associated with some very short duration events (in particular, the transverse load spike in the 45° rear end impacts discussed previously, which is associated with a reversal in the direction of motion of the impact point along the barrier), were not credible. Resolution of such questions was left to the test program.

Test Results

Following the completion of development tests on the individual buffers, a series of full system tests was made. The front and rear energy absorption systems were mounted on a test vehicle which consisted simply of an X-braced frame of structural steel channels mounted on a pair of trailer axles and ballasted to simulate the mass and CG location (with respect to the bumpers) of the ESV. The yaw and pitch moments of inertia of both the test vehicle and the ESV were also approximately equal. Apart from making the test vehicle as rigid as possible, no attempt was made to simulate the structural characteristics of the ESV. Also, since the tire reactions are small compared to the other loads applied in these high energy impacts, no attempt was made to simulate the ESV suspension characteristics or even the precise wheel locations.

The systems described previously in this paper were developed in part from the results of these tests; consequently, they differ in some details from those used in the tests. In particular, the test bumpers were of welded steel (4130) construction rather than aluminum and weighed considerably more (175 lb vs 104 lb). Transmission of moments to the buffer pistons in the test system was obtained with a device using the deformation of aluminum in a closed chamber, rather than a torsional plastic hinge. Finally, the test buffers differed in the seal design used and in the piston end fittings, the latter made of steel rather than aluminum construction.

The test program was designed to obtain the maximum amount of information compatible with the limited number of test components available, and hence, except for the final tests on the front and rear systems, the major components had to survive each test.

The tests had the following configurations and objectives:

1. 0°, 50 mph rear impact with 4000 pound moving barrier – verification of system characteristics for the simplest high energy impact.
2. 45°, 20 mph rear impact with 4000 pound barrier – to provide a preliminary estimate of transverse loads and evaluation of system behavior before proceeding to the 30 mph, 45° case specified in the work statement. [These were cases for which the computer model had indicated a high transverse load spike.]
3. 45°, 30 mph rear impact with 4000 pound barrier – to determine peak transverse loads and evaluate system behavior.
4. 45°, 30 mph front impact – similar objectives to (3). [(3) and (4) are kinematically different configurations, and the computer model had indicated this case to be less severe than the rear impact; in particular, the transverse load spike was absent.]
5. 0°, 30 mph central pole front impact – evaluation of bumper center section behavior under severe initial impact loads; evaluation of hydraulic system char-

acteristics for a moderate energy symmetrical impact.

6. 15°, 40 mph fixed barrier front impact – preliminary evaluation of system characteristics, particularly those associated with the buffer interconnection concept, before proceeding to the 50 mph case.
7. 15°, 50 mph fixed barrier front impact – evaluation of system characteristics for one of the most severe cases for the hydraulic portion.

The first test, the 50 mph rear barrier impact, was uneventful; the rear energy absorption system operated as anticipated, with both buffers stroking close to the maximum of 14 inches. The vehicle acceleration trace (with peaks of duration less than 5 milliseconds averaged out) is shown in Figure 11-1.

The two rear 45° impact tests were made with no damage to the buffers and very little permanent deformation to the bumper; in fact, the bumper wings did not fold out of the way nearly as completely as intended and the load application point remained well outboard of the buffer centerlines. As a consequence of this, and of the fact that the moment transmitted to the outer end of each buffer averaged only about 220,000 in-lb instead of the desired 400,000 in-lb, the stroke differential in each case was larger than anticipated (about 5.5 inches instead of perhaps 2 inches). These tests were, however, extremely encouraging in that they confirmed the supposition that buffer elasticity and elastic and plastic deformation of the bumper wings would smooth out the severe transverse load spike seen in the computer model and discussed earlier. The peak total transverse load was 28,500 lb for test (2) and about 58,000 lb for test (3), whereas the model had shown 290,000 lb for the 30 mph case. This made possible a certain amount of weight saving in the bumper/buffer connection for the ESV. In the test system, this had been designed to take 80,000 lb transverse load per side, while in the system used in the ESV, 40,000 lb/side is the figure used. The revised bumper/buffer connection and bumper wing connection, both utilizing torsional plastic hinges, are much more predictable than those used in the test system, which should cure the problems of insufficient moment transmission to the buffers and insufficient deflection of the bumper wing.

Test (4), the 30 mph 45° frontal impact, illustrated the advantage of having the bumper wing deflect enough to move the load application point close to the buffer centerline. Following tests (2) and (3), the flanges on the bumper center section to which the bumper wings attach had been stiffened in an attempt to concentrate deformation in the bumper wing itself. This was accomplished, rather emphatically, when the impact tore the bumper wing off completely in this test. As a consequence, the stroke differential was small, slightly in excess of 2 inches. This was less than the model

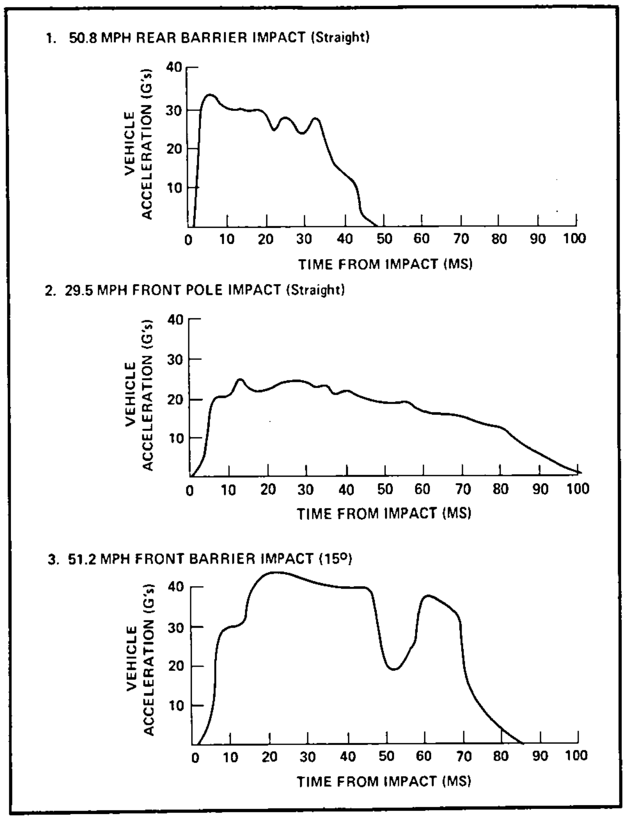


Figure 11

prediction of 2.5 inches for a coefficient of sliding friction on the barrier of 0.5. However, it appeared that the regulating sleeve in the buffer on the impact side had seized slightly, resulting in a higher than normal resistance for that buffer; this would tend to decrease the stroke differential. In accord with the model predictions, the total transverse loads were not as high as for the corresponding 45° rear impact. The model showed a 29,600 lb peak, while the measured peak was 31,500 lb.

Test (5), the 30 mph central pole impact, was uneventful as far as the second (stroking) phase of the impact was concerned. However, the first phase (stopping the bumper and buffer pistons) put a slight kink in the bumper (¼ inch permanent deformation between the buffer centerlines). The vehicle acceleration trace is shown in Figure 11-2. Extrapolation from the results of this test indicate that a 50 mph central pole impact would have resulted in the bumper taking a permanent set of about 0.75 in.

The results of test (6), 40 mph, 15°, indicated the buffer inter-connection scheme was working as anticipated, since the pressure in the buffer on the impact side rose very quickly to a value (16,000 psi) well above the nominal value for a 0° 40 mph centered impact (10,000 psi). They also indicated that it would be unlikely that 25,000 psi (the safe limit for the cylinders) would be exceeded in the subsequent 50 mph test.

Test (7), nominally a 50 mph 15° impact, was actually run at 51.2 mph. The buffer piston on the side remote from the impact failed in the end fitting about 5 ms. after the initial contact; this, however, had a minor effect on the results. As soon as the other buffer had stroked about 7 inches, the full width of the bumper center section contacted the barrier and applied load to the broken buffer, forcing it to stroke. The failure was attributed to internal cracks in the welded steel end fitting. The design to be used on the ESV eliminates welding to the piston.

The vehicle deceleration trace is shown in Figure 11-3. The 40 g limit was exceeded for more than 5 ms. in this case. Correction of the acceleration trace for the higher than nominal impact velocity results in a 4.8% decrease in acceleration values which brings the peak down to 42-43 g's. It is not known whether the manner of applying load to the broken buffer resulted in any unusual transverse loading conditions with associated high bearing friction; however, the g-loads appear high in relation to what would be computed from the pressure traces.

Of greater significance in this test is the operation of the buffer interconnection system. Figure 12 shows a plot of the pressure traces in the two buffers. Although

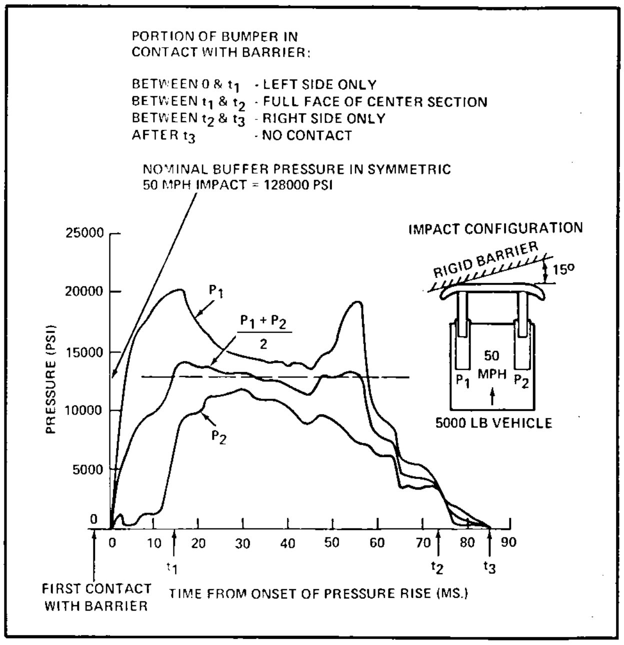


Figure 12

the pressure traces, individually, deviate considerably from the nominal value for 0°, 50 mph impact, the average pressure is close to the nominal value for most of the impact duration. This is precisely what was desired.

Summary And Conclusions

Front and rear hydraulic energy absorption systems capable of functioning in a wide variety of impact geometries at impact velocities of up to 50 mph have been designed, built and tested for the DOT ESV program. Each system consists primarily of two parallel hydraulic buffers, a bumper, and connections between the bumper and buffer which maintain parallelism between the buffers while allowing them to stroke unequally in oblique impacts. The buffer stroke increases with impact velocity, and the buffers are interconnected hydraulically in such a way as to minimize the variation of energy absorption characteristics with impact direction.

The hydraulic energy absorption systems have achieved, in the main, the performance objectives established for them. The only objective which was not achieved (and just barely so) was to keep the vehicle frame deceleration under 40 g's in a 50 mph 15° impact. When used in conjunction with a vehicle frame rigid enough to support the loads imposed by the buffers, they will make it possible for the vehicle to satisfy virtually all the crashworthiness goals for front and rear impacts outlined in the DOT Work Statement for the ESV program. In a few cases, these goals will be exceeded by a considerable margin; for example, in 0° rear impacts with a 4000 pound movable barrier, the vehicle should remain damage-free at impact velocities near 25 mph, while in rear end collisions with a similarly equipped vehicle, the damage-free range should extend to 40 mph or more.

The combined weight of the front and rear systems used in the test program was approximately 1100 pounds; using what was learned from the test program, this has been cut to 800 pounds for the system used in the ESV and described in this paper. With another round or two of design/testing/redesign, another 100 pounds might be pared off the total.

To obtain further weight (hence, production cost) reduction, it would appear to be necessary to adopt a philosophy in which the energy absorption function is shared by the vehicle structure and the hydraulic system; this should allow weight to be cut in both areas.

A NEW HIGH SAFETY GLAZING FOR AUTOMOBILES AND OTHER VEHICLES

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Summary

It is clear and well admitted that the present conventional laminated glass windshield with a thick plastic interlayer has much improved occupants' safety in a car when they undergo the "second crash."

And yet, the conclusions of official reports dealing with the whole of the crashes that have been analysed as well as the publications of specialists of automobile safety show that its laceration potential is still a severe disadvantage that ought to be lessened and if possible suppressed.

We come to the same conclusion when we consider the other glazings like the side and rear windows.

Several formulas have been suggested to reduce the risks of cuts for occupants who hit the windshield and whose heads and more particularly faces enter into brutal contact with the bits and broken fragments of glass.

None of the solutions that has been considered up to now seems to be a satisfactory compromise to meet with the requirements of the manufacturers as far as mass-production windshields are concerned.

It is very important to underline that the windshield whose laceration potential would have become very low and even non-existent should also have all the other performances that are required, especially a good optical quality that does not impair too much the visibility of the passengers and does not obstruct the view either because of an unforeseen fracture or by progressive natural aging.

Considerable progress has been achieved in manufacturing very thin glass of good optical quality in view of using it, strengthened as a part of high safety glazings[1 2].

However, it has been shown that the withstand against hard flying stones impact is improved when increasing the thickness of the outer sheet and the windshield rigidity; this results in preventing the propagation of fracture after indentations.

To find the best compromise, we have established the program of research described here, with three aims:

1. To study experimentally the numerous parameters which state the laceration potential of a windshield
2. To define, for increasing impact velocities, the best compromise between two antagonistic requirements:
   - high resistance to head penetration on one side
   - fairly limited severity index with a reasonable peak of deceleration on the other side
3. To set off the factors that could turn the windshield into a real passive restraint system.

This program is to be carried out in three successive phases. The first of them is explained here.

1) Tests about the impact of the headform free falling at impact angle on flat samples and full scale curved windshields. Measurement of the mechanical factors and estimate of the biomechanical characteristics of the impact, more especially of the laceration index as a function of the different parameters such as impact velocity, temperature, increase of its mechanical resistance, etc. The results of the first phase will be used as a basis and orientation for the other two.

2) Tests about the impact of primates against the types of windshields selected during the first phase. Estimate of the lacerations together with an X-ray study of the fractures and an attempt of diagnosis of the cerebral and cervial traumatisms.

3) Tests about the impact of anthropomorphic dummies and cadavers against the same windshields in the conditions of simulated crashes following the method used for instance at the Wayne State University.

The estimate of the results gathered then can be made but by direct and systematic comparison with the experiemental data related to the conventional glazing undergoing the same tests under the same conditions.

This compared experimentation has two parts: one carried out on flat samples (size: 24 x 36 in.) adopted by the SAE Glazing Study Group; and one carried out on large windshields fixed on automobile body openings.

The increase of safety of the new windshield can be roughly rated by extrapolation based on numerous investigations about the behaviour of the post 1966 current windshield during crashes.

The studies here considered are a part of this research program whcih aims to develop a laminated glass windshield whose laceration potential is very weak and even almost non-existent.

Two basic types of new safety windshields are tested. They only differ by the strengthening level of the V.H.R. glass which is used.

In both cases, the very thin 0.050 in. (1.2 mm) thick inner sheet and the 0.110 in. (2.8 mm) thick outer sheet are made of V.H.R. glass. Nevertheless, the glass of the outer ply has a voluntarily limited tensile strength.

The polyvinylbutyral plastic interlayer is 0.030 in. (0.76 mm) thick.

The evaluation of the biomechanical behaviour of these windshields is made in different ways among which laboratory studies, described here, and including impact tests with a headform free falling on positioned samples.

During the impact, all measures defining the main safety performances are recorded or filmed at high speed; the deceleration peak along two orthogonal axes, the resultant severity index, relating to the initial impact and to the plow in, the tearing length of the plastic interlayer and finally the laceration potential.

The latter is evaluated on basis of the laceration rating scale used by Prof. Patrick at the Wayne State University; a lateration index is given following the number and size of the cuts measured on the two superposed chamois leathers covering the headform.

The experimental parameters whose influence is more particularly studied are: temperature, impact velocity, impact location, increase of the mechanical strength of the sheets, decrease of the inner sheet thickness combined with increase of the interlayer thickness.

The researches are systematically carried out in order to compare the new windshield safety performances with the conventional laminated ones.

All the results of the measurements are analysed after the statistical method: parameters of distribution, lines of regression, analysis of correlations, signification tests, etc.

The new safety reinforced laminated windshield, whose laceration potential is very low and even non-existent at very high impact energy, might be used as a true passive restraint system if the tensile strengths of the reinforced glass are adjusted.

This double performance will have to be developed in a later series of tests about simulated crashes with anaesthetized primates, anthropomorphic dummies and, if possible, human cadavers.

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1. R. van Laethem, "A New High-Safety Glazing for Automobiles and other Vehicles," Twelfth STAPP Car Crash Conference Proceedings, New York: Society of Automobile Engineers, Inc., 1968, pp. 360-386.
2. E. Plumat, P. Eloy, L. Leger, F. Toussaint, and R. Van Laethem, "Safety Improvement of the New Laminated V.H.H. Glazing for Cars," FISITA STAPP Car Crash Conference, Proceedings, Detroit et Bruxelles: Society of Automobile Engineers, Inc., 1970, pp. 1152-1170.

ESV ROLLOVER TEST METHODS

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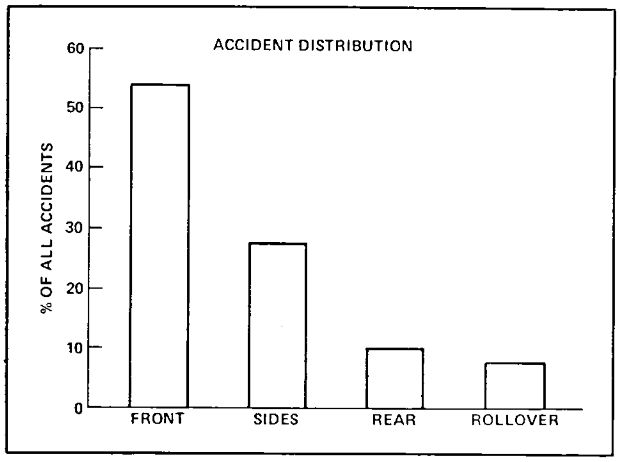
Before evaluating rollover test methods, it is of interest to examine the real life situation. Road accident studies in the United Kingdom indicate that rollovers account for less than 10% of all road accidents (Slide 1).

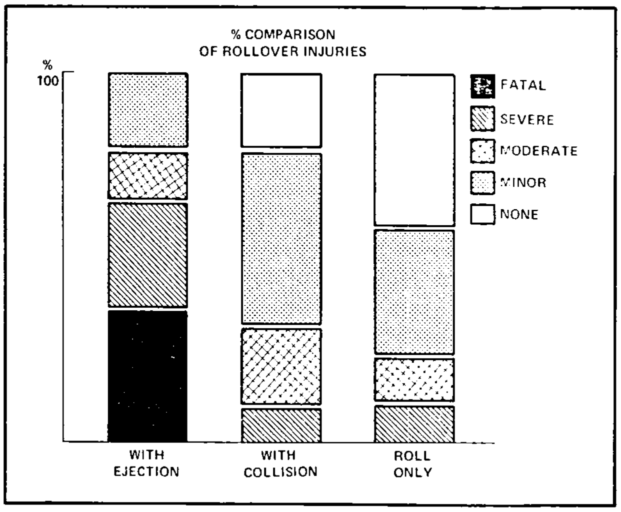
Rollover statistics can be divided into three categories:

- Rollover with collision
- Rollover without collision
- Rollover with ejection

A typical breakdown of the injuries sustained in UK rollovers[1 2] for each of these categories is shown on Slide 2. It is immediately apparent from this figure that if no ejection occurs, the probability of the vehicle occupant being injured in a rollover reduces dramatically.



Slide 1



Slide 2

Rollover With Collision

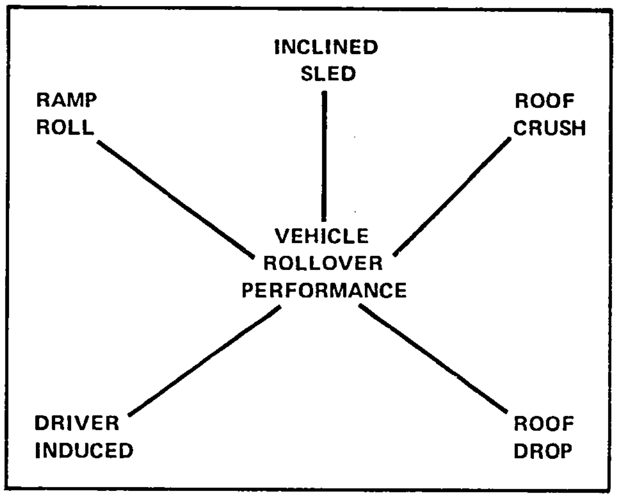
Collision can occur either before or after the rollover has taken place. In the former case they can be the prime cause of the rollover. The striking or struck object can be of almost any size or shape, and be stationary or in motion.

It is obviously not possible to devise a test method which could simulate all the variables connected with rollover with collision. Effort centred on vehicle handling and the .siting and impact properties of roadside furniture would be far more rewarding.

Rollover Without Collision

If we consider the pure rollover case, there are again a considerable number of variables. A number of test techniques have been developed in an effort to obtain a realistic and reproducible method of assessing vehicle rollover performance.

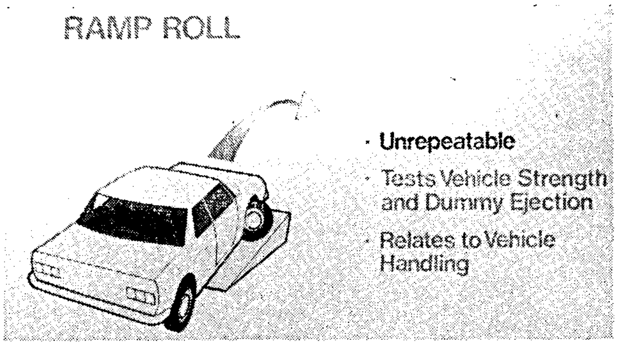
The main techniques currently employed are as follows: (Slide 3)



Slide 3

Ramp Method (SAE J857) (Slide 4)

The test is realistic in that it provides the forward component of velocity normally present in rollover accidents, and it is related to vehicle handling. With this type of test, however, there is an inherent lack of repeatability in the rollover mode.

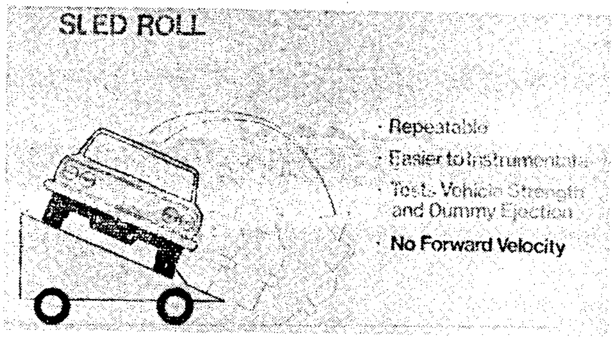


Slide 4

Sled Method (FMVSS 208) (Slide 5)

The test vehicle is towed in a straight line in the direction of a ramp. The vehicle is released just prior to reaching the ramp and a rapid full turn of the front wheels initiated. The rollover takes place on a dirt or turfed surface. Anthropometric dummies are employed to study occupant kinematics.

This test is not as realistic as the ramp method as it does not cater for the forward velocity component. Test results have shown, however, that it effectively simulates a broadside roll and that, dependent on the characteristics of the test vehicle, both fender corner to "A" pillar and the roof only roll modes occur with this type of test. It is also more repeatable than the ramp test and, because of the more predictable roll path, easier to instrument and photograph.

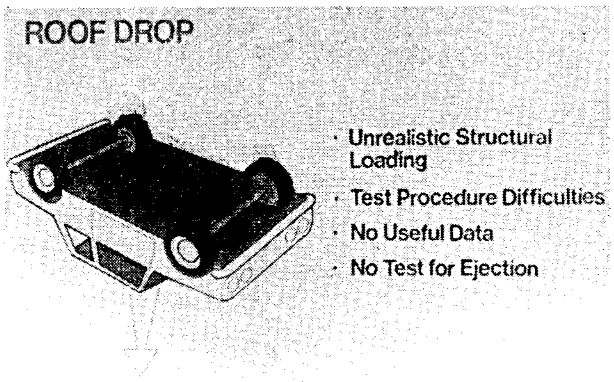


Slide 5

Roof Drop Test (SAE J996) (Slide 6)

The test vehicle is inverted and suspended at a compound angle and then released from a specified height on to a firm flat surface. No occupant simulation is employed.

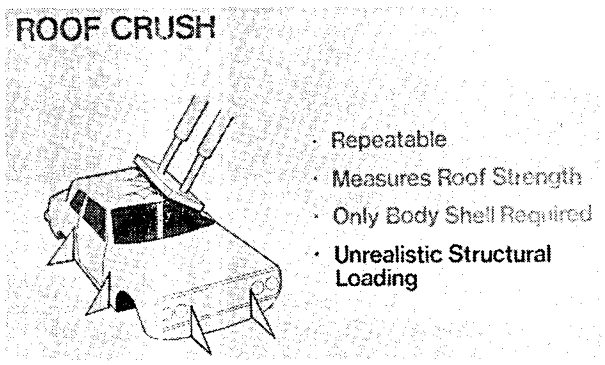
This type of test is intended to measure the resistance to intrusion of the roof structure during a rollover. It is a difficult test to conduct, and gives test data of limited value.



Slide 6

Roof Crush Test (SAE J374) (Slide 7)

This is a laboratory rig test where the vehicle's roof is subjected to a gradually applied load a specified compound angle. No occupant simulation is employed.



Slide 7

Whilst far from representative of the real life situation, this test, conducted with a rigid 12 inch by 72 inch loading platten, does give a static measure of roof strength and has a high degree of repeatability.

Driver Induced Rollover

A high speed run is made and full lock suddenly applied to occasion a broadside rollover. A high degree of realism is achieved with this test once the rollover has been induced. The major problems are lack of reproducibility and the moral implications of placing the driver in a hazardous environment. This is particularly significant if it is considered that prototype vehicles will be involved.

Object Of Rollover Techniques

Handling Stability

Primarily, the vehicle's handling characteristics should prevent rollover occurring unless excessively severe conditions are encountered. Our test technique should demonstrate, therefore, that a vehicle's handling characteristics are anti-rollover.

Current proposals for roll stability tests take the form of a J turn at speeds up to 70 mph with a steering wheel deflection rate of at least 120°/second. This is a complex test to conduct by remote control, requiring sophisticated control gear if any degree of repeatability is to be obtained. The test could be conducted with a driver, but this would degrade repeatability still further, and introduces the ethical problem of placing the driver in a hazardous position.

Occupant Containment

When excessive conditions do exist and vehicle rollover occurs, then our aim becomes one of occupant protection. Road accident studies have shown that occupant ejection is the predominant cause of serious injuries and fatalities. If the occupant remains in the vehicle throughout the roll cycle, he stands an excellent chance that any injuries he sustains will be of a minor nature. Our test technique should demonstrate, therefore, that should rollover occur, an occupant would not be ejected.

Structural Integrity

A further factor that should be considered is the resistance of the vehicle roof structure to intrusion. The strength of a vehicle's roof must have a bearing on the integrity of the passenger compartment in a rollover type accident. The correlation between occupant safety and roof intrusion, however, is far from established. Gross intrusion can be equated with an increase in the severity of occupant injury, but these injuries may be more related to the associated increase in severity of the secondary impact of occupant to vehicle interior structure.

The lack of correlation between intrusion and occupant injury makes it difficult to establish a meaningful test technique related to roof intrusion resistance.

Next to the doors remaining closed, the retention of the vehicle's fixed and side glass is the most important factor in preventing the ejection of the unrestrained occupant. If the force/deflection characteristic of a vehicle's roof structure could be related to the ability of its body structure to retain the fixed and side glass, then this could possibly be used as a measure of rollover performance.

Relationship Between Rollover Test Techniques And Vehicle Design

The relationship between body exterior design and rollover performance presents us with a complex situation when related to occupant protection.

A vehicle basically round in shape will obviously roll more smoothly and at higher rotational velocity than a vehicle with a square profile. This will subject the occupants to a higher centrifugal force, tending to hold them in a fixed position inside the vehicle during the rollover. This is particularly so for the small European package.

A rapid continuous rolling action also minimises damage to the body structure, kinetic energy being dissipated in rolling friction, rather than structural deformation. The vehicle will also decelerate more gradually than its rectangular counterpart, minimising the secondary impact of the occupant with the vehicle interior.

This would seem to suggest that our test requirement should encourage the design of vehicles with pronounced tumblehome to ensure as smooth a rollover cycle as possible.

We have not, however, taken account of the total distance covered whilst the vehicle is out of control. Obviously, the greater the distance covered, the greater the risk of collision occurring with a second vehicle or some stationary object. Should collision occur, the previously advantageous tumblehome could now become a liability, as it is less able to resist crushing loads to the roof structure. The occupant's head is also closer to the roof rail and liable to receive a more severe lateral impact.

However, it would appear from the limited test data available that the roll distance covered by saloon vehicles of differing shapes and sizes is approximately the same. Comparative 30 mph inclined sled tests on a Zodiac Mark IV and a Capri show that whilst the large rectangular shaped vehicle completes less than two rolls, it tends to skip along on its corners and covers almost the same distance as the rounder vehicle does, whilst executing over three full rolls.

On balance, therefore, some degree of tumblehome would seem advantageous, and it should not be penalised as could be the case if the SAE static roof crush test were employed.

Rollover Test Results

The tests that Ford has conducted support the conclusion that was drawn from the rollover accident studies; namely, that where ejection does not occur, the levels of occupant head and chest acceleration are low – significantly lower than the requirements of FMVSS 208. This finding was endorsed by a curb rollover test conducted by Ford with a professional stunt driver in a Cortina Mark II. The vehicle struck a 5 inch high curb broadside at 45 mph, and executed two full rolls without the driver sustaining any injury (extract from cine film). These low levels of occupant acceleration are also supported by a number of inclined sled tests on different UK vehicles conducted by the Motor Industry Research Association.

Conclusions

All of the rollover test techniques discussed are either lacking in realism or subject to poor repeatability. Any method selected for assessing the performance of an experimental safety vehicle will involve major compromise between realism and repeatability.

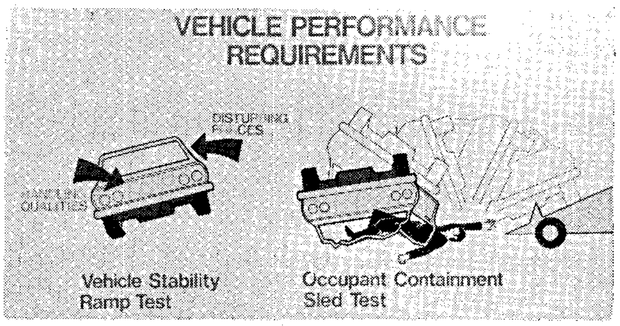
Rollover Without Collision

As road accident data shows no definite relationship between roof crush and occupant injury, there appears little justification for a roof strength requirement. What can be concluded is that for rollovers without collision, the roof strength of the majority of current European vehicles is satisfactory.

Apart from the obvious need for the vehicle to possess a high roll stability, one factor predominates as the criterion for rollover performance. That factor is containment of the occupant throughout the rollover cycle.

Vehicle Roll Stability: (Slide 8)

It is possible that the ramp technique would make a better roll stability test than it does a rollover test. A performance specification could require that no rollover takes place when a vehicle negotiates the ramp with full adverse lock at a given speed. Both speed and ramp height could be fixed to achieve a given level of roll stability.



Slide 8

This test would not be as realistic as the J turn manuever, but it could be made more rigorous without the same degree of complexity, and would possibly be more repeatable.

Occupant Containment: (Slide 8)

The soundest test method for establishing occupant containment would appear to be the inclined sled test. Whilst not quite as realistic, the rollover cycle from the sled is similar to that of the ramp test. It gives an indication of the body's ability to resist intrusion, and is appreciably more repeatable than the ramp test.

A further advantage of the inclined sled is that it facilitates photographic coverage of the dummy motions – essential if occupant containment is to be the performance criterion.

Rollover With Collision

It is not possible to specifically cater for rollovers involving collison because of the wide range of variables. Little could be done, for example, for the "broad roof" impact with a tree where effectively, the occupant sustains primary impact with the tree at full impact velocity. Improved vehicle roll stability and design or elimination of roadside furniture would seem the most effective action.

If the severity of the secondary impact of occupant to vehicle structure could always be kept within survivable limits, the ability of the roof structure to resist intrusion would then become significant. The SAE roof crush procedure, whilst far from realistic, does give a repeatable measure of roof strength, and would possibly provide a useful basis on which to compare roof crush resistance.

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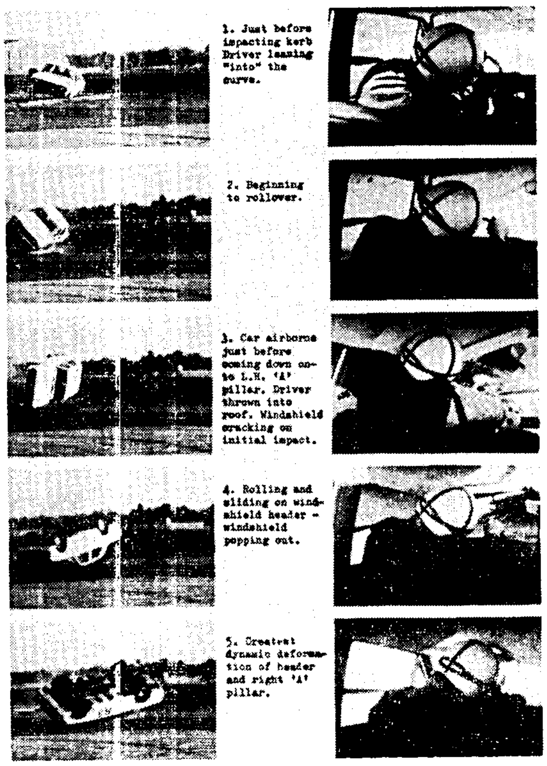
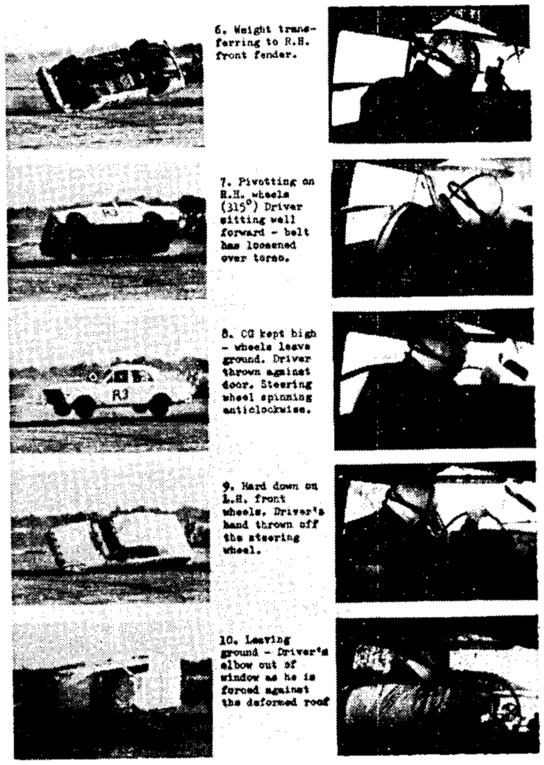
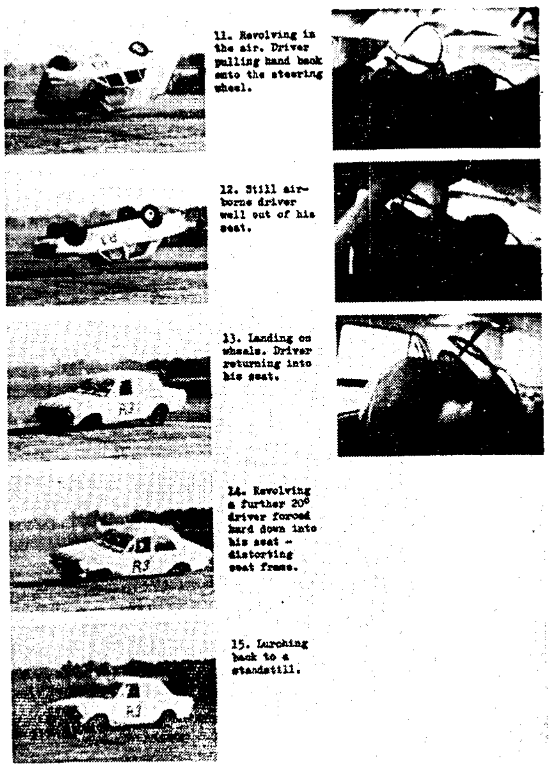


R3 Third rollover attempt, successfully resulting in two complete rolls. Adjacent external and internal views are approximately coincident.



R3 Third rollover attempt.



R3 Third rollover attempt.

FIRST CONCLUSIONS FROM ANALYSIS OF HIGHWAY CRASHES

Dr. Claude Tarriere
Laboratory of Physiology and Biokinetics of Peugeot/Renault Association

Since this Conference started, important questions that each participant was asking himself, have become rather significant after they were treated again and again during the succession of statements by the various Delegations.

Let us formulate the more fundamental ones:

1. What is the connection between the ESV requirements and actual crashes?
   The tests retained and the required speeds – are they really justified?
   Is it justified for safety reasons requiring, for example, that the *average* deceleration of the passenger compartment in a very severe crash (which remains statistically exceptional) be less than 40 g?
2. The injury criteria, presently in use, are they really justified in biokinetics? We particularly mention the injury criteria of the head. We feel that a particular effort must be devoted to progress in the knowledge of human tolerances.

About these two series of questions, a two ways analysis[1] of road accidents and a thorough research on the informations obtained should provide some more satisfactory answers than those we presently have.

This should not be interpreted as animadversion on applicable rules.

In a way, these ones are measures of conservation – using the terms of lawyers – which are intended to reduce the severity of crashes. However we may not stay at such a point because we are in a prospective line and we must try verifying the value of the solutions adopted, evaluating their merits, and suggesting new possibilities.

For these reasons Peugeot and Renault have undertaken the hereby described inquiry including its methods and first results.

In this course, we only examined highway crashes. Their particularities have indeed seemed to us significant enough to be put to evidence, and their case shall be considered in the future more especially as the number of highways is supposed to be extended in a short time.

1. Method Of Inquiry

At any place where a crash happens, the police take photographs of each vehicle from standardised angles and collect information on which we know by experience that their validity is cancelled by any delay. These are: identification and location, utilization of safety seat belts, aspect and position of seats and seat backs, condition and position of doors, possible ejection. The docket containing these elements is forwarded to the Office of Inquiry.

In the hospital, at the emergency department, each case of injured person is registered on a medical form, which is completed and updated one month later.

Each vehicle involved in a crash is again photographed and analysed by the inquiry staff during the days following the crash.

The dockets concerning crashes involving Peugeot or Renault vehicles are periodically examined and discussed in meetings between engineers of the various departments of the Technical Center. Moreover, some of these informations are shared with those owned by the National Office of Traffic Safety, which is proceeding on its side to a similar inquiry.

2. First Results

2.1 Description of Crashes

2.1.1 Principal Impact Areas

From the 233 crashes first analyzed, the obstacles encountered in the more severe impacts are distributed as follows:

- Vehicle type obstacles 160
- Dead obstacles 65
- No obstacle 8

We find (Table I) 138 front impacts, that is 60 percent (which occurrence is similar to the one observed on the whole road system). On the other hand, the number of rear impacts is much more important – 22 percent (it would be more and more important if we would consider rear impacts resulting in property damages only), in comparison with lateral impacts which occurrence is relatively feeble – 9 percent. Then, we find 9 percent of rollover crashes.

TABLE I

Relative occurence of the principal impact areas

	Principal Impact Areas				
	Front Impact %	Lateral Impact %	Rear Impact %	Rollover/ Crash %	N
U.S.A. (A.C.I.R. 1965)	57	10	9	24	40,000
Great Britain (MacKay 1969)	54	28	9.8	8	812
Highway	60	9	22	9	233

[1] Medical-engineering form

2.1.2 Number Of Impacts Per Vehicle

Vehicles involved in a highway accident are much more likely to be impacted twice or more than once. Moreover in 10 percent of cases, the more severe impact occurs after one or several minor impacts. The selection and the realization of passive restraint systems must be subjected to that evidence (Table 2).

2.1.3 Location of the Distortion Resulting from the Main Impact

In a front crash (statistic is established from 74 vehicles representing the 138 ones of that group), the whole front part of the vehicle is distorted in 16.2 percent of cases (Fig. 1). More often, the distortion is supported only by the left front part (24.3% of cases) or the right front part (23 percent). Accordingly in a rear crash the selected vehicles are more often partly distorted (80 percent) than on the whole width (20 percent of cases). Lateral impacts are not numerous enough to be analyzed so accurately.

We feel it would be profitable considering these remarks, that progress in the area of safety be closely depending from the carefulness of manufacturers and lawmakers in diversifying the future impact test requirements, as much as suggested by actual facts.

This point is essential and must be emphasized. Indeed, once more during this Conference, the existence of a frontal crash test at a high velocity and against a rigid fixed barrier must be justified.

Would a car, having top performances in this type of impact at 80 km/h, be satisfying in the same conditions to non-symetrical impacts supported by a part of its front structure? Of course, we have no reasons to think so.

Accordingly, the aims retained in the ESV program – must they not be reset giving priority to the solutions insuring a better protection in different impact at lower speeds?

A corner impact or a staggered head-on impact, at a 60 or 65 km/h velocity may be considered as an insufficiently ambitious objective, but it would be a very significant test, knowing that mass production vehicles are today very vulnerable to that sort of impact.

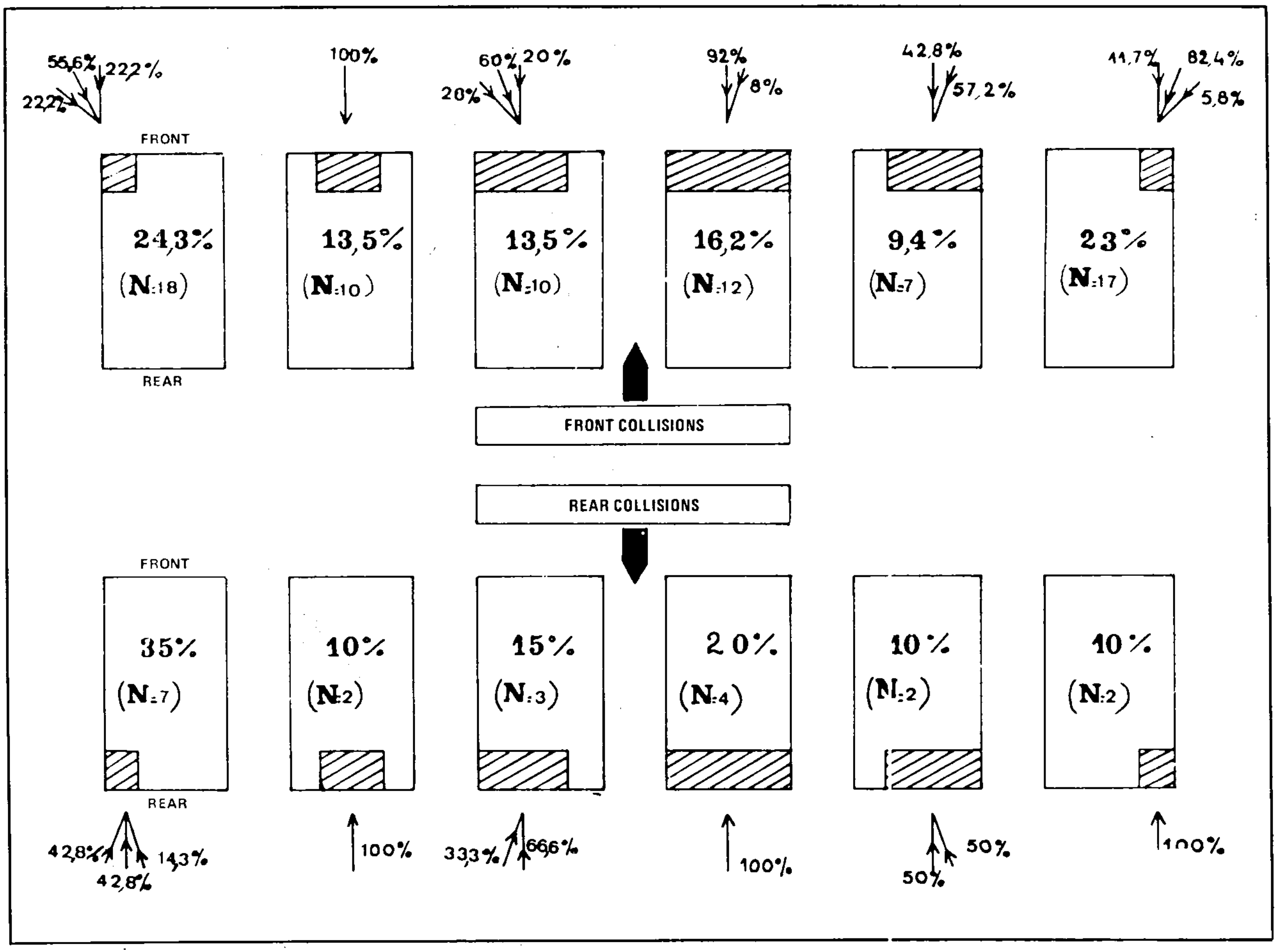


Figure 1

TABLE II

Number of impacts per vehicle crash

	Number of Impacts				
	1 Impact	2 Impacts	3 Impacts	4 Impacts or more	Others
Highway	19% (N=45)	52% (N=122)	18% (N=43)	11% (N=23)	
MacKay 1971(*)	71% (N=75)	17.1% (N=18)	1.9% (N=2		9.6% (N=10)

(*) MacKay's percentages are obtained from 105 severe accidents which are significant of accidents involving severely injured people, in Great Britain.

In fact, we know that most of front crashes are unsymetrical (70 percent) and that one of two is supported by the outer part of the front structure. Especially, in this latter case, distortions are considerable and the passenger compartment remains rarely undamaged, and one can guess the consequences.

Then, the validity of a front crash against a wall perpendicular to the trajectory of the vehicle may be contested, however it remains the main reference in designing cars.

Considering the cost-efficacy ratio, is there not any possibility in changing the criteria of efficacity of a car in a front crash and modifying some design conceptions?

The Peugeot-Renault Association is considering these questions very seriously. We hope the problem would be re-examined.

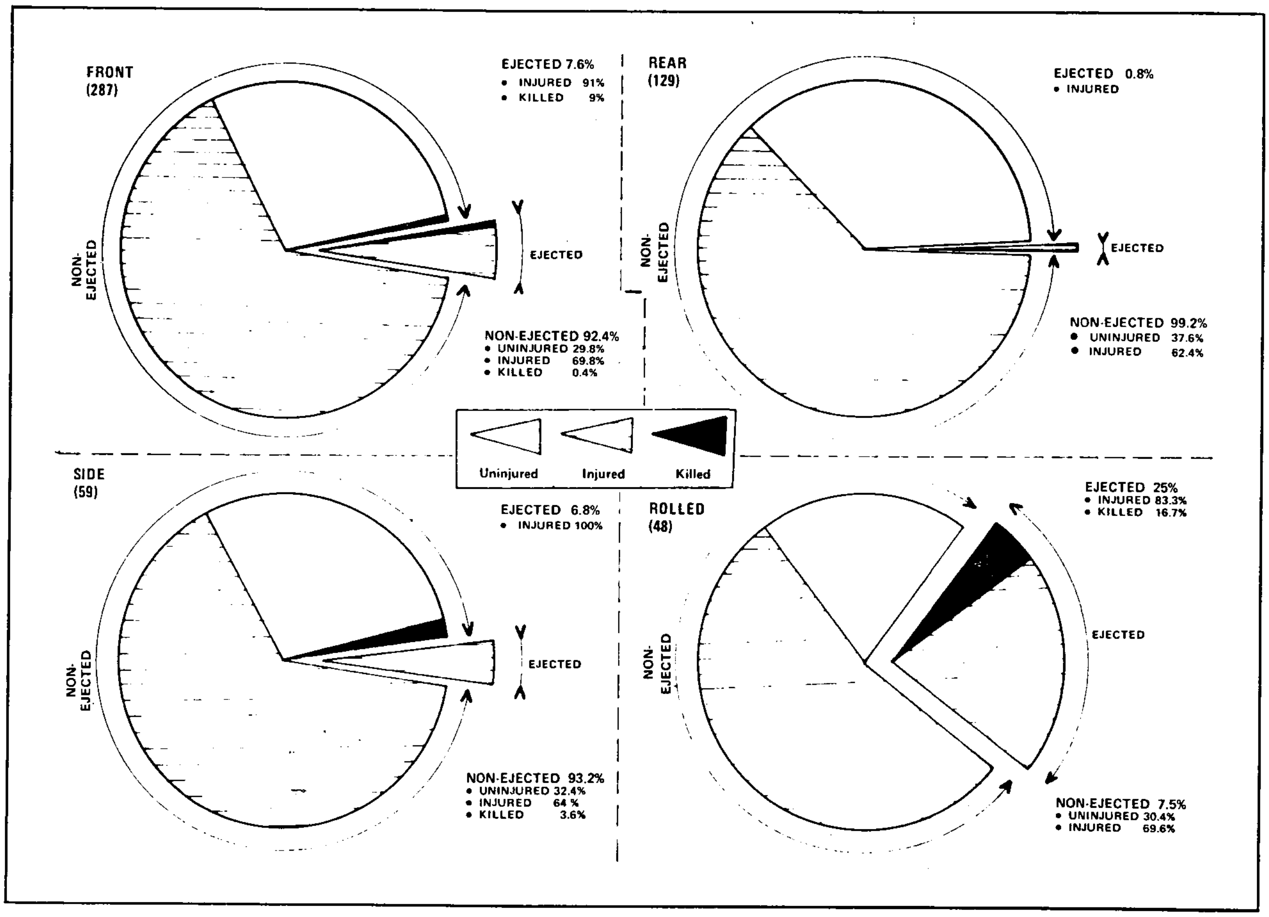


Figure 2

2.2 Occupants

523 occupants have been involved in the above mentioned accidents. Their characteristics are evidenced in Table 3.

TABLE III

Distribution of the number of occupants involved function of the kind of obstacle encountered

Obstacle Encountered	Number of Impacted Vehicles	Deaths	Injured	Uninjured
Vehicle type obstacle	160	6	236	113
Non-vehicle type obstacle	66	7	96	37
No obstacle	7	1	21	6

One can find (Fig. 2) that front crashes and rollover crashes are entailing the more frequent deaths or injuries (in a rollover crash the severity is due to the ejection of the occupants; this appears very clearly in the figure). We did not notice any death in rear impacts, and this is due to the rocking backward of seats, and for rear occupants they were in most cases children who were protected by the rear seat back. In some other vehicles the rear occupants have not been injured owing to the height of rear seat backs that are taller than at the front places.

Many crashes happening at impact velocity of more than 100 km/h, entailed no consequences for the occupants, though the vehicles were in some cases very distorted. We think this happened any time the front occupants were getting in contact with the front part of the passenger compartment at the time when the vehicle impacted a non-rigid obstacle, on which it did not zero its velocity, allowing the occupants to move jointly with the passenger compartment during all the period necessary for the vehicle to stop, either against another obstacle, or in an unrestricted area. Such accidents enable us to understand the usefulness of wide emergency clearing zones, with no rigid obstacles, that should be found on the sides of any road. We are sorry we can make no comments on safety seat belts; 10 to 390 front occupants had fastened their belts. This is a poor sample. It is unquestionable that self-acting belts, with entirely passive operation, will greatly favor the protection of occupants (Ref. 2 and 4); then there is no doubt that the utilization of belts would have avoided any serious or deadly injury. Indeed, lateral impacts, for which belts provide a poor protection, have not proved till now very severe.

Of course, we may not reveal in any circumstance, comparisons that we could have observed in evaluating the superiority of such or such kind of vehicles to another. In the field of safety we may only make a general comment on some aspects.

It appears evidently, from analysis of front crashes, that some driving wheel particular designs can considerably lower the consequences of the second impact. This is evidenced by the enclosed photographs (Fig. 3 and 4). The driver supported only slight thoracic contusions.

However, it must be noticed that important improvements have to be done in the area of the instrument panel. Many severe injuries of legs are due to inadequate location of controls or equipment.

In this field, very significant improvements appeared on new models and others are to be done.

Figure 3

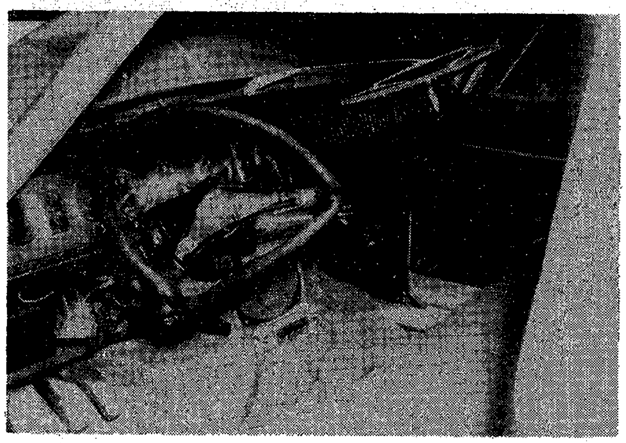


Figure 4

3. Working On Results

It is essential, in order to understand the phenomena appearing in each crash, knowing as exactly as possible the level of severity of the impact; referring to this we can make more progress in evaluating human tolerances and the behavior of the various components of the vehicle which have a great importance in occupant protection.

The index of distortion is devoted to that purpose: deducting from its values, the level of severity of the impact supported by the vehicle described and its occupants, it is profitable comparing these values to those obtained with the same index when applied to a similar vehicle in an impact test, for which the level of severity of the impact is measured accurately (Fig. 5).

Figure 5

This method involves performing crash tests on each model of vehicle Peugeot and Renault. To the whole lot of these impact tests is added the data collected by the three French groups of inquiry, in connection with the Office of Traffic Safety which will take in hand the synthetical work.

4. Conclusions

Concerning the kinds of impact and their severity on highways, it appears speeds belonging to 100 and 110 km/h for the first impact – which involves higher cruising speeds – that occupants may not support severe injuries when some conditions are fulfilled:

- The car must stop far from the obstacle encountered (this implies it is movable and can be distorted, and a wide unrestricted area on the road side).
- The occupants must not be ejected from the car.
- The seats must be reinforced and equipped with head restraints avoiding any impact of front occupants on rear occupants or impacts against the inner surfaces in a rear crash, or rear occupants swinged to the front and impacting front occupants in a front crash.

The first results obtained in this bi-disciplinary investigation have no statistical value, owing to the low sample. However, it allows us contesting the value of some of the ESV requirements.

From that comparison:

- ESV requirements (and applicable rules), and
- Real crash conditions,

it results that inquiry on crashes must have top priority.

Evidently, it must direct the development of rules and corresponding tests.

Finally, the data collected in bi-disciplinary investigations (for which the number of samples is necessarily low) could be used in verifying the value of the information collected in wide inquiries, of the nation-wide type performed by the Police, which are necessarily more superficial.

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FUTURE LEGISLATION WITH REGARD TO ESV SPECIFICATIONS

Mr. Wolfgang Rosenau and
Mr. Ulrich Seiffert
Volkswagenwerk A.G.
Wolfsburg

Crash Worthiness Seminary

1. Introduction

Ever since automobiles were first built, the various legal bodies have had an influence upon the design of motor vehicles to a fairly extensive extent through the issue of relevant legislation. In Europe in addition to the national law-issuing authorities there are also the organisations of the ECE and the EEC. Technical reglements for type approval of vehicles are issued by the ECE and directives for common market construction and use permits are released by the EEC with the object of elimination of trade restrictions.

In the United States, in addition to the licensing regulations of the various individual states, there is also legislation on vehicle safety from the National Highway Traffic Safety Administration. Further to this, various countries are cooperating internationally within the framework of the ISO with the aim of achieving uniformity of testing.

The details which follow mainly cover legislation on vehicle safety taking into account the requirements and development work on the experimental safety vehicle. It is of course essential to study the present position of the legislation before considering the future of the ESV project. There are considerable differences in the issuing of laws in the United States and in Europe. The procedure in the USA is as follows:

Before a new law is passed the NHTSA asks for the opinions on various points of the problem (e.g., requirements on brake equipment) from the industry, from the universities and independent experts by issue of a docket. Following receipt of these opinions which are frequently based on research work performed on behalf of NHTSA, the parties interested are again given an opportunity of comment at various stages by way, for example, of a Notice of Proposed Rule Making. When all commentary has studied the law can then be passed. NHTSA legislation is on a federal basis and supersedes individual state laws existing on the same subject.

In Europe an attempt is being made to obtain uniformity of vehicle type approval on an internal basis within the framework of the ECE and EEC. It is not possible to obtain a direct opinion from the individual manufacturer on the proposals put forward by these organisations. In the working groups of the governmental representatives from the traffic ministries of the associated states in the WP 29 of the ECE, the industry is only represented by observers. In the advisory stage and passing of the EEC directives the industry is almost without any influence. Since it is merely represented on an observer basis the need to incorporate the common market directives into national legislation of the member states of the community presents a difficult situation. Because it is still necessary to establish a reasonable procedure, the preparation of various items of legislation has progressed so slowly that a number of governments have passed the drafts of the regulations as law in their countries. In some cases work has been and still is duplicated, for example, on fuel tank and brake system legislation.

The number of countries associated within the ISO framework is even greater. In consequence the passing of internationally valid testing procedures suffers delay due to negotiations which are frequently long and drawn-out.

When comparing the systems in the USA and Europe it would seem, at a first impression, that the American procedure is the better of the two. In the recent past, however, it has been shown that even this system is often not the ideal one and that the NHTSA had published such a large number of proposed new, basic laws which did not appear to have been correlated internally in all cases and that the automotive industry has been overburdened by a time schedule of requirements which are not even precisely formulated. Because of this the NHTSA has gone over to development of a planned schedule detaching the essential draft legislature and the deadlines envisaged. This plan is supposed to be still in front of ESV conference.

What is needed in the near future is internationally uniform legislation from a committee which could perhaps be divided into 2 blocks, e.g., USA and Europe.

As an interim solution it is necessary that the various committees or countries issuing laws find out where and what regulations already exist before an act is passed in order to avoid duplicated work or laws which only differ in the actual wording. International issue of legislation should then supersede national promulgation of laws. To sum up it may be reiterated that

a. internationally uniform laws are necessary, a question still to be considered being whether it is necessary to separate this into USA – Europe because of different traffic conditions and
b. national legislation should then be lifted.

2. Relationship between the ESV and Legislation

A number of the draft laws contain some requirements which are either design regulations or regulations which are not particularly effective or which cannot yet be complied with because of lack of investigation. In the building of the experimental safety vehicles one of the points to be aimed at should also be to demonstrate the limits of what is technically possible with due consideration to what is still economically acceptable. This places two further requirements with regard to legislation, these being:

a. a law should be passed only when technical solutions are available and
b. when new legal stipulations are being established the cost to benefit ratio must be considered.

The ESV requirements have been detailed by the various governments in cooperation with the industry and have been discussed to a great extent on the agenda so far. The fact that different requirements are detailed in the German Specifications as compared with the American ones typifies the differing attitudes on the subject of vehicle safety. The main differences concern the responsibility of the driver of the vehicle and the passengers. In Europe the opinion is held that the driver of a vehicle is responsible for his vehicle and his behaviour in traffic, whereas in the United States the principle is that, even in the event of gross negligence on the part of the driver, both he and his passengers should have full protection. This is clearly illustrated by taking the example of the restraint equipment. In the United States introduction of a passive passenger protection system is being demanded whereas in the German Specifications there is the alternative of an active restraint system. This example alone is characteristic of the European attitude quite apart from the higher benefit to cost ratio associated with an active restraint system. Some other differences in the official specifications are detailed below.

1. Range of body sizes in seating arrangements: USA Specifications: 5% female to 95% man VDA Specifications: 5% female to 95% man for front seat to 50% man for rear seat
2. Depression of passenger cell: USA Specifications less than 3" VDA Specifications: Assessment with a dummy
3. Indirect field of vision:
   USA Specifications: 24 degrees horizontal, 8 degrees vertical
   VDA Specifications: 24 degrees horizontal
   USA Specifications: ground level visibility at 50 feet (△16 m) (no horizontal limitation)
   VDA Specifications: ground level visibility at 15 m, 12 degree range
4. Load assumptions in vehicle body design:
   USA Specifications: e.g., longitudinal brake force 2.5 + 0.5 g
   VDA Specifications: no stipulations
5. Steering effect:
   USA Specifications: transverse acceleration possible 0.4 g
   VDA Specifications: no stipulations

We hope that during this conference the differences will be eliminated.

A further target of ESV development is to demonstrate the technically feasible limits as already mentioned. In the requirements, the design specifications section has been deliberately kept as small as possible. (Ratio of design specifications to performance specifications is 1 : 3 in the USA and 1 : 3 in Germany.) It would of course be impossible to dispense altogether with design stipulations e.g., signal arrangements, but the proportion should be kept down to a minimum in order that the manufacturer may select from the possible solutions and that technical progress is maintained. The list of requirements should therefore call for performance stipulations and avoidance of rulings on design.

3. Realisation of ESV specifications in Series Production Vehicles

This problem which is anything but a simple one is directly associated with legislation. The question may be subdivided into a financial one and one of time provided that it can be assumed that the technical problems in the development of the ESV can be solved. It would not be of benefit to anybody if, to go to the extreme limits, the death and injury rate for car passengers were to be lowered by putting motor vehicles beyond the reach of a high proportion of owners. Such requirements as that of a 50 mph barrier collision test ought to be carefully reexamined to see, for example, whether the cost of increasing the chances of survival by raising the test speed from 60 kph or 37 mph to 50 mph involves benefits which are reasonably proportionate to the costs. The benefit to costs ratio should be considered in the setting of any requirements. The degree of urgency of the requirement also provides a direct relationship for the time needed to incorporate the results of the research work into the line produced vehicle. It is therefore important that there be clarity over the timing of incorporating the knowledge gained in ESV development into series production vehicles.

Series production vehicles may well have to be basically redesigned in many ways. It is therefore necessary that sufficient time be allowed when the resultant legislation is put into effect.

In conclusion, it is possible to define various points the priority of which is impossible or very difficult to lay down because they are more or less inter-related.

1. Internationally uniform legislation is necessary
2. Lifting of national legislation
3. Passing of a law only once technical solutions are available
4. Consideration of the benefit to costs ratio
5. Development of performance requirements and avoidance of design stipulations
6. After passing of a law sufficient time must be allowed for it to be put into effect in series production
7. The fact that road traffic involves vehicles of vastly differing designs must be duly considered by the legal authorities

The entire work on the Experimental Safety Vehicle is only of purpose provided the above points on legislative activities are regarded, that quoted under 7 not having been taken into account so far in the issue of legislation.

SECTION 4

ACCIDENT AVOIDANCE SEMINAR

Part 1 — Introduction

Mr. Francis A. DiLorenzo, *Chairman*

Part 2 — Visibility

Dr. Hermann Bruns, *Germany, BMW*
Mr. R. Schmidt, *Germany, VW*

Part 3 — Vehicle Steering and Handling

Mr. Vor Der Brueck, *Germany, Ford*
Mr. Berlioz, *France, O.N.S.E.R.*
Dr. K. Enke, *Germany, Daimler-Benz*
Mr. Yasuhiko Fujiwara, *Japan, Nissan Motor Co.*
Dr. K. Enke, *Germany, Daimler-Benz*

Part 4 — General Topics Concerning Accident Avoidance

Mr. Iichi Shingu, *Japan, Toyota Motor Co.*
Mr. W. B. Haro Kopus, *USA, Bendix Research Lab Laboratories*
Mr. F. A. DiLorenzo, *USA, Office of ESV/DOT*

Part V — Vehicle Braking

Mr. R. Cochrane, *United Kingdom, Girling*
Mr. F. A. DiLorenzo, *USA, Office of ESV/DOT*

SECTION 4

PART 1 INTRODUCTION

Mr. Francis A. DiLorenzo,

Chairman, Accident Avoidance Seminar

Part I - Introduction

Opening Remarks

Good afternoon Gentlemen, I am Mr. Francis DiLorenzo and it is an honor and pleasure to chair the Accident Avoidance Seminar. We have received an excellent response to our call for discussion papers and therefore as you can see from the agenda we have a very busy afternoon.

I appreciate that most of you had only a short time to review the papers that will be presented here today and regret that we were unable to exchange papers earlier. Perhaps at the next conference more time will be available.

We will undoubtedly be discussing topics this afternoon that are close to many of us and perhaps even controversial in nature. I would hope that through this free exchange of information, we will better understand each other and improve our research efficiency. We are involved in a scientific endeavour that is technically changing very rapidly. This factor alone necessitates that we communicate freely and exchange ideas.

For the discussions of the papers to be presented, I request that all questions be held until the final paper of each major topic has been presented. For relaxation and further informal discussions among yourselves we have scheduled a short break about midway through the seminar. I would also like to add that for those who do not get a chance to discuss everything they would like to today, there will be a second opportunity tomorrow morning during the seminar summations.

Without further delay then, the first topic this afternoon is a paper on visibility by Dr. Bruns from BMW, Dr. Bruns – – –

SECTION 4

PART 2 VISIBILITY

RANGE OF VIEW, STOPPING DISTANCE AND DRIVING SPEED ON CURVED ROADS

Dr. Hermann Bruns
Bayerische Motoren Werke A.G.
Munchen

Accident Avoidance Seminary

Modern road vehicles allow high curvature-speeds, which may be much higher than the velocity, the road was designed for. There is the problem, that the range of view is not relative to the required stopping distance. A model should give some results in this theory.

1. Introduction

Contrary to railroad vehicles, the driver of a road-vehicle has a broad range for choosing his driving speed. Except the driver's qualities, the physical borders are the car itself and the road conditions (rain, snow, mist etc.). Both limitations cannot be separated exactly, because for each driving situation, both, vehicle and road have to be considered together. In most cases, the limitation is given by the form of the road, the traffic-density and other environmental influences.

Each road is designed for a certain velocity. It is designed in such a way, to give a good compromise between the expected traffic and the resulting costs. For normal environmental conditions it may be overstepped without any danger.

Table 1 and 2 show an extract of the German instructions[1] for building main roads, concerning the influence of surroundings and radius of curvature.

It will be the goal of each driver, to reach his designation as fast as possible, so he usually will overstep the designed velocity[2], especially in curves. Therefore it's necessary to give a relation between radius of curvature, stopping distance, range of view and driving speed.

Table 1

Designed velocities (km/h) concerning the difficulties of the landscape [1].

landscape		anticipated load factor (vehicles / day)			
		≤1000	>1000-2000	>2000-3000	>3000
I.	Flat	50	60	80	100
II.	Flat and hilly	40	50	60	80
III.	High-lands	30	40	50	60
IV.	Mountain-Terrain	30	30	40	50

Table 2

Minimum radius of curve for different designed velocities [1].

designed velocity	minimum radius of curve	lateral acceleration
v_e (km/h)	R_{min} (m)	b_q (m/sec^2)
30	35	2,0
40	70	1,78
50	120	1,6
60	180	1,54
80	350	1,41
100	600	1,28

2. Relation Between Driving Speed and Stopping Distance.

At first it would be interesting to know the relations between driving speed and stopping distance, without considering radius of curvature, Figure 1,[3]. For comparison you see the required stopping distance for sufficient range of view s_h for RAL[1].

In a curve it is not possible, to brake with maximum deceleration b±4. The maximum force between a rolling wheel and the street is limited by the wheel load G and

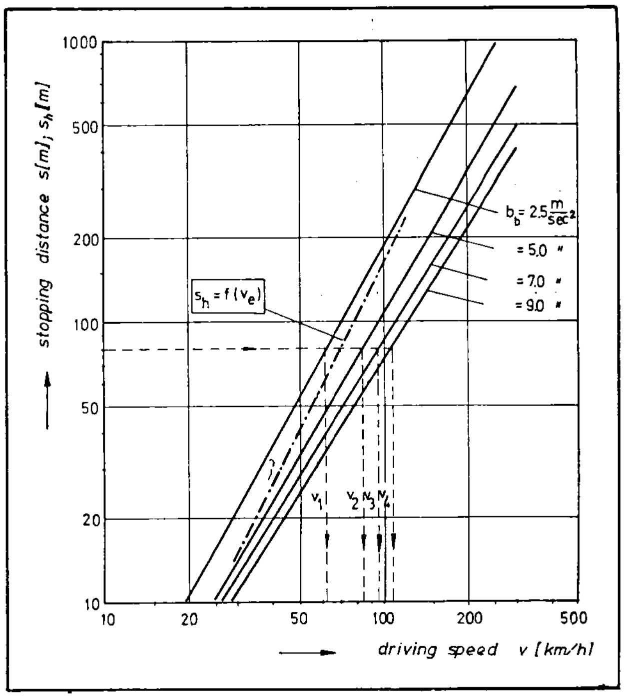

Figure 1 – Relation between driving speed v and stopping distance s, respectively range of view for stopping s_h.

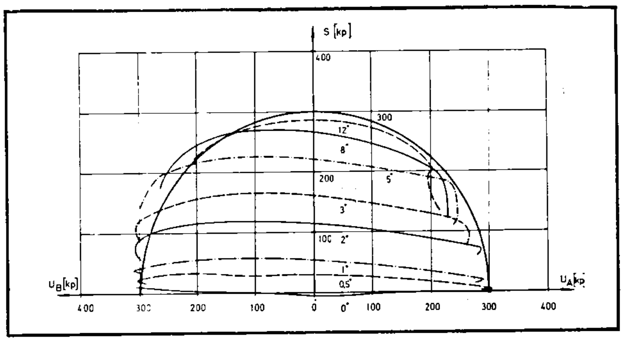

Figure 2 – Lateral force S of a radial – tire as a function of horizontal forces U for different slip angles[5].

the friction coefficient μ. The division in lateral and horizontal forces is given by a special diagram for each tire, Figure 2[5,6]. the relation between maximum lateral acceleration b_q and maximum deceleration b_b can be described by a circle-equation. Supposing the same friction coefficient in radial and axial direction, you get the following formula

$$S = \mu \cdot G = b_q \cdot \frac{G}{g} \qquad (1)$$

$$\frac{S}{G} = \frac{b_q}{g} \qquad (1a)$$

and

$$U_B = \mu \cdot G = b_b \cdot \frac{G}{g} \qquad (2)$$

$$\frac{U_B}{G} = \frac{b_b}{g} \qquad (2a)$$

$$\left[\frac{b_{qmax}}{g}\right]^2 + \left[\frac{b_{bmax}}{g}\right]^2 = 1 \qquad (3)$$

With high lateral accelerations there is a deviation from course[7].

3. Relation Between Driving Speed and Radius of Curve.

If a vehicle is going on a horizontal circular path with radius R having a driving speed v in direction of the tangent to course, there is a lateral acceleration

$$b_q = \frac{v^2}{R} \qquad (4)$$

For maximum lateral acceleration b_q = 9,81 m/s² there are maximum velocities v_{max} as a function of radius of curve R as shown in Figure 3. For comparison measured driving speeds in curves v(±10%) are added[8]: The resulting lateral accelerations are

$$\bar{V}_m \text{ (Km/h)} = 25 \cdot R^{0.2} \text{ (m)} \qquad (5)$$

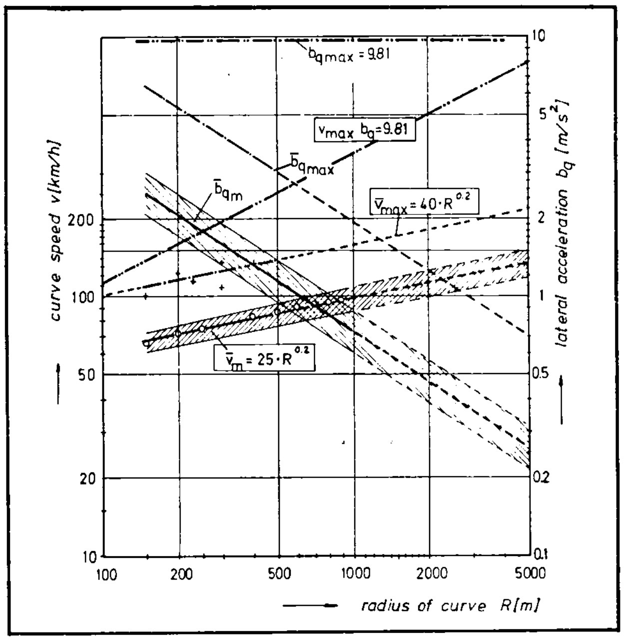

Figure 3 – Relation between driving speed v, radius of curve R and lateral acceleration b_b v_m mean speed [7] for normal drivers, b_{qm} relation lateral acceleration.

v_{max} racing speed, b_{qmax} relating lateral acceleration. V_{max} driving speed for maximum lateral acceleration 9,81 m/s² = constant.

$$\bar{b}_{qm}(m/s^2) = \frac{48.3}{R^{0.6}\,(m)} \qquad (6)$$

A skilled driver is good for higher driving speed in curves, see v_{max} in Figure 3.

$$\bar{V}_{max}(Km/h) = 40 \cdot R^{0.2}\,(m) \qquad (7)$$

$$\bar{b}_{qmax}(m/s^2) = \frac{123.4}{R^{0.6}\,(m)} \qquad (8)$$

(That means 1.6 times the velocity and 2.56 times lateral acceleration of a normal driver.)
According to the utilized lateral acceleration, remains a braking deceleration b_{bmax}

$$\frac{b_{bmax}}{g} = \sqrt{1 - \left[\frac{b_{qmax}}{g}\right]^2} \qquad (9)$$

Supposing an extreme way of driving, you get a relation between the maximum possible braking deceleration and radius of curve by using equation[8] and [9], Figure 4.

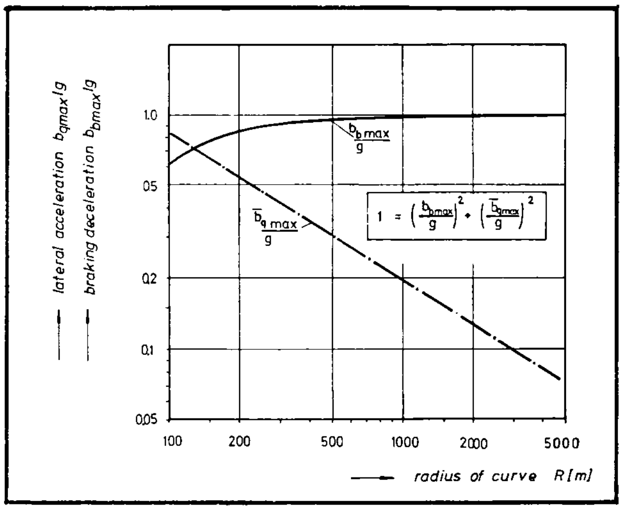

Figure 4 – Functional relation of lateral acceleration and braking deceleration from radius of curve, calculated from equation[8].

$$\frac{b_{bmax}}{g} = \sqrt{1 - \frac{12.5}{R^{0.6}}^{2}} \qquad (10)$$

Equation[10] equals 0 for $R^{0.6} = 12.5$ that is R = 67.3 m. In the range of R = 0 ÷ 67.3 m the driver used the full lateral acceleration $b_{qmax} = 9{,}81\ m/s^2$.

4. Radius of curve and range of view.

On an even road the range of view only depends on the radius of curve.

Figure 5 shows the model for a vehicle in a curve. The distance between the driver's eyepoint and the inner boundary may be a (AD).

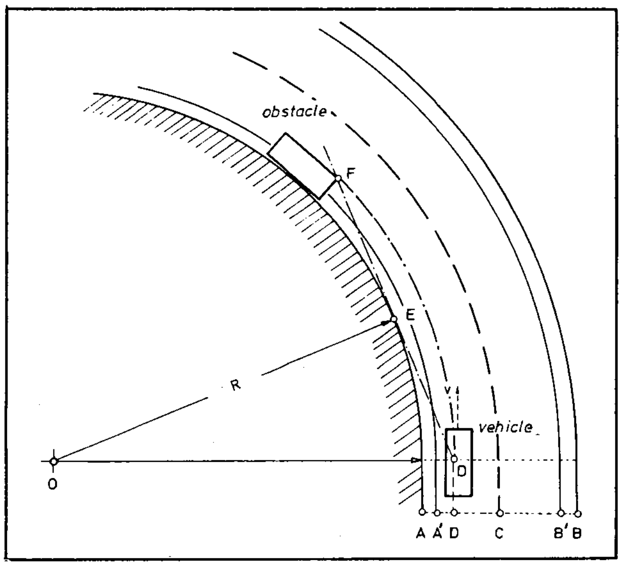

Figure 5 – Vehicle driving a curve:
D: eyepoint of the driver, DF = 2 DE distance d to the obstacle. AD: distance a of driver's eyepoint from the inner border of the road; AB: width b of the road; AA': width of the marginal track; R: radius of curve.

For simplifying, the distance DF equals twice the distance ED with

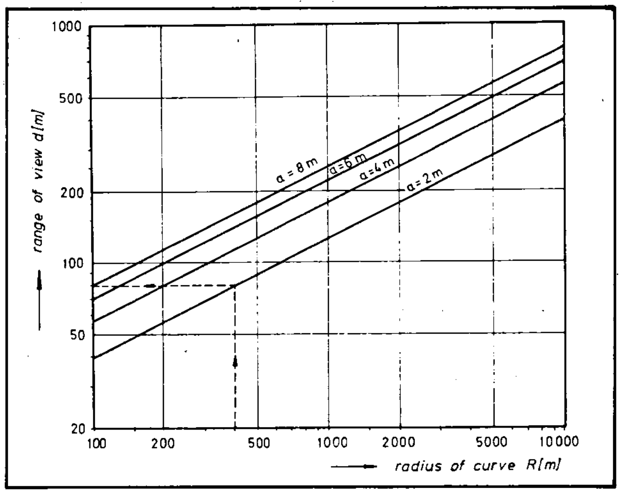

Figure 6 – Dependence of range of view from radius of curve R with eyepoint-distance a as parameter.
with the eyepoint a as a parameter. For example: as-

Figure 6 shows these relations in logarithmic scale, suming a_{min} = 2m and R = 1000 m you get d = 126.5 m, for a_{max} d = 255 m. This influence gets important, if a car overtakes another one in a curve and has to change the lane.

$$\overline{DF} = d = \quad 4a \cdot (2R + a) \qquad (11)$$

5. Correlation Between Driving Speed, Range of View and Stopping Distance in a Curve

The problem exists in finding the right driving speed for the necessary ratio of range of view to stopping distance. Claiming, that the range of view d should be never less than the stopping distances, you get the resulting driving speed for each radius from the shown figures, Figure 7. The range of view for a certain radius of curve, you get from Figure 6. With the condition

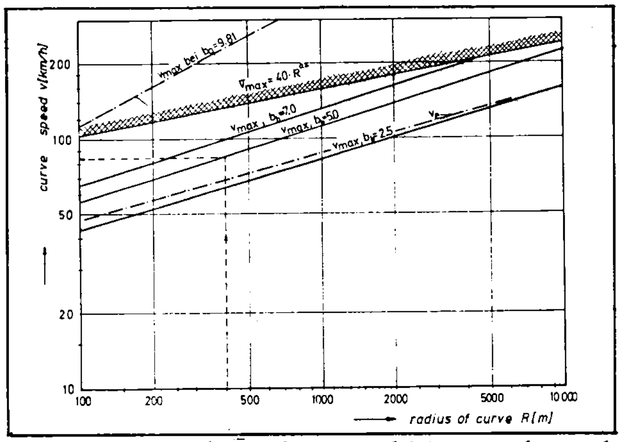

Figure 7 – Relation between driving speed v and radius of curve R, depending on the range of view for different braking decelerations b_b, with constant eye-point distance a_{min} = 2 m.

you get from Figure 1 the concerning driving speed v_{max}. Braking deceleration b_b is the parameter. The limitations in Figure 7 are given by the velocities, driven by skilled drivers. An example may show the way from Figures 1, 6 and 7. For a radius of curve R = 400 m and braking deceleration b_b = 5.0 m/s^2 you get an allowable driving speed of 84 mk/h, if the range of view is limited by for example walls on each side of the curved road.

A BRIEF SURVEY OF REARVIEW SYSTEMS

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Accident Avoidance Seminary

The field of vision which may be obtained through rearview mirrors may be demonstrated by reference to three rearview systems and the advantages or disadvantages of these systems explained. In addition to this these systems are compared with the essential requirements of a rearview system as laid down in the VDA, ESV and docket specifications.

The three systems comprise

1. a conventional rearview system consisting of an interior mirror and an outside mirror on the driver's side,
2. a plane mirror which projects with one half above the roof the other half being within the vehicle body and
3. a periscope system.

Before going into detail on the systems, reference should first be made to some of the optical physiological features of our organs of sight. In the act of seeing, one very important factor is the time which elapses before the eye can again see clearly following a change in the direction of view. In today's dense traffic conditions it is essential to locate the mirror arrangement in such a way that the time which it takes to see a clearly defined picture in the rearview mirror is as brief as possible. The total delay is made up of the diversion of the direction of vision to the mirror and the time taken for accommodation, this term being used to imply the time required to recover full focus. To quote an example, under conditions of high light intensity, the time taken to achieve full clarity of vision when looking away from the instrument panel to a far distant point on the road is in the region of one second. When the light intensity is low this time is vastly increased.

Basically it can be said that the further the rearview mirror is from the normal direction of vision the longer the delay. Because of the focussing properties of the eye, a rearview mirror should be located within a conical space of not more than 30 degrees from the normal line of vision. This not only cuts down on the rearview time, it also means that both the mirror and the normal direction of vision are still inside the peripheral 10% vision area. This then ensures that, even while glancing into the rearview mirror, large obstacles in front of the vehicle can still be recognized. Conversely while looking in the normal visual direction, vehicles approaching from behind and coming into the range of the rearview mirror are noticed *without* concentrating on the mirror.

Because of the physiological optics of the eye an image which is projected on to the periphery of the retina is more likely to be unnoticed the less its movement relative to the retina and the further it is from the normal visual axis. Since the relative movement of following vehicles is frequently very slight, if the rearview mirror is located *far* away, they are relatively easy to lose in the local adaptation function even although they may have quite noticeable features.

Figure 1 – The first illustration diagrammatically shows a conventional rearview system comprised of a plane interior mirror and a plane exterior one. The fields of view have been arranged in accordance with the VDA or ESV specifications. The positions and heights of the fields of view, Q, SR, SL, TR and TL conform with the specifications outlined in Docket No. 72-3a, Notice 1. The size of the interior rearview mirror should be such that as much as possible of the vehicle on which it is mounted – preferably the entire rear window section – should be visible in the interior rearview mirror. This ensures that the relative positions and directions of the vehicle and the vehicle behind may be viewed and makes it much easier to estimate distances.

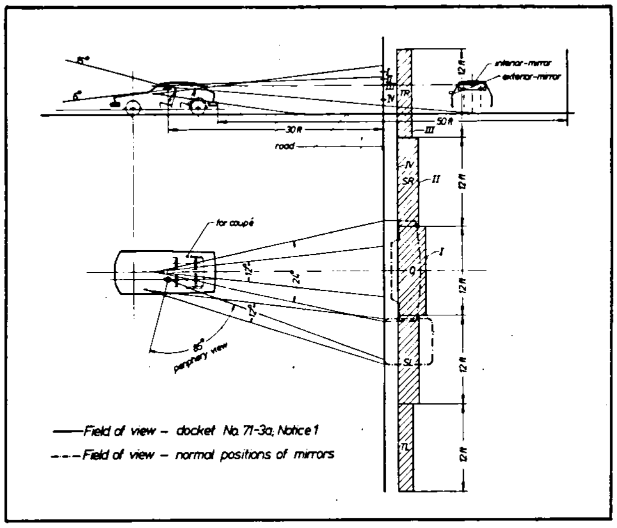


Figure 1

The dimensions of the interior mirror are 195 x 55 mm and those of the outer one 175 x 120 mm. In this case the exterior mirror is not within the 30 degree conical range, the reason being to keep the field of vision as big as possible and to overcome the blind spot with the aid of the peripheral vision.

The main advantages of the conventional rearview system are

1. The good field of view directly behind the vehicle, the surface of the road being viewable 36' (10.90 m) behind the tail-end of the vehicle;
2. the relatively good view to the side when the exterior mirror is appropriately mounted on the driver's side of the vehicle, the road surface then being seen 12' (3.64 m) to the rear of the car, which is a very important feature in being able to see cyclists or motorcyclists in the process of overtaking; and
3. the *low* technical outlay.

The disadvantages experienced are:

1. limitation of the horizontal field of vision by the rear roof pillars; and
2. slight obstruction of view by the rear headrests. These visual obstructions are however not within the range prescribed in the docket.

The requirements laid down in the VDA and ESV specifications in respect of the horizontal and vertical angle ranges are complied with. (VDA and ESV demand a 24 degree horizontal field of vision through the rear window and that the road surface be visible from a point 15 meters behind the rear end of the vehicle to the horizon). The requirements placed on the exterior mirror (12 degrees horizontal field of vision, visibility of the road surface from 35 feet behind the mirror) are fulfilled without difficulty. In the arrangement illustrated the road is already visible at 19 feet.

Figure 2 – The second picture shows the principles of a rearview system involving a plane mirror with one half above the roof and the other within the vehicle.

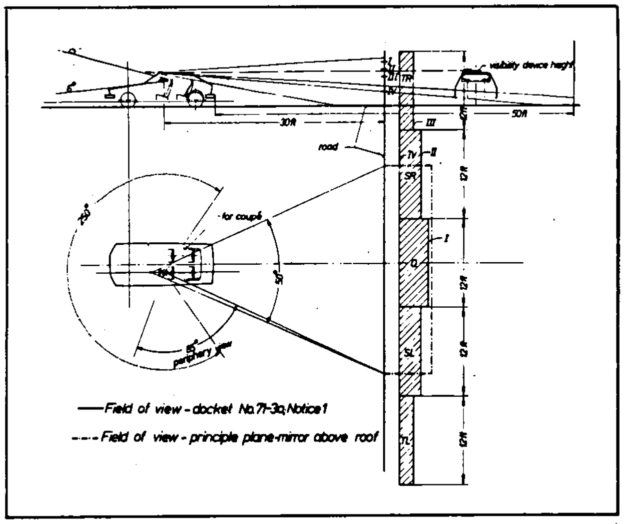


Figure 2

The principal advantages of this system are:

1. Very good visibility directly behind the vehicle (the road can be seen 17 feet beyond the rear limits of the car);
2. The wide horizontal angle of 50 degrees in this case;
3. No obstruction to vision by headrests.

The disadvantages found are:

1. The blind spot behind the car due to the roof shape;
2. The inadequate visibility sidewards;
3. The height of the viewing arrangement in the vehicle resulting in severe impediment of forward vision. It is necessary to change the direction of vision by more than 30 degrees;
4. The *high* technical cost.

Although this system fulfills the requirements in the dockets from 1 Jan. 1974 to 31 Dec. 1976 problems are still presented by the sidewards visibility. The only remedy here is an external mirror. Apart from the important VDA and ESV specification requirements in respect of visibility to the side the remainder of the requirements on rearwards visibility are complied with.

Figure 3 – The third illustration demonstrates a periscopic rearview system.

The essential advantages this offers are:

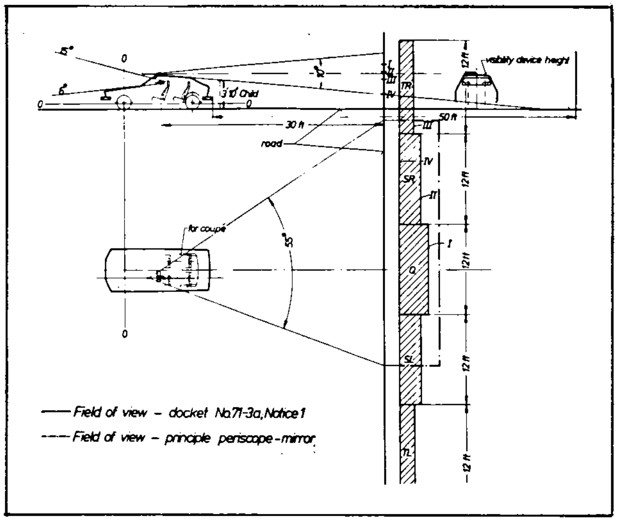


Figure 3

1. The wide horizontal field of vision (55 degrees) and
2. no headrest obstruction.

The disadvantages include:

1. The view directly behind the vehicle is very limited, e.g., a child of 3'9" (1.15 m) immediately behind the car would not be seen at the road, surface only becomes visible at 44 feet (13.2 m). Reversing is safe only if the driver turns round.
2. Inadequate visibility sidewards close to the vehicle. The periscopic system also does not overcome the blind spot on the left side of the vehicle.

Although the horizontal field of vision can be extended through a periscopic system it is necessary to ask the basic question as to whether or not the docket requirements in respect of the horizontal field of vision are really advantageous and the high cost of a periscope system really justified, since the disadvantages of that system (poor visibility directly behind the car, poor sidewards visibility directly adjacent to the vehicle) are not present with the interior mirror combined with an outer mirror on the left: In addition to that, the horizontal field of the interior mirror can be extended by appropriate design of the rear roof pillars.

In light of the features presented, we consider than an interior mirror and a left outside mirror is the right solution on the ESV.

SECTION 4

PART 3 VEHICLE STEERING AND HANDLING

THEORETICAL AND EXPERIMENTAL INVESTIGATIONS FOR EVALUATION OF VEHICLE HANDLING QUALITIES

Mr. R. Vor Der Brueck, Ford of Germany

Objective

In the "technical requirements on experimental safety vehicles" the VDA committee "safety car" has established various requirements on vehicle handling behaviour emphasizing the particular importance of handling qualities for traffic safety.

At present, during the development of a motor car the tuning of the handling performance is based mainly on subjective evaluations although there has been many efforts to establish objective criteria on the vehicle handling qualities. Efforts are made recently to establish test methods on vehicle handling behaviour but the results of at least a part of these test methods are strongly influenced by the skill of the test driver.

Generally valid evaluation methods should be based therefore on the objective measurement of vehicle response for steady state as well as for transient vehicle handling behaviour. The test results gained from these measurements must be related to the subjective assessments in order to obtain results which are evaluated by the human response factors.

Based on criteria for evaluation of vehicle handling behaviour gained in such a way, the influence of different design parameters and of tire characteristics on handling qualities could be investigated already when the first layouts for a new model are available, in order to optimise the basic design.

Method Of Investigation

1. The Mathematical Model Of The Car

For the prediction of vehicle handling behaviour a mathematical model has been developed and a digital computer program for simulation of vehicle handling response has been established. In order to have a realistic mathematical approach the following parameters additionally to the main vehicle data were included in the investigation: the steering elasticity, suspension kinematics, the non-linearity of spring-rates and shock absorber characteristics, and the non-linear relationship between the dynamic wheel loads and tire cornering characteristics.

Either a steering input of arbitrary shape or a side wind gust can be chosen as the exciting function.

2. Test Equipment

For validation of theoretical results road tests have been carried out and the recorded test data have been compared with theoretical results. During the road tests the following vehicle response functions have been recorded:

- the lateral acceleration and the roll angle using a "stabilised platform"
- The yaw velocity with an angular velocity gyroscope
- the yaw angle with a position gyroscope
- the position of the steering idle arm as measure for steering wheel and road wheel angles

3. The Test Car

As test car a medium size sedan has been used which was equipped to this purpose with an adjustable link-controlled rear suspension.

The adjustable solid rear axle allows a considerable change of the understeer character of the test car.

The rear axle consists of two longitudinal links, a torque reaction bar, a Panhard rod, stabilizer and coil springs.

Different hinge point heights both on body and on rear axle for the longitudinal links allow to change the roll steering effect of the rear axle. Roll centre height can be changed by using different hinge point heights for the Panhard rod, roll couple distribution is varied by using different stabilizer bars.

4. The Road Tests

For validation of the computer results the mentioned test data have been recorded for the two following test manoeuvres:

- Entry into circle
- Slalom test with different wave lengths

The road tests have been carried out for a number of modifications on the test car.

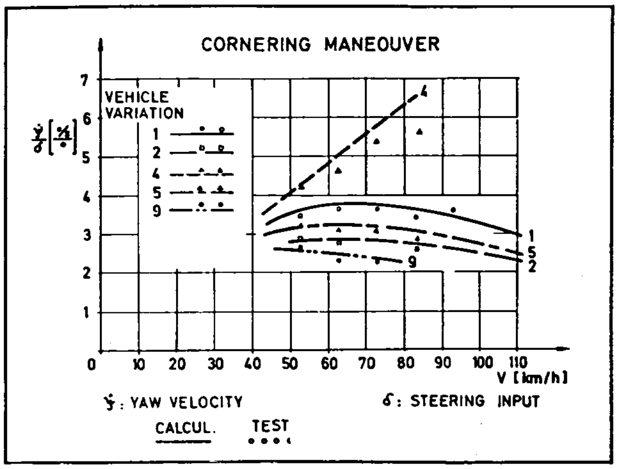
In order to find a relation between the subjective assessments of the driver and the results of calculations and measurements – that means with the response functions of the car – all investigated modifications on the car were evaluated subjectively by a driver team.

Results

1. Entry Into Circle

The test manoeuvre "entry into circle" was carried out as follows: Under the initial conditions of a straight ahead drive with various constant speeds the car was subjected to a constant steering input and the steering wheel was held constant until steady state cornering condition was reached.

The following Slide 1 shows the yaw velocity gain; that is yaw velocity divided by steering input angle,



Slide 1

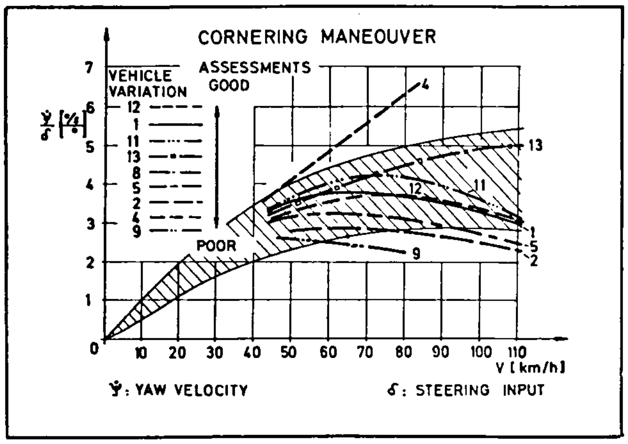
versus vehicle speed for steady state cornering condition.

This diagram is explained on the following example. For steady state cornering the yaw velocity is determined as the ratio of vehicle speed to turn radius. For the same vehicle speed and the same radius the car with a stronger understeering tendency requires a greater steering wheel input, the ratio of yaw velocity to steering angle of road wheel becomes smaller.

With increased understeering tendency of the vehicles the yaw velocity gain, the ratio of yaw velocity to steering input, becomes smaller.

The curves in the diagram are derived from computer calculations, the dots belong to the test results and the figures indicate the various vehicle modifications. The conformity between results of calculations and tests have been found good, only for Vehicle variation No. 4 with more oversteering tendency was the deviation of tests from prediction larger.

In the next Slide 2 all results are compared with the subjective assessments of a driver team.



Slide 2

First vehicle variation 1 with the original condition was rated as the best one, the most oversteering vehicle 4 and especially strongly understeering vehicle 9 have been judged to have the poorest handling qualities.

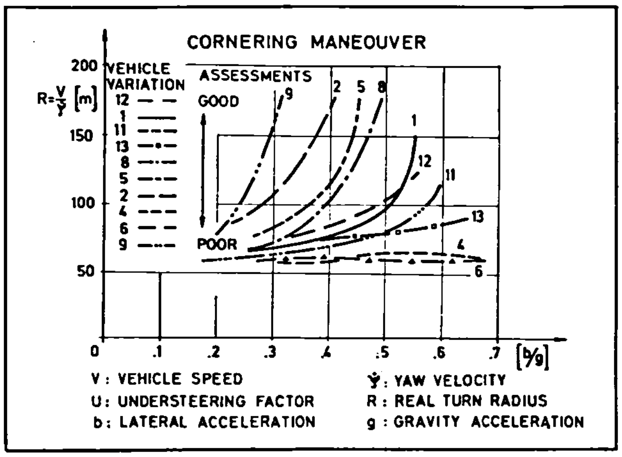
Based on computer calculations it was tried to achieve a further improvement in the subjective rating of handling qualities with small modifications on vehicle 1. This was succeeded with vehicle variation 12.

Due to the correlation of test and calculation results with subjective assessments the hatched area has been settled as the acceptable range.

The following Slide 3 shows the ratio of vehicle speed to yaw velocity, which is corresponding to the turn radius for steady state cornering, versus lateral acceleration divided by gravity acceleration. The steering input was the same for all vehicle variations.

For the same steering input and increasing vehicle speed the turn radius is grown up rapidly with an increase in understeering tendency. From this diagram an "understeering factor" for steady state vehicle cornering can be derived, similar to Hamann's definition.

The understeering factor U is defined as the gradient of the turn radius versus lateral acceleration divided by the Ackermann Radius for the corresponding steering input.



Slide 3

For evaluation, the "understeering factor" at .4 g lateral acceleration has been used. This diagram shows again, that both the more oversteering vehicles 4 and 6 and the strongly understeering vehicles 9, 2 and 5 have the poorest ratings.

The curve of turn radius for constant steering input versus lateral acceleration shows for the vehicle variation 12 – which has been rated as the best one – a flat shape without a sudden increase in turn radius for any lateral acceleration value.

2. *Slalom Test*

The second type of manoeuvre was a slalom test. The test track, which was marked with pylons, was driven through with step by step increased vehicle speeds. Having reached the highest possible speed for a certain wave length the distance of pylons has been increased for the next test run. The wave length was between 40 and 80 m.

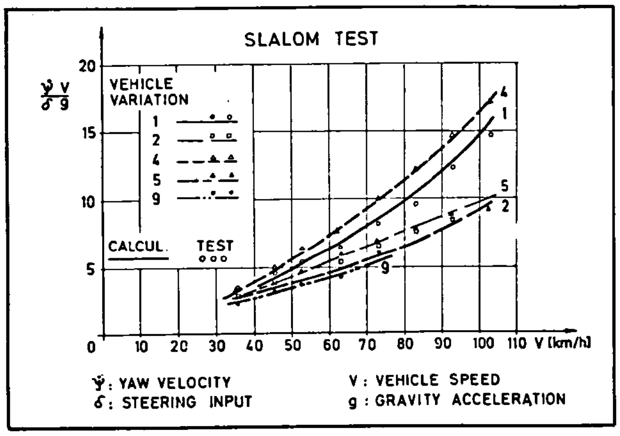
Different possibilities of plotting the results have been investigated, with the aim to get a simple graph which is suitable for a comparison of the test results with subjective assessments and which clearly indicate the difference of the various vehicle modifications at increasing vehicle speed.

From the vehicle response functions, the ratio of lateral acceleration to steering input versus vehicle speed was plotted first. As the slalom track was the same for all vehicle variations, also the lateral acceleration must be nearly the same for same vehicle speeds. Only the necessary steering wheel angles for driving through the slalom track are different, due to the vehicle variations.

The lateral acceleration "b" is equal to sum of yaw velocity "$\dot{\psi}$" and slip velocity "$\dot{\beta}_s$" multiplied with vehicle speed "v."

In order to analyse the handling qualities of the different vehicle variations it seems more convenient to investigate the two components of the lateral acceleration separately.

The ratio of yaw velocity $\dot{\psi}$ multiplied with vehicle speed to steering angle at the front wheel versus vehicle speed is shown in Slide 4. In order to get a coefficient without dimension the value has been divided by gravity acceleration.



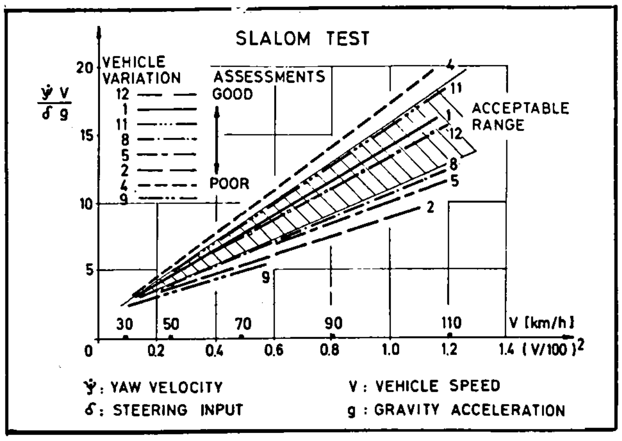
Slide 4

The curves in the diagram are derived from computer calculations, the dots belong to test results which are averaged values from several sinusoidial movements per test and from several test runs.

In conformity between the results of calculations and measurements was found good, the calculated difference between vehicle 5 and 2 was more than that which was obtained from road tests.

The diagram indicates that the upper range of curves corresponds to vehicles with a higher yaw response; that means an increasing tendency of oversteering because for the same vehicle speed and steering input the yaw velocity becomes larger.

These results are compared with the subjective assessments in Slide 5. In this diagram the slalom



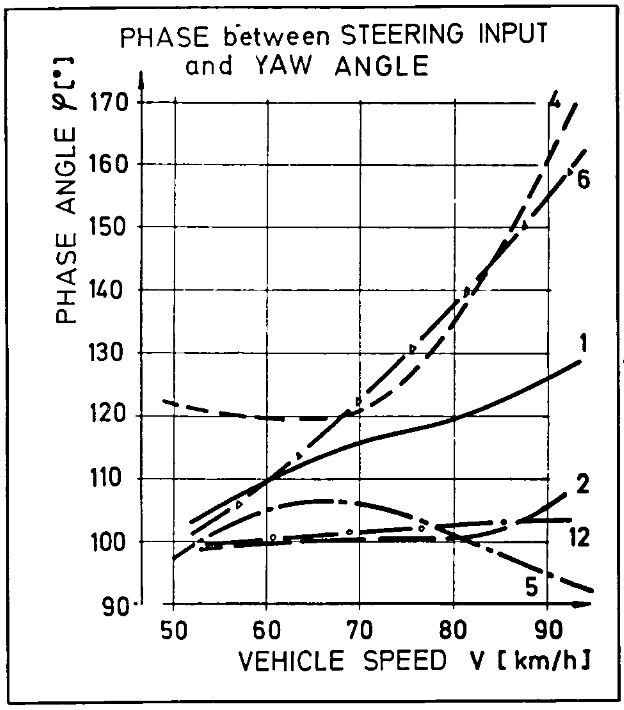
Slide 5

coefficient is plotted over the squared vehicle speed divided by 100 km/h which delivers a dimensionless graph. The parabolic curves of the last diagram have become straight lines in this graph.

The slopes of the different straight lines are used as characteristic values for comparison with the subjective evaluation.

The vehicle No. 8 was accepted as "still acceptable understeering," which draws the limit to acceptable understeering tendency. The limit to oversteering tendency was found by calculations and subjective assessments and vehicle No. 11 has had about the same rating as vehicle 8.

Slide 6 indicates the change of phase relation between steering input and yaw angle versus vehicle speed for the different vehicle variations.



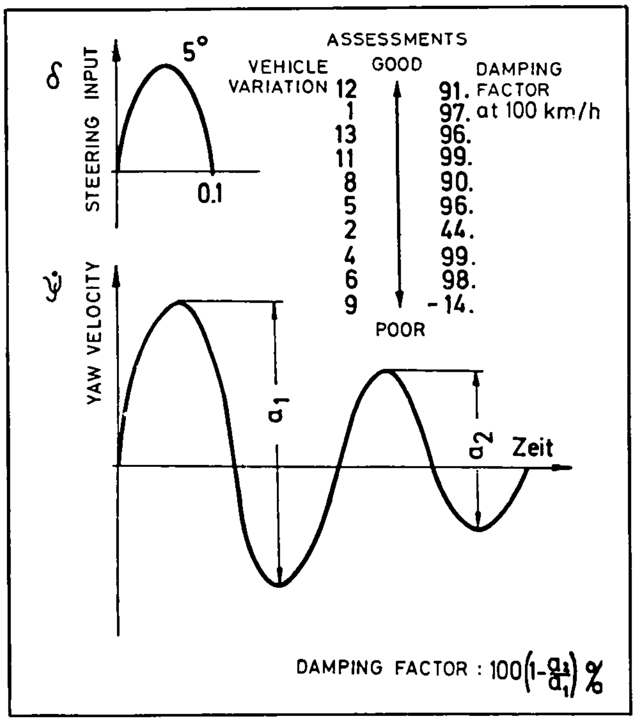
Slide 6

The diagram indicates the increase in lead time for the steering input with an increase in vehicle speed for vehicles with a more oversteering tendency.

It is interesting to note, that the vehicle variation 12 – which was evaluated subjectively to be the best one – has a smaller phase difference between steering input and yaw angle than vehicle variation 1, whereby in this case the phase relation is nearly constant with increasing speed.

The next step was the investigation of the yaw damping as shown in Slide 7.

The factor one minus the ratio of the second to the first double amplitude of the yaw velocity was used as a



Slide 7

criterium. Investigations have shown that this factor should not essentially be lower than 80%. The negative value of the damping factor for vehicle 9 indicates that this vehicle is oscillatorily instable. This fact was also identified during road tests.

The yaw time period was between 0.7 and 1.4 sec. for the different vehicle variations.

The vehicle variation 12, rated subjectively as the best one, has a yaw time period of 0.8 seconds.

The objective of this investigation was to develop a suitable mathematical model for the prediction of vehicle handling qualities, to compare the results of road tests with calculations and to correlate these with the subjective assessments of a driver team. A successful correlation between theoretical results and measurements could be found for the investigated test manoeuvres. The investigation has indicated that several criteria should have values in comparatively small ranges for an acceptable handling performance.

These investigations should be considered only as an attempt to define handling qualities with suitable objective criteria.

Further extensive investigations are necessary to get confidential correlation between subjective assessments and vehicle response functions gained from road tests and prediction.

Further targets of these handling investigations are to develop handling measuring procedures, which are satisfactory repeatable and are not complicated. The test engineer should be able to use these methods without complicated hardware and these should be applicable to check the future legal requirements concerning handling performance as well.

THE MEASURING OF THE DYNAMIC BEHAVIOR OF VEHICLES

Mr. Claude Berlioz, O.N.S.E.R.

The dynamic behavior of vehicles is actually appraised, in the great majority of cases, in a subjective manner by professional testers. The general problem that arises is to render this appraisal objective. It is a question of measuring the behavior of a vehicle by guide marks rather than measuring it in an exact sense, since it is not a measurable quantity, the sum of two behaviors seeming difficultly definable.

I. Use of Models

1. Analytic Models

We will call analytic model a model of which the parameters are determined by a knowledge of the characteristics of the make-up of the vehicle: body, suspension system, shock absorbers, tires, direction, etc. Their purpose is to foresee the consequences of certain modifications of a vehicle on its behavior under certain circumstances, and even, in a more ambitious perspective, to foresee the behavior of a vehicle still in a projected state. Such models have been studied by O.N.S.E.R. in collaboration with Charles Deutsch, and are still being studied. It seems difficult to quantitatively represent a vehicle in a precise manner, even with the help of relatively simple models, especially with the differences in phase. One can, on the other hand, obtain valuable qualitative indications.

This type of model, therefore, due to its imprecision and its theoretical character, does not supply a satisfactory answer to the measuring problem; people are often little familiar with the validity of the schemes and simplifications that are adopted.

2. Empirical Models

We will call an empirical model, a model of which the parameters are adjusted due to the knowledge of the real behavior of the vehicle in certain circumstances. Their purpose is to sum up reality by a group of coefficients permitting the reconstitution of this reality in a rather precise manner.

There exist relationships between analytic and empirical models, the choice of the form of the empirical model is guided not only by the rate of the responses of the vehicle at certain entries but also by the form of the aforesaid analytic models. Inversely, the precision with which one arrives at setting up an empirical model of a given form allows one to judge the validity of any hypotheses leading to an analytic model of the same form, independently of measuring errors which might affect the coefficients of the latter, the particulars beginning with the components of the vehicle.

An empirical model is relative to a domain of its usage, defined by limits of speeds, limits of acceleration, limits of the grip of the wheels and limits of the frequency of entries. These entries are the orders of the driver, the steering wheel, the accelerator, the brakes, and the imperfections of the testing area, such as the unevenness of the roadway or aerodynamic disturbances. A vehicle will not, therefore, be represented by an empirical model but by a group of models relative to diverse domains of usage. These domains should be sufficiently vast to limit the number of models, but restricted enough to obtain a precision sufficient for the interior of these domains. In fact, the choice of one of the models depends upon the particularities of the behavior in which one is interested.

3. The Interest of Empirical Models

Independently of any models, one could seek to define the dynamic behavior by an untested result, representative of a certain domain of usage. This result could be:

–A maximum test speed. This presents the serious inconvenience of depending very heavily upon the qualities of the driver. It indicates nothing about the easiness of the drive, and the consequences of an error in appraisal.

–The maneuvering turns of the driver to obtain a definite trajectory beforehand with a certain precision. These maneuvers allow an appraisal of the simplicity of the driving, but not for the consequences of an error in the appraisal. Moreover, the tests could become very long in order to obtain the maneuver adequate for a very precise, given trajectory in difficult conditions.

–Trajectories obtained following automatic entries. This type of test presents the inconvenience of necessitating very large asphalt surfaces, as soon as one operates at realistic speeds, the response of one given entry being able to very enormously from one vehicle to another. Since it tells nothing about the simplicity of the driving, it should be grouped with the preceding type.

–Another important point is the stability of the car.

The empirical model should permit the obtaining of the two types of preceding data by means of a single test, needing neither automatic drive nor a gigantic surface nor absolute adherence to a trajectory fixed beforehand. One would identify the model through the results of a test carried out in the interior of the domain, and the model would furnish the maneuvers necessary for certain trajectories and trajectories resulting from certain entries. Furthermore, one could determine equivalencies between different types of entries: for example, a blow from the steering wheel could be equivalent to a particular unevenness in the roadway.

4. *The Possibility of Obtaining an Empirical Model*

The study which we are now going to present had for its goal to estimate the possibility of setting up a simple empirical model with sufficient precision. For this first attempt we have chosen simple conditions: constant speed, a smooth and dry roadway, a calm atmosphere and a straight line crashing maneuver. The vehicle was a Citroen stationwagon equipped with a gyroscopic platform giving the angles of sway, roll and pitch. (The vehicle is in fact destined to being measured by the geometric characteristics of the road; it operates, therefore, at a low speed and with the suspension jammed.)

II. Method of Identification

1. *General Remarks*

The identification of a process is the operation which consists of representing it by a mathematic model, this latter serving thereafter either to study the properties of the process in a laboratory and thereby avoid costly experiments on location or to define the system of command which will guide it.

Different methods can be put to work. For example, harmonic analysis allows one to define a linear system by its response curves of gain and phase: this method is inconvenient in that it demands a good number of tests in order to obtain these curves.

Other methods put transfer functions for linear systems directly to use. These pose the problem of representation in cases of connected systems.

Often the direct approach by means of a continuous or discontinuous equation of state is chosen. This will be the case here.

The identification problem is in fact subdivided into two parts: a problem of model structure and a problem of coefficients of a model for a given structure. These two problems can arise according to the objectives one wants to attain.

If the physical laws ruling a process are sufficiently known, the effect of these laws leads to a mathematical form capable of representing the process. Starting with this form, (example: a system of differential equations) nothing remains but to determine the coefficients.

In the case where the physical laws are not sufficiently well known, the problem arises of finding not only good coefficients but also good structure.

Finally, it is sometimes desirable to simplify the base structure in order to have a more flexible and less redundant tool with which to work. Therein intervenes the notion of precision of the identification. The choice of the simplified structure depends upon the user.

Let us note immediately that the search for the best coefficients for a given structure being done mainly on a numerical calculator and said calculator working only on numerical sizes, it is often desirable to directly research a discontinuous mathematical model of the process (discontinuous model of state or system of recurrent equations.)

The typical scheme of identification is the following:

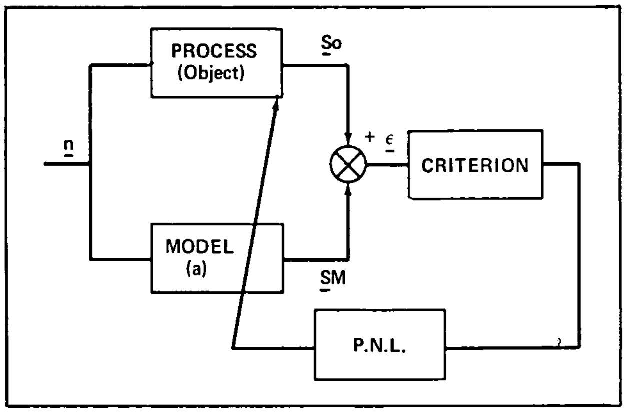


Figure 1

The process, or object, and the model for which one assumes a given structure, having the coefficients to optimize a are subject to the same entry u. A functional of the error between the departures, object and model, should be minimized. This is done with the help of an algorithm of non-linear programming in the general case. One obtains thus a group a_O of optimal coefficients corresponding for a given entry to a certain precision of identification.

The criterion of minimization is often taken from a quadratic type.

Let us note that the identification is worthwhile only for a given entry, in general, an allowable entry. According to the nature of the entry, the model will be able to vary slightly, for it is evident that this entry sensitizes more or less the appropriate methods of the system. One will see this in the continuation on entries of a loop-hole variety. The delicate problem of these so-called sensitizing entries is often overcome by the fact that in practice one knows the real domain of allowable entries.

2. The Method Used

The algorithm allowing for the obtaining of optimal coefficients is derived from the method of the least squares. It allows the identification of linear models having a great number of coefficients when the best methods of non-linear programming can handle only from 6 to 8 coefficients.

Let there be a process having n departures (s) and one entry (e), for example:

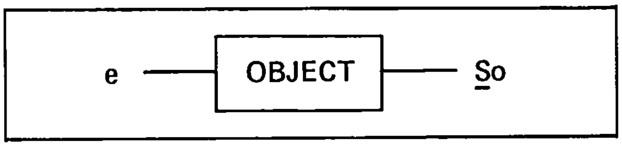


Figure 2

One intends to determine the coefficients of A i and B such as in the recurring model that follows:

$$\underline{S}^{+} = [A]_0 \underline{S} + [A]_1 \underline{S}^{-} + \ldots + [A]_p \underline{S}^{p(-)} + B\,e$$

best represents the process as far as the least squares.

The choice of a recurrent model of this form can be explained by the fact that the number of measured departures is lower than the number of variables of state of this system in a general case. The passage to a discontinuous equation of state is immediate.

$[A]_i$ IS A MATRIX n x n
B IS A VECTOR WITH n COMPONENTS

ONE COULD WRITE $S^{+} = [M]\,\underline{U}$ (i)

$$[M] = \left\{[A]_0 \ldots\ldots [A]_p, B\right\}$$

DIMENSION n x (p.n + 1)

$$\underline{U} = \begin{bmatrix} \underline{S} \\ \underline{S}^{-} \\ \cdot \\ \cdot \\ \cdot \\ \underline{S}^{p(-)} \\ e \end{bmatrix} \quad \text{DIMENSION } (p \cdot n + 1)$$

ONE HAS $\Sigma\, S^{+}\, PU^{T} = [M] \cdot \Sigma\, UPU^{T}$

P matrix of positive definite ponderation, the sign expanding to the entire horizon of identification (duration of the test). One has, therefore:

$$[M] = \Sigma\, \underline{S}^{+}\, PU^{T} \left\{ \Sigma\, \underline{U}\, P\underline{U}^{T} \right\}^{-1}$$

The computation of M is not repeated. If the results obtained are not judged to be good, a repeated computation beginning with these results allows for a better approximation. The problem rests on the inversion of a matrix of a high order, which could be delicate when the matrix is badly conditioned.

3. A chosen example

The example presented concerns an identification of ID 19 upon which the recording of the following variables has been carried out:

β_1 :Steering lock of the wheels before entry

Ψ :Angle of sway } Departures
θ :Angle of roll }

The criterion of quality is of this form:

$$C = 100 \times \frac{1}{2} \left[\frac{\Sigma\,(\Psi_M - \Psi_o)^2}{\Sigma \Psi_o^{\,2}} + \frac{\Sigma\,(\theta_M - \theta_o)^2}{\Sigma \theta^2} \right] \%$$

being spread to the horizon of identification.

In the sense of this criterion, it is a question of finding the structure and the best connecting coefficients. Three linear models of the second, fourth and sixth order have been tested.

III Results

1. Identification with a model of the sixth order

This model is chosen from the form

$$S = \begin{bmatrix} \Psi \\ \theta \end{bmatrix}^{+} = [A_1]\,\underline{S} + [A_2]\,\underline{S}^{-} + [A_3]\,\underline{S}^{--} + [B_1]\beta_1 + [B_2]\beta_1^{-} + [B_3]\beta_1^{--}$$

$A_i = (2 \times 2)$
$B_i = (2 \times 1)$

This recurring model can be easily placed in the form of a discontinuous equation of state.

$$
\begin{cases}
\underline{X}^{+} = \begin{bmatrix} A_{(1)} & A_{(2)} & A_{(3)} \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \underline{X} + \begin{bmatrix} B_1 \\ A_2^{-1}\, B_2 \\ A_3^{-1}\, B_3 \end{bmatrix} \beta_1 \\
S = \begin{bmatrix} \Psi \\ \theta \end{bmatrix} = [100]\ \underline{X}
\end{cases}
$$

For a criterion of 0.75% one obtains

$$
\underline{X} = \begin{bmatrix} 0.85 & -0.17 & 0.27 & 0.11 & -0.12 & 0.03 \\ -0.10 & 0.83 & 0.16 & -0.07 & -0.04 & 0.04 \\ 1 & 0 & & & & \\ 0 & 1 & & & & \\ & & 1 & 0 & & \\ & & 0 & 1 & & \end{bmatrix} \underline{X} + \begin{bmatrix} -0.02 \\ -0.22 \\ 0.22 \\ 1.63 \\ -5.14 \\ -13.14 \end{bmatrix} \beta_1
$$

$$
\underline{S} = \begin{bmatrix} \Psi \\ \Theta \end{bmatrix} = (100)\ \underline{X}
$$

The comparisons between the departures, model and object, are given in Figure 3.

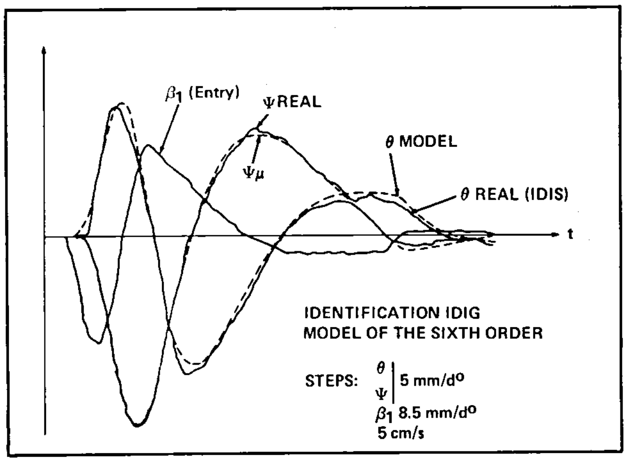


Figure 3

2. *Identification with a model of the fourth order*

$$
\underline{S}^{+} = \begin{bmatrix} \Psi \\ \theta \end{bmatrix}^{+} = [A_1]\ \underline{S} + [A_2]\ \underline{S}^{-} + [B_1]\ \beta_1 + [B_2]\ \beta_1^{-}
$$

FOR A CRITERION OF 0.86% ONE OBTAINS:

$$
\underline{X}^{+} = \begin{bmatrix} 0.96 & -0.21 & 0.03 & 0.16 \\ -0.11 & 0.93 & 0.12 & -0.09 \\ 1 & 0 & & \\ 0 & 1 & & \end{bmatrix} \underline{X} + \begin{bmatrix} -0.22 \\ -0.06 \\ -0.40 \\ 1.67 \end{bmatrix} \beta_1
$$

$$
\underline{S} = (1\ \theta)\ \underline{X}
$$

3. *Identification with a model of the second order*

$$
\underline{S}^{+} = \begin{bmatrix} \Psi \\ \theta \end{bmatrix}^{+} = (A)\ \underline{S} + (B_1)\ \beta_1
$$

FOR A CRITERION OF 6.82% ONE OBTAINS:

$$
\underline{X}^{+} = \begin{bmatrix} 0.99 & -0.08 \\ 0.02 & 0.89 \end{bmatrix} \underline{X} + \begin{bmatrix} 0.32 \\ -0.51 \end{bmatrix} \beta_1
$$

$$
\underline{S} = \begin{bmatrix} \Psi \\ \theta \end{bmatrix} = \underline{X}
$$

The comparison of the three retained models is made in Figure 4. The first two models are good, the third seems to be insufficient. One can deduce from this that the model of the fourth order fittingly represents the ID 19 in the sense of the problem put forth.

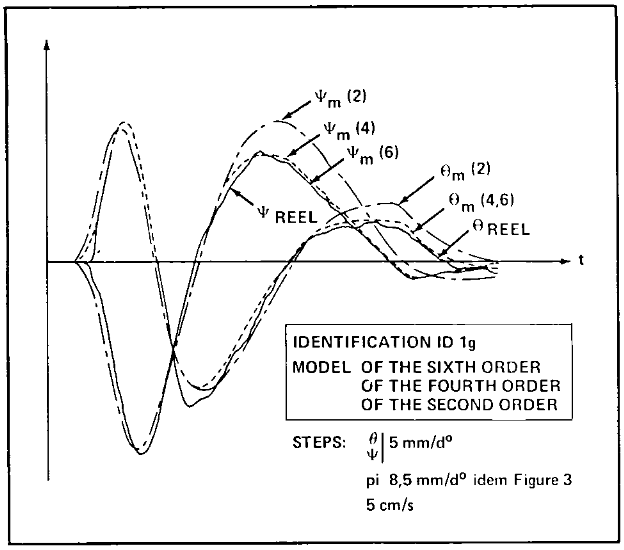


Figure 4

4. *Comparison of the poles in Z*

It is interesting to know the nature and the value of the poles of the three models; figure five allows for their comparison.

5. *Another example of an application*

To test the method used on a more complex type of automobile and with very difficult entries, or again sensitizing entries of all the types appropriate to the system considered, one has proceeded to the identification of a process of which the departures, rather than being measured on location, result from the

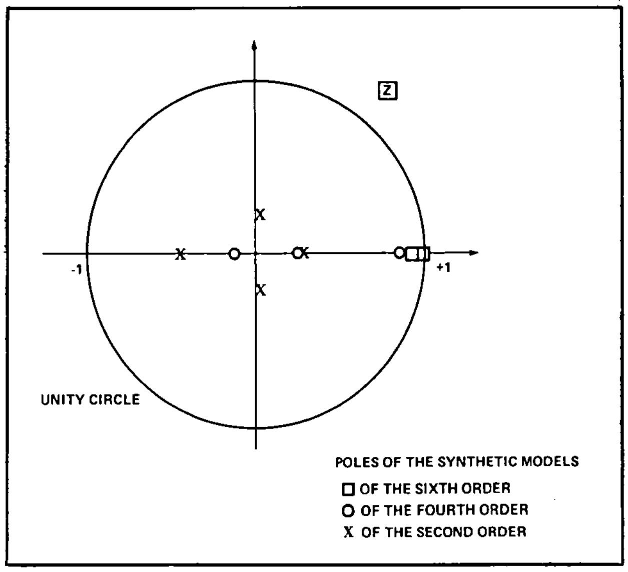


Figure 5

integration of a very complete analytic model giving the evaluation of the speed of the sway (Ψ), of the steering lock of the wheels (β_1), of the drift (α), and of the angle of roll (Φ), in function of the angle of the steering wheel (β_v).

The synthetic model looked for has the form (sixth order):

H

$$\underline{X} = M\underline{X} + N\beta V$$

$$S = \begin{bmatrix} \alpha \\ \dot{\Psi} \\ \theta \\ \beta_1 \end{bmatrix} = \underline{C} \qquad \text{WITH } \underline{X} = \begin{bmatrix} \alpha \\ \dot{\Psi} \\ \dot{\theta} \\ \beta_1 \\ \dot{\beta}_1 \end{bmatrix}$$

The identification has furnished curves of the departure-model superimposable on the curves of the departure-object for diverse entries, in particular, an entry in loop-hole form. This entry forcefully stirred up a wavering model on ( ).

While considering in another test a more simple synthetic model of the form:

$$\underline{X}^+ = P\underline{X} + \theta\beta v$$

$$\underline{S} = \begin{bmatrix} \alpha \\ \dot{\Psi} \\ \theta \\ \beta_1 \end{bmatrix} = \underline{X}$$

The waverings of the departures due to this style have been smoothed over. One sees in Figure 6 that the

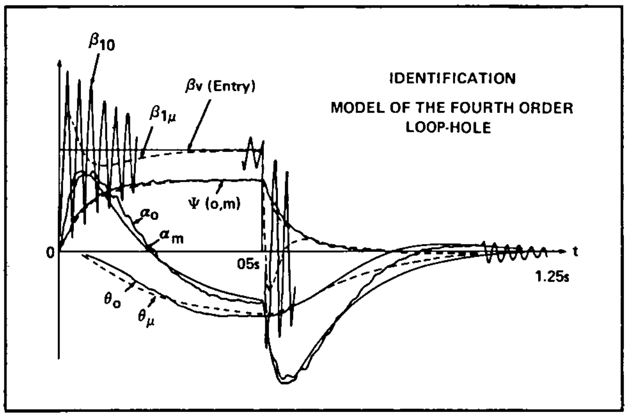


Figure 6

simplified model isn't appropriate for realizing the whole of the dynamics. Can one conclude therefrom that this model is insufficient?

–No, if one considers that in normal functioning a car can never be subjected to a perfect loop-hole and it is therefore not useful to retain in the dynamics a style which will never be brought up.

–Yes, if one studies the particular problem of a blow from the steering wheel wrought upon the driver or upon a supplemental cause, a blow from the steering wheel which could be very weak and could, however, have distressing consequences insofar as safety, for example. In this type of study it will probably be good to keep in mind the synthetic model.

IV. Questions remaining to be asked

This first study has shown the possibility of identifying a relatively simple model in simple conditions with good precision. There remains to be determined in which domain of usage this precision is sufficient. This is the objective of the tests undertaken this year.

Other entries should then be introduced: brakes, accelator, unevenness of the roadway, aerodynamic forces.

Likewise, it will be necessary to determine, by experimenting with representative subjects from the driving population, the dynamic behaviors seeming favorable or unfavorable for safety.

ANALYSIS OF THE STEERING BEHAVIOUR OF AUTOMOBILES BY TESTS WITH AND WITHOUT MAN AS DRIVER

Dr. Kurt Enke, Daimler-Benz

In all tests to assess the handling of automobiles the question always arises whether this handling can be described in simple measurements, such as those listed in the U.S. experimental safety vehicle specifications and whether the boundaries between safe and unsafe can be defined in valid terms.

Nobody seriously believes that this is possible in all details and it remains to be discussed in how far these simple measurements, which, no doubt, have the advantage of being easily carried out, are useful.

It must be said at the outset that we at the Daimler–Benz Company are not able to present a complete alternative program. Thus we are able to discuss only a small sector very incompletely but this is excusable in that it shows some of the complexity and dangerousness of hastily fixed regulations.

By alterating the springs and changing the tires we have designed one and the same car, a Mercedes model 250, once with a stronger and once with a less strong tendency to understeer than the production car. Let us define it as heavy, medium and slight understeering.

In addition, we drove the car in these tests in each of these designs first occupied by one driver, weight G = 100%, moment of inertia I = 100%, and then lead weights were attached in the adjustments

G = 120%	I = 100%
G = 120%	I = 155%

In one case, these weights were attached in the centre of the car and in the second, at the outside on the bumpers.

We should like to show you now the results of the yawing response during steady-state turning and the transient behaviour according to the U.S. experimental safety vehicle specifications and finally give you the subjective impressions gained by various drivers.

First, Figure 1 showing a slightly understeering vehicle during steady-state turning, the straight line representing the yaw response with the same slip angle at the front and rear, i.e., with neutral behaviour.

It can be clearly seen that all characteristics for the various lateral accelerations and loads may be relatively high, that is, small steering angles are required for a specified yaw velocity.

Figure 2 shows our standard layout. The curves for 0.4 g are still above the so-called acceptable range while the curves of 0.6 g lie noticeably deeper.

(Bildtext von Bild 1)
Giergeschwindigkeit = Yaw velocity (°/sec)
Radeinschlag = Road wheel angle (°)
Gewichte auf den Stobstangen = Weights on the bumpers
Ohne Gewichte = without weights
Gewichte im Schwerpunkt = Weights in centre of gravity
$\frac{v}{l}$ fur l = . . . $\frac{v}{l}$ for l = ... mm
(Bildunterschrift)
Steady-state yaw response, slightly understeering car

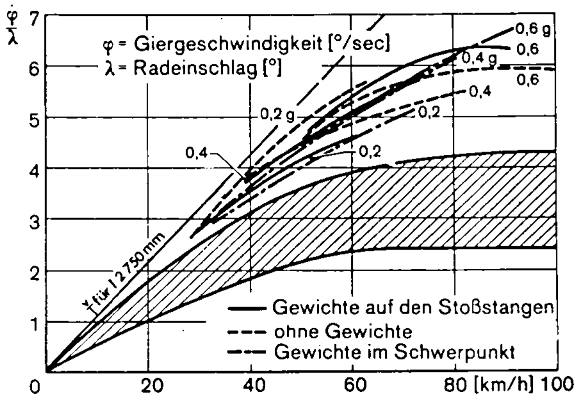


Figure 1

(Bildtext von Bild 2)
Giergeschwindigkeit = Yaw velocity (°/sec)
Radeinschlag = Road wheel angle (°)
Gewichte auf den Stobstangen = Weights on the bumpers
ohne Gewichte = without weights
Gewichte im Schwerpunkt = Weights in centre of gravity
(Bildunterschrift)
Steady-state yaw response, medium understeering car

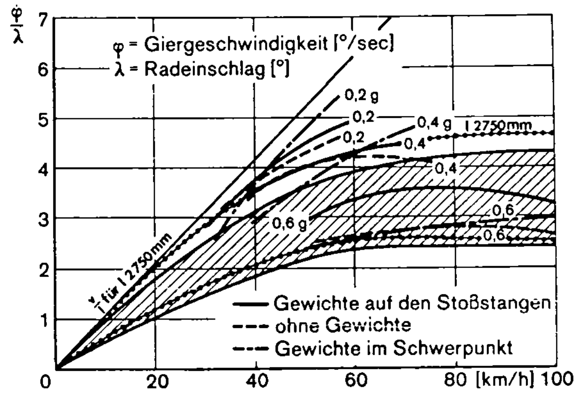


Figure 2

The pointed limiting lines would apply for the smaller wheelbase of 2750 mm. They are so calculated that the relationship between the wheelbase and the distance of the cornering force point of application behind the centre of gravity is the same as in the limiting curves of the U.S. experimental safety vehicle specifications.

The car with a strong tendency to understeer is depicted in Figure 3.

(Bildtext von Bild 3)
Giergeschwindigkeit =Yaw velocity (°/sec)
Radeinschlag = Road wheel angle (°)
$\frac{v}{t}$ for l = 2750 mm
Gewichte auf den Stobstangen = Weights on the bumpers
ohn Geiwchte = without weights
Gewichte im Schwerpunkt = Weights in centre of gravity
(Bildunterschrift)
Steady-state yaw response, heavily understeering car

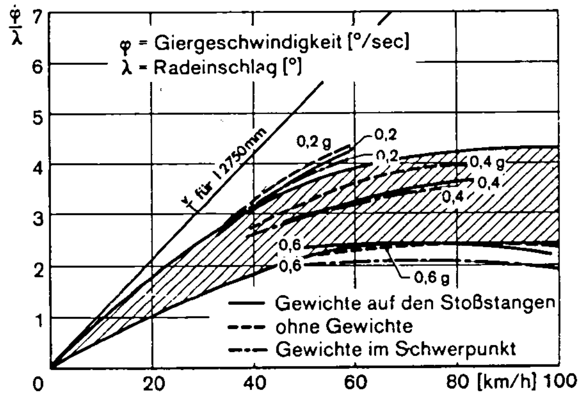


Figure 3

All characteristics lie still lower, in particular those of 0.4 g; the characteristics of 0.6 g lie even below the shaded area.

(Bild 4)
Gewichte auf den Stobstangen = Weights on the bumpers
ohne Gewichte = without weights
Gewichte im Schwerpunkt Weights in centre of gravity
(Bildunterschrift)
Transient behaviour, car slightly understeering

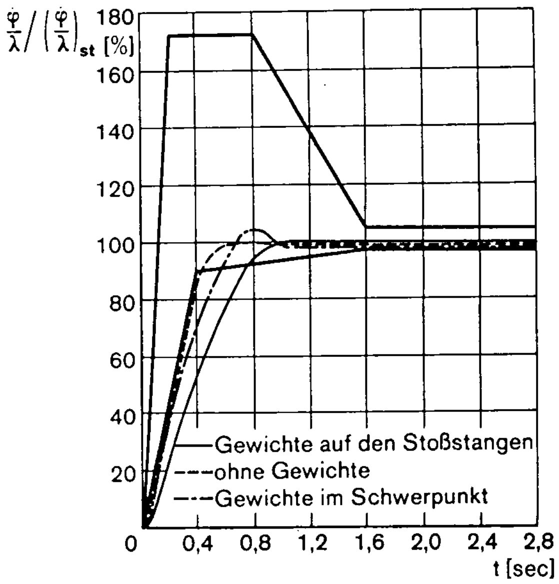


Figure 4

The measurements for the transient behaviour follow now in the same sequence. At first in Figure 4 we have again the slightly understeering car at 112 km/h. Because of the small steering angle necessary to obtain the defined yaw velocity the car at first responds inertly and runs into the following steady-state turning almost without any overshooting.

For comparison, Figure 5 shows our medium understeering standard design in which overshooting is observed after fast response of the car before steady-state turning is attained.

(Bild 5)
Gewichte auf den Stobstangen = Weights on the bumpers
ohne Gewichte = without weights
Gewichte im Schwerpunkt = Weights in centre of gravity
(Bildunterschrift)
Transient behaviour, medium understeering car
v = 112 km/h

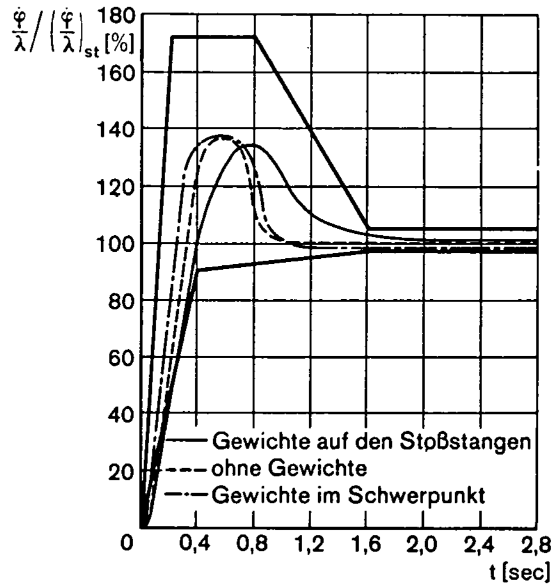


Figure 5

Finally Figure 6 shows the heavily understeering car in which the yaw acceleration is very great because of the rather wide steering angle. As a consequence, great overshooting is observed as a result of which the steady-state condition is attained only after a few small oscillations.

As the last series let us again show the transient behaviour of the 3 vehicles, now at 40 km/h. Firstly, Figure 7 shows the slightly understeering car, and secondly, Figure 8 the medium understeering standard car and Figure 9 the heavily understeering car.

Today we cannot present objective tests which include the control characteristics of the driver. But the

(Bildtext Bild 6)

Gewichte auf den Stobstangen = Weights on the bumpers

ohne Gewichte = without weights

Gewichte im Schwerpunkt = Weights in centre of gravity

(Bildunterschrift)

Transient behaviour, heavily understeering car

v = 112 km/h

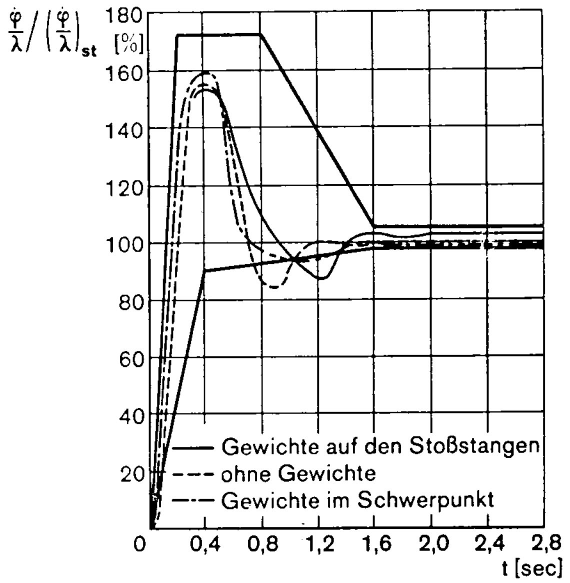


Figure 6

(Bildtext zu Bild 7)

Gewichte auf den Stoßstangen = Weights on the bumpers

ohne Gewichte = without weights

Gewichte im Schwerpunkt = Weights in centre of gravity

(Bildunterschrift)

Transient behaviour, slightly understeering car

v = 40 km/h

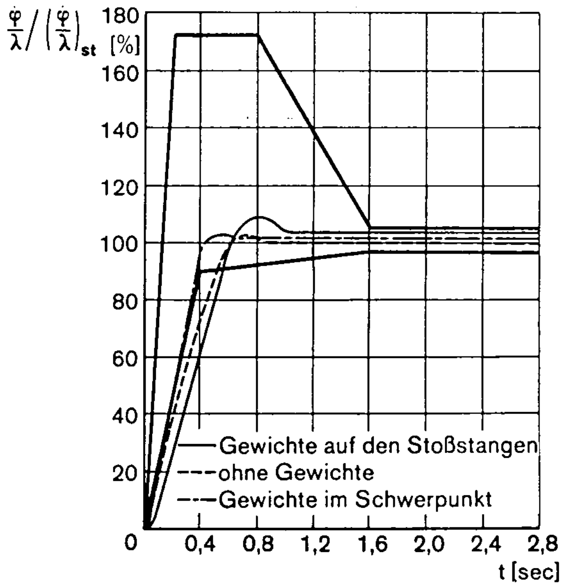


Figure 7

following can be said about the subjective impressions gained by various drivers with cars of varying designs.

The changes from the initial condition towards a car with a lesser or stronger tendency to understeer were very great. It was our aim to demonstrate particularly extreme conditions. In spite of this, all 3 designs are hardly different during normal operation apart from the fact that the heavily understeering car requires rather a lot of steering work, which is particularly felt with cars without power steering. This is also confirmed by the last 3 diagrams.

The difference becomes obvious only when the adhesion limit between tire and road is approached. Here it is shown clearly that for this car with these axles the medium understeering design effectively results in the safest overall behaviour of the vehicle.

The slightly understeering design requires careful, finely controlled steering motions and tends to rear axle swerving if the accelerator pedal is depressed when the adhesion limit is reached.

The medium understeering design is steerable and can be corrected with normally controlled steering angles up to the critical adhesion limit; bends can be entered without corrections. Since the vehicle shows strongly dampled yaw oscillations and never requires very great steering motions, it remains easily steerable for less skilled drivers even in extreme situations.

The heavily understeering car in this design generally demands a good deal more steering work and drifts out of the bend when passing the limit with the steering turned to lock. For great and fast corrections the hand must be moved around the steering wheel while the feel for the straight-ahead position is lost. Corrections made by releasing the accelerator pedal on bends produce a strong turning motion into the bend with steering wheel strongly turned in which requires very great, fast counterturning to effect corrections. When entering a bend, more steering corrections must be made because of the overshooting which was clearly shown in Figure 6, that means, increased concentration is necessary. This is not a point against the heavily understeering design itself; it merely shows that optimal handling can be obtained and defined only in terms of overall design. It varies from vehicle to vehicle.

Only the range of high speeds and high lateral accelerations is decisive for this design and here in this range the handling of the vehicles is determined by the interaction of an extremely large number of factors which are frequently nonlinear. In this regard particular consideration must be given to motions of the driver,

(Bildtext zu Bild 9)
Gewichte auf den Stobstangen = Weights on the bumpers
ohne Gewichte = without weights
Gewichte im Schwerpunkt = Weights in centre of gravity
(Bildunterschrift)
Transient behaviour, heavily understeering car
v = 40 km/h

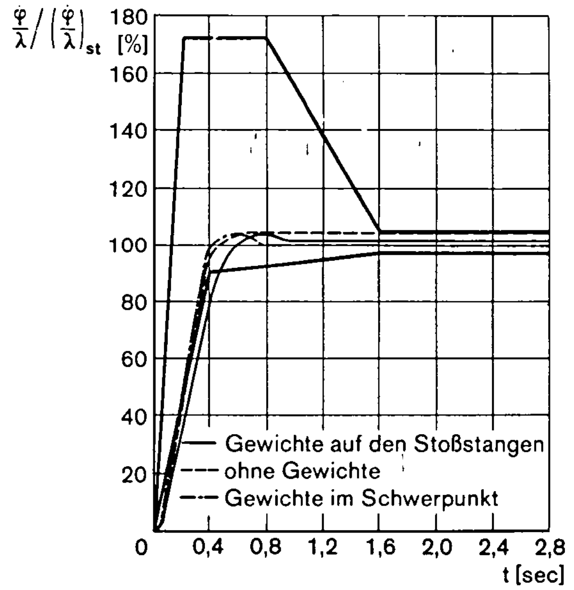


Figure 8

including reflex actions of an unskilled or bad driver, in response to possible vehicle motions fed into the control loop in critical situations.

At the present time, we know of no suggestion that takes sufficient account of this fact for the purpose of judging the handling of a vehicle. If we had a measuring method for this we would describe as good and safe the vehicle that offered, together with this driver-response function, the best results in difficult maneuvreing situations and in emergencies.

At the same time, the steering work and concentration required for steering a vehicle under normal driving conditions below the critical situation should be considered in the analysis. And finally the transition from normal driving to critical conditions will still have to be assessed; whether the different behaviour comes suddenly or is announced long enough in advance, i.e., the car does not take you by surprise.

Under these comprehensive aspects different overall behaviour will be found to be optimum for cars with different mass distribution, units and dimensions. And it would be wrong to demand the same behaviour for all cars merely to eliminate the need for the driver to accustom himself to new handling characteristics.

It is possible that cars with the same layout in respect of individual features, but of different sizes, will have a

(Bildtext zu Bild 8)
Gewichte auf den StoBstangen = Weights on the bumpers
ohne Gewichte = without weights
Gewichte im Schwerpunkt = Weights in centre of gravity
(Bildunterschrift)
Transient behaviour, medium understeering car
v = 40 km/h

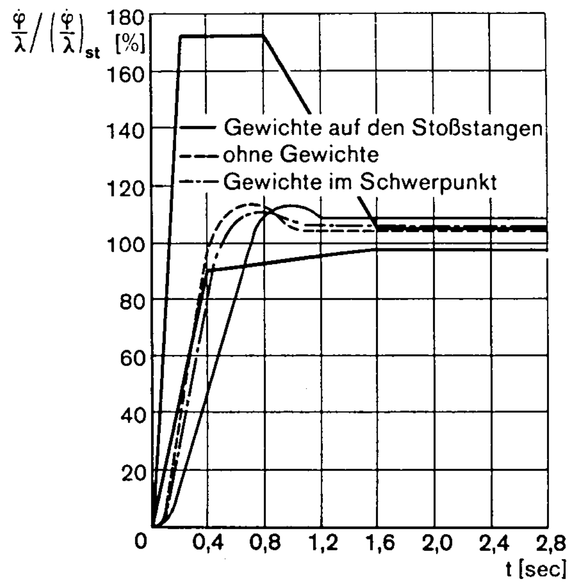


Figure 9

tendency to different, and for the driver unexpected reactions in the boundary range, which endanger the user to a far greater extent than if the driver unconsciously gets used to somewhat different overall handling characteristics.

Finally, we summarize again the reasons why the driver together with his characteristics should be included when judging the handling of a car.

1. Individual measurements cannot analyze all the interacting influences.
2. The danger zone is close to the adhesion limit; there, individual measurements cannot be combined because of the many nonlinear characteristics.
3. The general optimum overall behaviour is obtainable by various combinations of individual features.
4. Cars of different lengths and weights (mass distribution) need different layouts.
5. The reflex actions of the unskilled driver determines to a great extent the directional stability and motions of the vehicle.
6. The information channels for the driver are different for different vehicles and have a different influence on the response.

AN ANALYSIS ON VEHICLE BEHAVIOR IN OVERTURNING

Mr. Yasuhiko Fujiwara
Vehicle Design Department
Nissan Motor Co., Ltd.

1. Introduction

Mr. Chairman and gentlemen, it is my great pleasure to present an analysis of the research conducted on vehicle overturning phenomena at this international conference.

Generally speaking, small-sized passenger cars are essentially handicapped in crash-type accidents. However, they inflict relatively small injuries on other cars. In addition, they have a history of good performance in the field of accident avoidance.

In developing a small-sized ESV of 2000 lbs. class, one of the most fundamental goals is to optimize the combination of various characteristics and to design a safety car as a total system. The theory of "Defensive Driving" as directed toward accident avoidance contributes to safety before an accident occurs. With this theory, however, overturning immunity is especially required, considering the serious accidents which can be caused by vehicles overturning.

In surveying the history of research on vehicle dynamics, the overturning phenomena have not been analyzed sufficiently. Therefore, we will systematically research it in developing ESV. In this seminar, I will report the test results of J-turn, which is one of the typical tests on overturning, and explain our first practical step of analysing the phenomena.

2. Overturning Accidents At Nissan Proving Ground

First of all, overturning accidents on the proving grounds of our company have been investigated for the purpose of understanding main factors of overturning.

Some samples are described in Table 1.

From this series of the past accidents, the following facts have been noted:

1. In most cases, vehicle overturn does occur in the state of uncontrollable skid caused by severe steering input.
   It is rare case that overturning occurs the instant steering input is initiated.
2. The direct cause of overturn is mostly the drastic change of the friction coefficient of road surface when the car is skidding on the ground, such as hitting the curb, riding into sand, or rim contact with the road surface.
3. However, there are some cases of overturning caused by essential vehicle dynamic characteristics, in spite of no disturbance from the road surface.

Our main purpose of this research is to analyze on the phenomena of No. 3 case.

Table 1

Some Examples of Overturning Accidents at Nissan Proving Ground

	Item of test during which overturning occurred	An immediate cause of overturning
1	Slalom Test	Wheel hitting the curb during uncontrollable skid
2		Rim contact with road surface
3		Characteristics of vehicle dynamics
4		
5		Ride into sand
6	Severe cornering test on racing course	
7	Severe lane changing test	Characteristics of vehicle dynamics
8	Transient yaw response test	Wheel hitting the curb during uncontrollable skid
9		
10	Steady state yaw response test	Braking force

3. Test Procedure And Test Results

As the J-turn test is dangerous to perform, we have developed a simple remote-controlled test car. First, an unmanned vehicle is attached to and guided by a piloted vehicle. After the test vehicle is accelerated to a required speed, the coupler is disconnected. 0.5 or 1.0 second later, the vehicle is steered by mechanical relay system and begins to turn. Braking force is given with radio control.

During vehicle turning, no accelerating force, nor steering disturbance is given in the tests which are shown in this seminar. Lateral acceleration, yaw rate, roll angle, steering wheel deflection rate and road wheel center motion in vertical direction are measured. Now, I will show you some examples of test results with the movies taken during these tests.

Datsun 510, standard specification, 110 km/h

Standard Datsun 510 does not overturn under the condition required in ESV specifications. Tire deformation is very large but the rim does not contact with road surface. Tire slip angle is about 30° to 40°. When radial tires with good performance of road grip are installed, vehicle will not overturn.

Datsun 510 – Over-load on the roof, 110 km/h

To investigate the overturning mechanism, we applied some weights on the roof of Datsun 510 and gave braking force while turning. As a result of this severe condition, Datsun 510 overturned at 110 km/h. Main factor of overturning may be the high position of the center of gravity.

Datsun 1200 – Standard Specification, 110 km/h

As in the case of Datsun 510, Datsun 1200 installed with a live axle type rear suspension will not overturn.

Datsun 1200 – Over-load on the roof, 110 km/h

When we applied some weights on the roof, vehicle overturned at 110 km/h just after steering input was given.

4. First Step Analysis

As a first step of analysis on vehicle overturning, we examined a simple mathematical model.

It is supposed that vehicle overturns when the relation of moments caused by the centrifugal force and gravity about the road contact point of outside tire satisfies the following condition:

Figure 1. Mathematical Model

φ	=	Roll Angle
J	=	C.G. Point Heave
H	=	Height of C.G. Point
h	=	Distance between Roll Center and C.G. Point

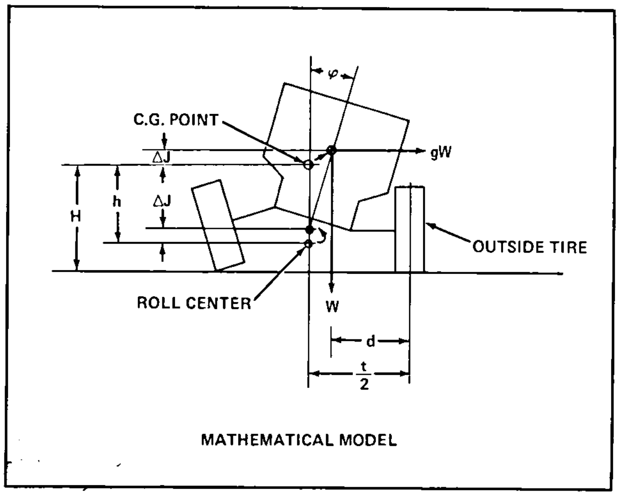


Figure 1

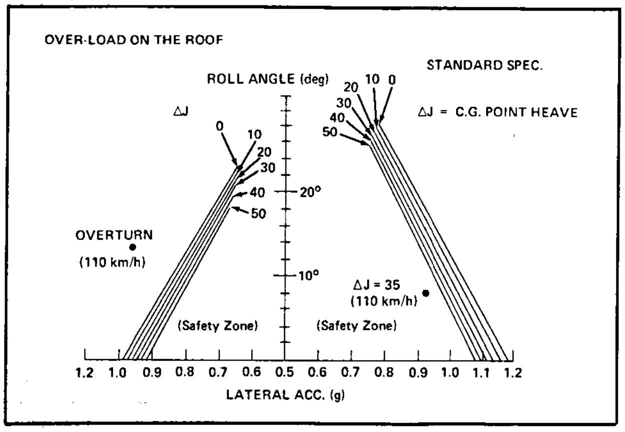


Figure 2

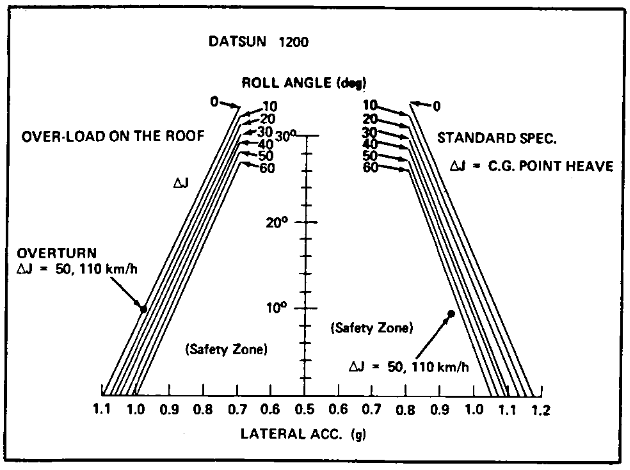


Figure 3

t	=	Time
g	=	Lateral Acceleration

The calculated results on Datsun 510 and Datsun 1200 are shown in Figures 2 and 3. In these figures, the relation of lateral acceleration and roll angle is shown with the parameter of C.G. point heave. The part under the slant line is the safety zone against the overturning.

In Figures 2 and 3, the test data of Datsun 510 and Datsun 1200 are plotted. The results coincide with the real phenomena. Therefore it can be said that the simple mathematical model above mentioned fairly well explains the criteria of vehicle overturning at the J-Turn test.

5. Conclusion

Both Datsun 510 and Datsun 1200 do not overturn if there is no disturbance from the road surface. So they have essentially the characteristics of overturning immunity.

Our simple mathematical model explains fairly well the overturning phenomena in J-Turn tests.

However, J-Turn tests simulate only partially the phenomena of vehicle overturning. So in order to research the real phenomena, more complicated tests will be made and the mathematical model which includes the other factors such as the rolling resonance with steering input and influence of accelerating force, etc. will be analyzed.

We will continue this research and present the results of the analysis about the completion time of Nissan ESV program.

DIFFERENCES IN STEADY-STATE AND TRANSIENT STEERING BEHAVIOR OF DIFFERENT CARS

Dr. Kurt Enke, Daimler-Benz

For some time now the problem of finding objective ways of measuring the handling characteristics of motor vehicles and of recommending limits for acceptable and unacceptable ranges has been receiving attention from a number of quarters.

As the control problem involved is a very complex one, recommendations are not readily available and the fact has been recognized that the driver must be considered, too. As far as we know, attempts made to objectify the driver and to include him and his control characteristics in the closed loop have not been successful so far and would certainly prove to be difficult as the human being is able to adapt and to alter his control characteristics depending on the manoeuvre carried out. The time simply has not come yet; we are unable to make any reasonable suggestions now, let alone issue binding regulations. Nevertheless, it is only natural that attempts should be made as, for example, in the U.S. safety vehicle specifications, to find certain standards for determining the roadworthiness of a vehicle by means of simple driving tests.

Two points should be discussed in this connection:

1. The extent to which these simple tests are actually of use in evaluating the handling characteristics.
2. The limits to be drawn between acceptable and unacceptable ranges.

As point 1 will be dealt with separately, let us consider point 2 first, with particular reference to steady-state cornering.

The limits for steady-state cornering set in the specifications for U.S. safety vehicles imply strong understeering. The location of the boundary lines is shown in Figure 1.

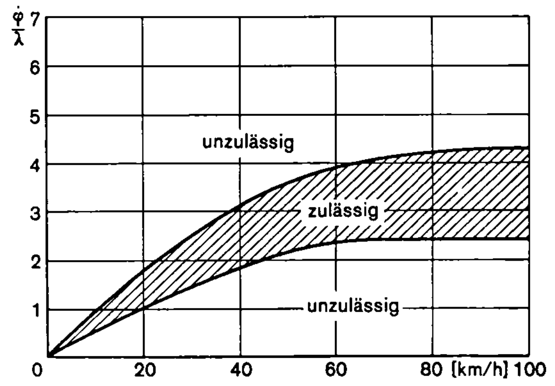


Figure 1

Bildbeschriftung:
unzulassig = not permissible
zulassig = permissible
Gierreaktion stationar, fur USA-Sicherheitsfahrzeuge =
Steady-state yaw response for U.S. safety vehicles
Bild 1 = Fig. 1

This range, which is meant for 0.4 g, is much too narrow to cover all types and sizes of vehicles.

Since this test covers a very limited range only – all more or less easily handled cars of the same size are very close to each other – we would suggest that it be dropped. At most the following definition appears to be acceptable:

"The permissible range according to Figure 2 lies below the straight line and depends on the wheelbase of the car."

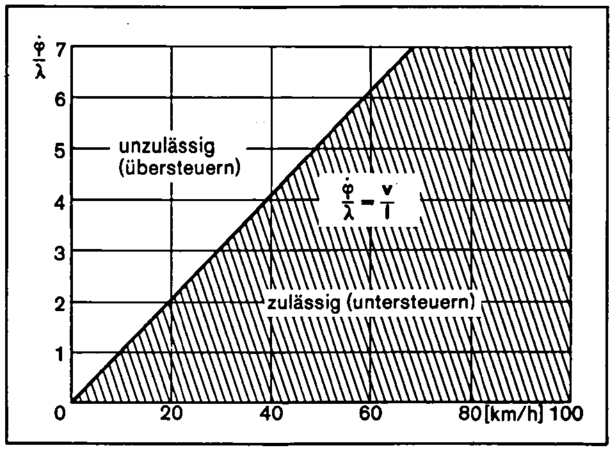


Figure 2

[Bildeschriftung:
unzulassig (ubersteuern) =
not permissible (oversteering)
zulassig (understeuern) =
permissible (understeering)
Bild 2 = Fig. 2]
Gierreaktion stationor, vorgeachlag. Grenze =
Steady-state yaw response,
proposed limit

φ = Yaw velocity
λ = Apparent front wheel angle
Steering wheel angle x steering ratio
(i.e., front wheel angle calculated
from steering angle)
ν = Driving speed
ι = Wheelbase

As is well known, this boundary line, adapted to the wheelbase, corresponds to the lowest stability limit. Cars exceeding this limit are still stable at low speeds, but starting from a certain critical speed they follow a curved path after a disturbance while the steering is held in straight-ahead position, which means that they are instable.

The definition of λ is necessary because the actual front wheel angle is always smaller than the apparent front wheel angle calculated backwards from the steering wheel angle and the steering ratio, since owing to the steering elasticity and the design caster the front wheels have a greater straight-ahead tendency.

This elasticity which can be chosen freely is an essential aid to the designer in adjusting the vehicles with respect to their handling characteristics, and not to include it would make an analysis of the steering behaviour not only inadequate but positively wrong.

The free variability below the boundary line in Figure 2 is necessary for obtaining acceptable transient steering characteristics for different vehicle sizes and mass distribution. To obtain identical or similar transient steering characteristics the long, heavy car must understeer to a greater and the short, light car to a lesser degree. The necessity to vary the degree of understeering becomes obvious during a simple test: Transition from straight-ahead driving to cornering with a single, abrupt turn of the steering wheel.

The car will respond to this movement of the steering wheel by a delayed rotation about the vertical axis changing over into cornering at constant angular velocity. If one neglects overshooting, the angular velocity curve plotted against the time is approximately as shown in Figure 3.

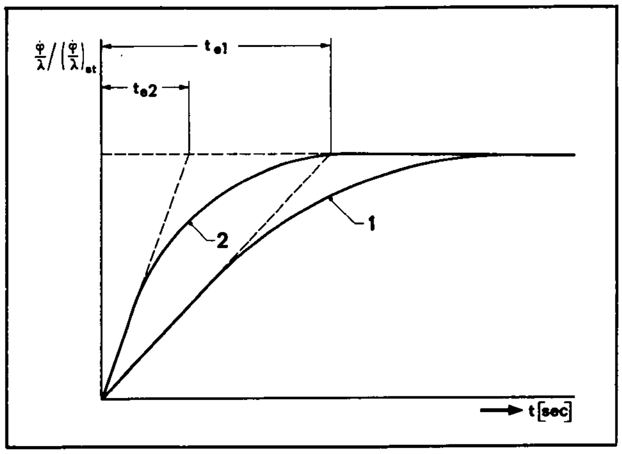


Figure 3

[Bildeschriftung:
Ubergangsverhalten verschieden trager Wagen =
Transient behaviour of cars with
different degrees of inertia
Bild 3 = Fig. 3]

For a given apparent front wheel angle, cars with the same degree of understeering will reach the same angular velocity when cornering. The approach to this angular speed is expressed by an exponential function.

The long, heavy car with greater inertia about the vertical axis (curve 1) will, however, reach this final angular velocity later than the light, short vehicle (curve 2). The rapidity of the response is often described by the time t_e, which is determined by the intersection of the zero tangent to the angular velocity/time curve with the final angular velocity. According to Fonda[1] we have, in a highly simplified form, the following expression for the delay time t_e:

where

t_e = Delay time (sec)

i	=	Radius of gyration about the vertical axis (m)
m	=	Vehicle mass (kg)
v	=	Driving speed (m/sec)
ι	=	Wheelbase (m)
c	=	Overall slip angle resistance of the tires (kp/rad)
x	=	Distance: Centre of gravity – point of application of the resulting cornering force (m), which is positive when the resulting cornering force is applied behind the centre of gravity.

The quantity x mentioned as the last item above, and also the ratio $X : \iota$ can, for a rough analysis, be interpreted as a measure for understeering:

Negative x = oversteering
x = zero = neutral
positive x = understeering

From equation 1 it follows that, for cars with an identical degree of understeering, t_e increases essentially as the ratio

moment of inertia about the vertical axis
wheelbase[2] . overall slip angle resistance
of the tires

The greater the weight of the car, the greater – with the usual design of mass distribution, wheelbase and tires – will be the increase in the numerator of this expression in relation to the denominator, i.e., the heavy car responds more slowly, t_e increases.

However, if acceptable transient steering characteristics are to be obtained, t_e must not be too great. For heavy cars, there are two ways of limiting t_e. One either uses very big tires that are clearly overdimensioned as

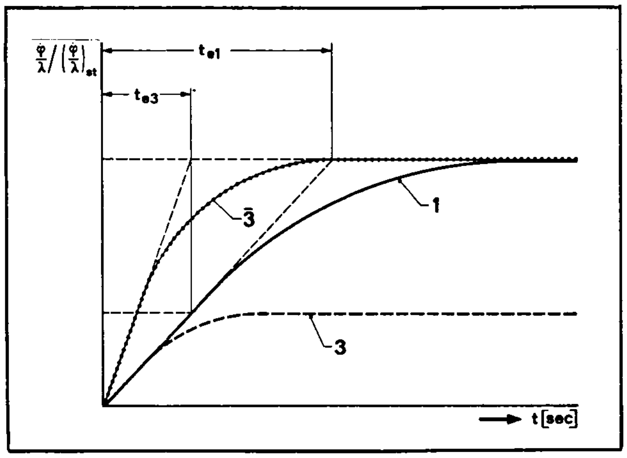


Figure 4

regards the load-carrying capacity, or uses a layout with a stronger tendency to understeering. For reasons of economy, the second approach is used in almost all instances, which is expressed in Figures 3 and 4 as follows:

The more heavily understeering car according to curve 1 in Figure 3 will, at the same steering angle, only attain a lower angular velocity while the yaw response gradient remains unchanged (curve 3, Fig. 4). The delay time t_{e3} is, however, shorter, as the zero tangent intersects the final angular velocity line earlier; this is expressed in formula 1 by the increase in the denominator of the last factor.

[Bildeschriftung:
Korrektur im Ubergangsverhalten durch
verstarktes Untersteuern =
Correction of transient behaviour
by increased understeering
Bild 4 = Fig. 4]

Thus a delayed-response car has, so to speak, been converted into a faster responding one, the difference lying in the fact that the response is weaker. To obtain as strong a response as in vehicle 2, which was lighter from the beginning, the front wheel angle must be increased accordingly to bring the angular velocity up to the desired value again.

This can be achieved, for example, by the steering ratio or by increased turning of the steering wheel. This is indicated by curve 3 in Figure 4, which practically coincides with curve 2 in Figure 3. Summing up, it can therefore be said that to obtain for heavy cars the same transient steering response as in light cars, heavier understeering plus a larger front wheel angle is required.

This means that it should be possible to obtain identical handling characteristics for the driver as far as the feel of the steering is concerned, if one leaves the effort required out of consideration. Cars of different weight, designed with different degrees of understeering for the purpose of obtaining identical transient behaviour, should be given a steering ratio that ensures that during the steady-state turning test identical steering wheel angles (not front wheel angles!) result in the same cornering radius.

So one would have to proceed as follows:

Light vehicle – slightly understeering – indirect steering
Heavy vehicle – heavily understeering – direct steering

With this measure – so it would seem at first sight – it should be possible to provide light and heavy cars with the same steering characteristics. However, this applies only as long as the first order of the system is considered. As soon as the second order, i.e., oscillations, is considered, too, conformity becomes impossible. The heavy vehicle which, owing to its possibly more direct steering ratio, is made to take corners with a greater front wheel angle, shows a greater tendency to overshoot, and slower damping of the overshooting, than the light vehicle.

In view of this fact it is necessary that the steering ratio of the heavy vehicle be made less direct again in order to attain an acceptable compromise between the first response to the turning of the steering wheel and the subsequent overshooting.

If one considers these interrelations it becomes clear that the very physical facts show the necessity for a wide margin for the design of the different vehicles.

Reference

1. A. G. Fonda, D. W. Whitcomb, Theory of a practical lateral simulator for the automobile, and derived concepts of vehicle behaviour. 1957 Cornell Aeronautical Laboratory.

THE CONTRIBUTING FACTORS TO ACCIDENT OCCURRENCES

Mr. Iichi Shingu
Vehicle Safety Laboratory
Toyota Motor Company, Ltd.

Prologue

The improvements of safety performances of automotive vehicles, environment and human being as a driver, should be based upon the analysis of the facts in an accident.

So far, many numbers of accident investigations have been conducted by many organizations. And they have contributed to promote the improvements of safety performance of vehicle, especially in the field of "injury reduction," because most of them have taken up the correlations between occupants' injuries and vehicle structures.

On the other hand, not so many are the investigations of causes for the accidents to be led to "accident reduction."

Still less are the analytic evaluations of drivers' roles in causes for the accidents, while the driver is the brain in the closed loop of "man-machine system" during vehicle operation.

We, staff members of Vehicle Safety Laboratory of Toyota Motor Company, have been continuing the investigations of automobile accidents, with which the employees of our company were involved, considering mainly the psychological and physiological behavior of the driver before the accident.

It started in February 1970 and is now under succession.

The interim report of our investigation for one year since its start was edited into movie film, so, hereby, I'm going to present it.

Title. Movie

This is the interim report of employees' traffic accidents investigation, conducted by the staff members of Vehicle Safety Laboratory of Toyota Motor Company. The purpose of this accident investigation is to make clear the causes for the accidents.

ACCIDENT INVESTIGATION

Interim Report: Feb.'70 to Feb.'71

Conducted by
Vehicle Safety Laboratory
TOYOTA MOTOR CO., LTD.

Figure 1

There are three reasons why the employees' accidents are taken up for study.

The first reason: Employees can be expected to be cooperative enough to tell true facts about their behaviors just before occurrence of their accidents. Because, it is possible to convince them previously through information network in the company that their explanation will never affect the penalty, nor the rate of responsibility relating to the amount of compensation money.

The second reason: The drivers involved in accidents are too much excited in general to give out the reliable

MERITS IN INVESTIGATION OF EMPLOYEE'S ACCIDENTS

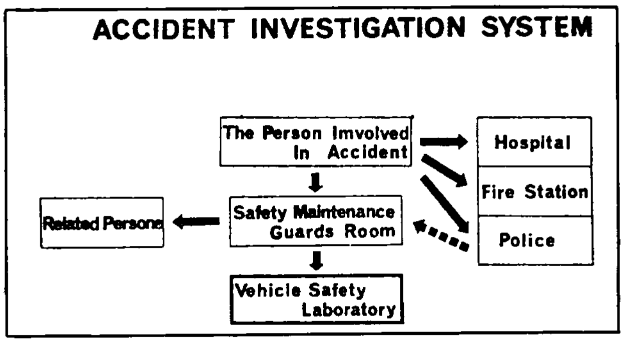
1. Co-operative
2. Convenient for Pursuit Investigation
3. Possible to take a Psychological & Phisiological Aptitude Test data

information. The drivers who are employees can be easily called in for further investigation a few days later, when they have recovered the presence of mind.

The third reason: The accident involved employee in our company is obligated to take the psychological and physiological aptitude test for vehicle operation, for the purpose of safety education. So the conferring of such test data and his behavior before the accident is easily possible.

Figure 2

This is our accident investigation system. When accident occurs, the employee of our company is obligated to report to the safety maintenance guards of the company, in addition to the police station, and if necessary, fire station and hospital.



The safety maintenance guards immediately inform of the accident our laboratory, at the same time to the employee's family and his other relations. Then, the investigators of our laboratory go out.

Figure 3

This shows the number of accidents at each hour in which our employees were involved from February 1970 to February 1971. There were about 670 accidents in all, and 184 accidents were investigated by our laboratory. Safety maintenance guards are on duty through day and night, but the investigators of our laboratory stand by from 8:30 in the morning to 8:00 in the evening.

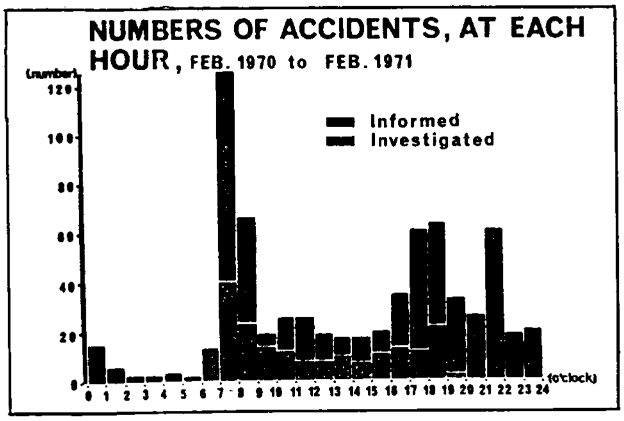
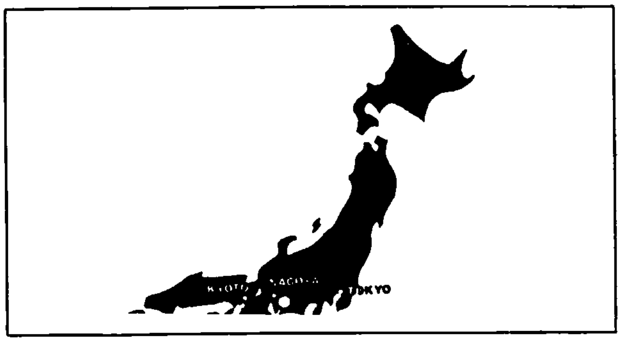


Figure 4

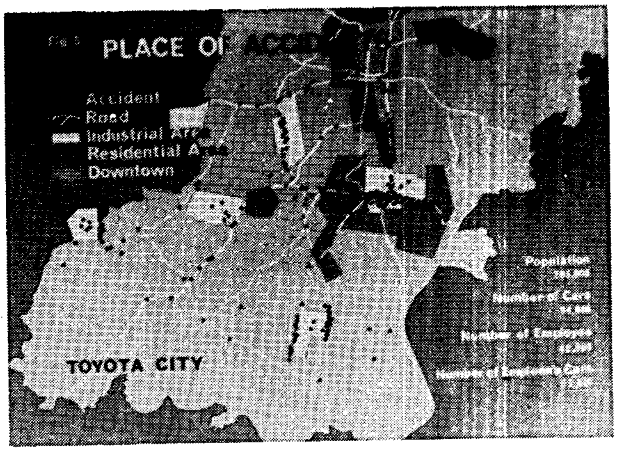
Toyota City, where Toyota Motor Company is located, is in the suburbs of Nagoya, that lies in the



midst of Japan and on the nearly halfway from Tokyo to Osaka.

Figure 5

This is a sketch of Toyota City. The yellow coloured area is downtown, pink coloured is such industrial area as factories and business offices, and green coloured is



residential area. The other grey is woods or farm field.

The places of accidents are dotted in red, and they concentrate around the industrial and residential area, as you see.

Figure 6

This picture is one of the scenes of accident investigation. An investigator with blue shirt and hat is inquiring of the driver concerned. Now, let's look at the general statistics at first.

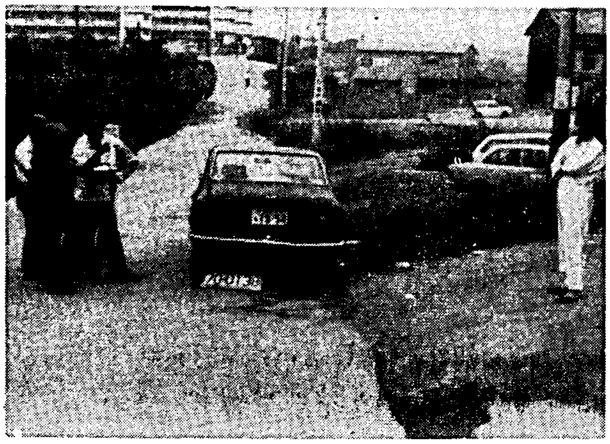
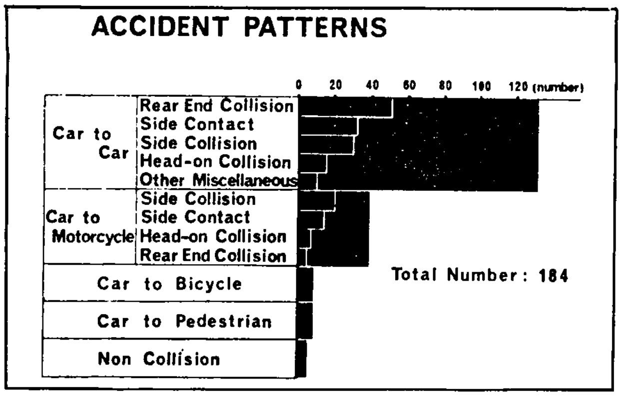


Figure 7

This figure shows the number of accidents we studied, according to accident patterns. The rear end



collision was most numerous of all accident patterns, and next was side contact.

Figure 8

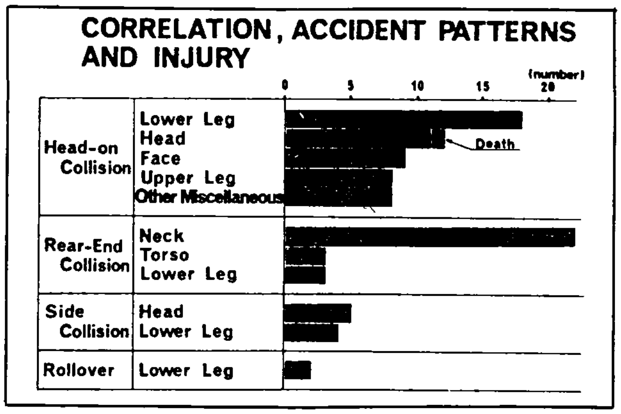
This is the correlation between the accident patterns and the occupants injuries.

In the case of head-on collision, the most numerous was the injuries on lower legs. Head, face, upper arms, and chest injuries were ranking lower in this order.

In the case of rear-end collision, whip-lash of neck was overwhelmingly numerous.

By the way, pretty old model vehicles occupied comparatively large rate of all the vehicles concerned, and the cars equipped with head restraints were about 40% of them.

Since our investigation activity was limited to the region around our company in the local city of Toyota, and limited to the accidents involving the employee of



our company, the number of fatal accidents were as few as one.

Accordingly our investigation presents not enough information, in regard to the crashworthiness or injury reduction.

However, from the view point of studying causes for an accident, the severity of the accident does not matter with the study. A slight accident might well be considered to give rather reliable informations than a severe one.

Now, let's turn to the subject of accident cause analysis.

Figure 9

This is the form for our investigation recording.

Maybe you couldn't understand this form in Japanese, so we present the translation into English.

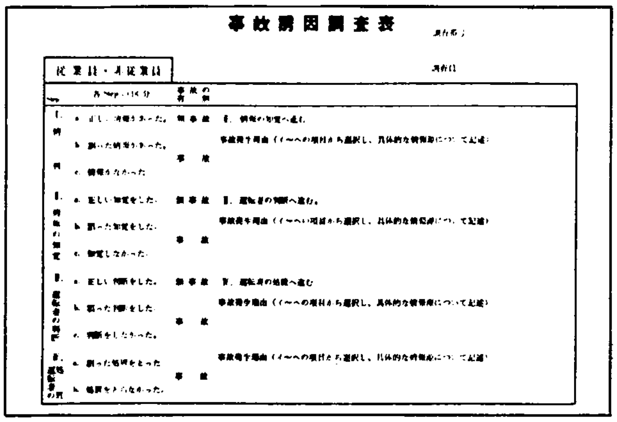


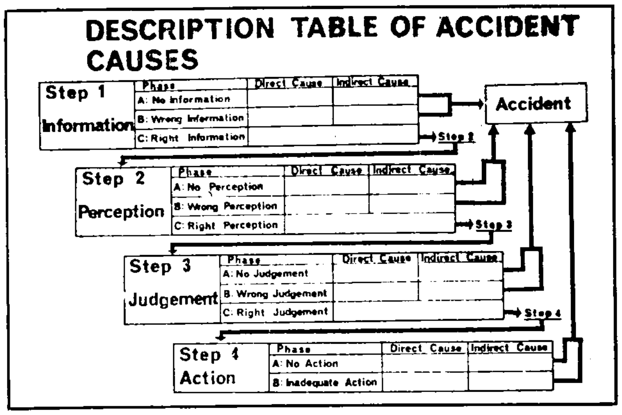
Figure 10

The procedure to an accident can be divided into four steps.

First step is the existence of information to the driver, and this step contains three phases, that is, no existence of information, existence of wrong information and existence of right information.

The investigator describes the information in detail in the column of pertinent phase. The column for description is divided into two parts. One is for the direct cause and the other is for indirect cause. Direct cause means the nearest cause for the accident, and indirect cause means the secondary cause that operates inductively or superposingly to the direct cause. When the phase of the first step falls in the existence of right information, the study goes ahead to the second step.

The second step is the perception of the information by the driver. This step also contains three phases, that is, no perception of the information, wrong perception and right perception. When the phase of the second step falls in the right perception, the study goes ahead to the third step.



The third step is driver's judgment from the information. This step also contains three phases, that is, no judgment, wrong judgement and right judgment from the information. When the phase falls in the right judgment, the study goes ahead to the final step.

The final step is the action of driver according to his judgment from the information. This step contains two phases, that is, no action and inadequate action.

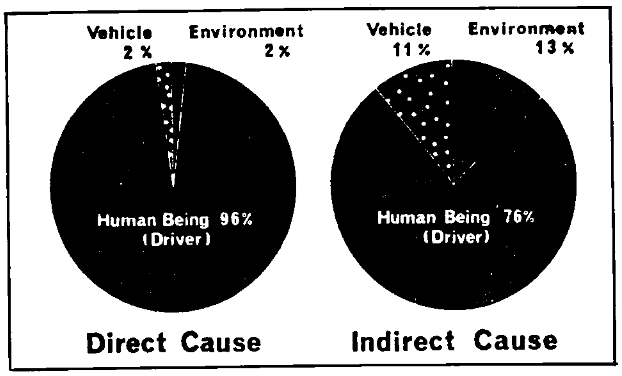
Using this form of study procedure, causes for any accident can be detected and classified into a specific phase of a specific step.

The distinction of a cause between direct and indirect is sometimes obscure, so, principally, it is left to the judgment of the person involved in the accident.

Figure 11

This picture shows the rate of causes, according to the classification of their attributes to driver, environments and vehicle.

As for the direct causes, as many as 96% of all were attributed to human beings, and as few as 2% of them



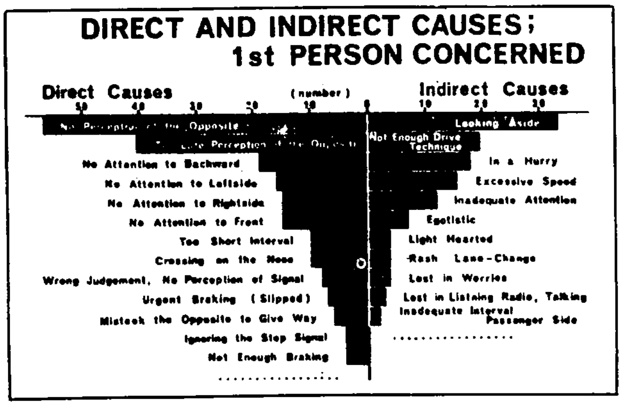
were attributed to vehicles and environments respectively.

As for the indirect causes, 76% were attributed to human beings, 11% to vehicles and 13% to environments.

Figure 12

This figure shows the detail description of causes attributed to human beings, in regard to the first person concerned with accident.

Here, the first person concerned means a person of greater responsibility for the accident than others.



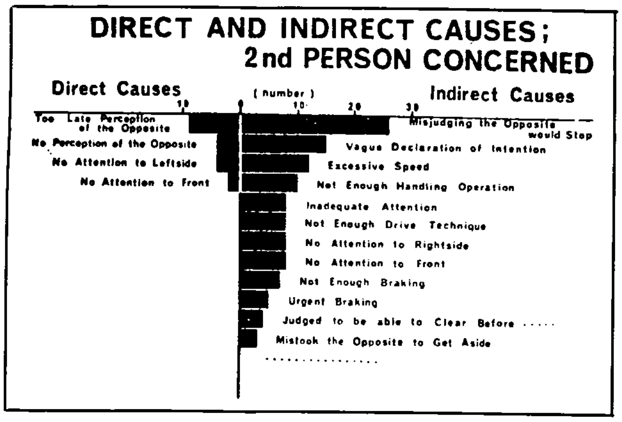
Another person of less responsibility for the accident is called here the second person concerned.

As you can see in this figure, more than half of all the direct causes in the first person concerned, were covered by such errors in the step of perception as no perception of the opposite and too late perception of the opposite.

Of the indirect causes, looking aside was most numerous.

Figure 13

This shows the direct and indirect causes found in the second persons concerned. The most numerous was misjudgment that the opposite would stop, and the next



was the vague declaration of their intentions.

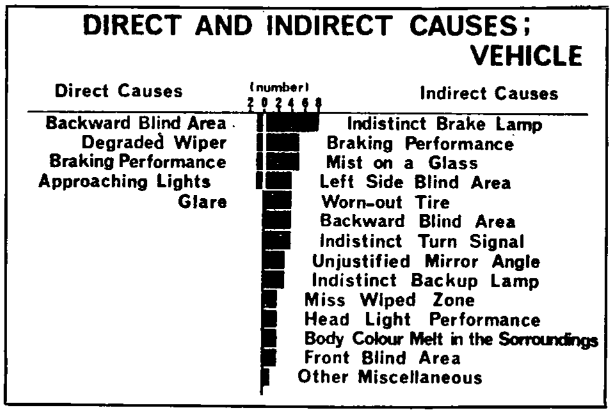
Considering the direct causes in the first person concerned and the indirect causes in the second person, we can understand the most probable situations before the accident. That is to say, one car runs on, not perceiving the opposite, and the opposite also goes on expecting that it will stop.

Here we can point out the lack of mutual communication during the car operation.

Figure 14

This figure shows the detail of causes attributed to the vehicle.

The direct causes were only four in all. They were backward blind area, not good wiping operation, poor



braking effect and glare by the approaching car's head lights.

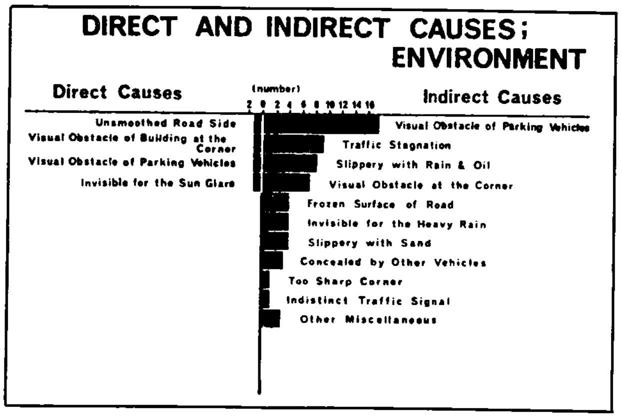
Most of the indirect causes were related to the visual performances, such as difficulties in distinction of brake lights.

Figure 15

This figure shows the detail of causes attributed to the environments.

Direct causes were as few as only four.

Indirect causes consist of 69% of visual troubles, 30% of road surface condition, and 10% of other miscellaneous matters.

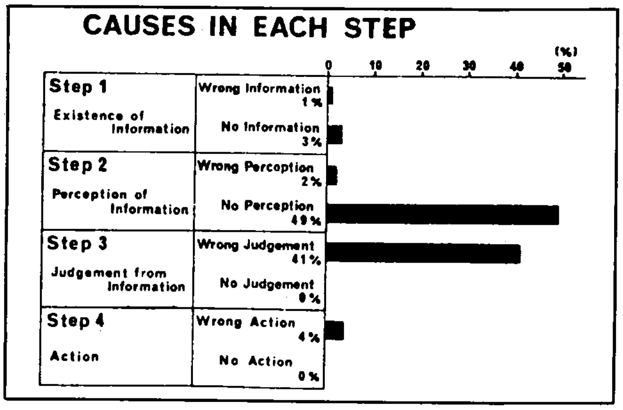


So as mentioned before, most of causes for accidents were found to be attributed to human being and a very few to the vehicle.

Figure 16

This figure shows the direct causes we studied, classifying into four steps mentioned before.

The first step of existence of information, and the final step of action of driver cover only 8% of all, 92% of them belong to the second step of perception of information and the third step of judgment from information.

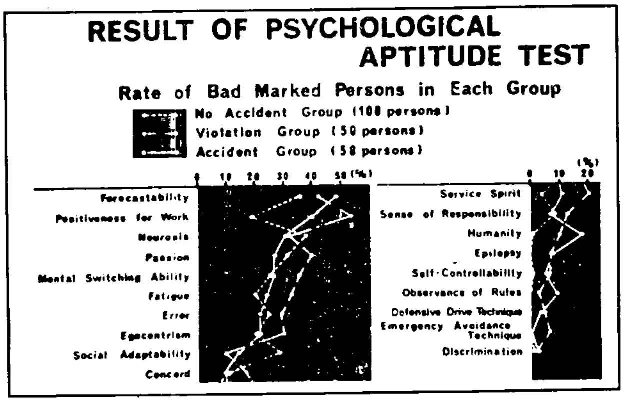


Moreover, these errors in the steps of perception and judgment were induced from or superposed by human factors in the indirect causes so much as 76%.

Now, we are reporting some aptitude test results of these persons concerned with accidents.

Figure 17

This figure is the result of psychological aptitude tests for vehicle operation, in regard to various components of psychology. It shows the rate of bad marked persons about three groups. They are groups of 100 persons who had never been involved in an accident for more than five years, group of 50 persons who had been arrested because of traffic violations during the past one year, and group of 58 persons who were investigated by us as the accident-involved drivers.



The testing procedure we used had been developed by Traffic Affairs Research Laboratory of Japan Industrial Design Co., and has been getting popular in Japan.

As you can see in this figure, group of accident-involved persons was evaluated worse than no accident group in each components of forecast-ability, positiveness for work, humanity, observance of rules, and self-controllability.

Figure 18

This figure shows the difference of bad marked person's rate, among the three groups, in regard to such remarkable components. By the way, this figure shows also that the group of violation is the first reserve for the accident group, in other words, they are liable to cause accidents.

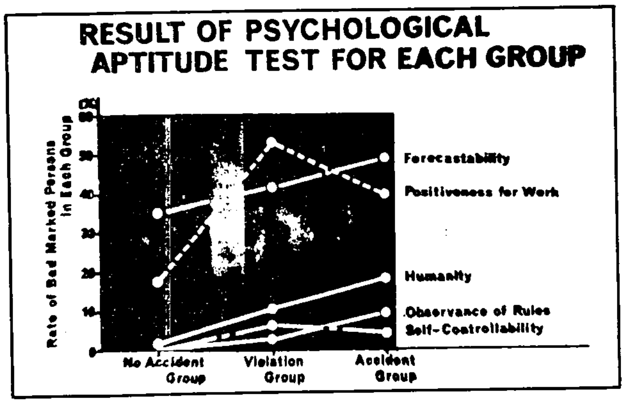
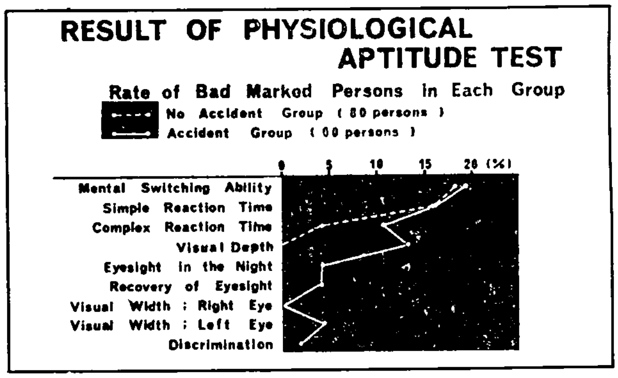


Figure 19

This is the result of physiological tests of the same no-accident group and accident group, and shows the rate of bad evaluated persons in regard to some physiological capabilities.

The testing procedure we used had been developed by Industrial Safety and Sanitation Maintenance Laboratory of our Company.



As the features of accident group, they are pretty inferior to the no-accident group, about time for complicated reaction and sensibility to visual depth.

Now, let's show the typical episodes of accidents caused by psychological or physiological unfitness.

Figure 20

This is an episode of Mr. T. who was 19 years old and had one year of operation career.

His accident occured at 7:45 in the morning on April 18th in 1970. It was rainy morning. He was turning right, to go to parking area for the employees of our factory. Then, he noticed another car approaching in the opposite direction. But he thought he would be able to clear before it came close, and went on. But he could not, and the opposite car bumped against the left front corner of his car.

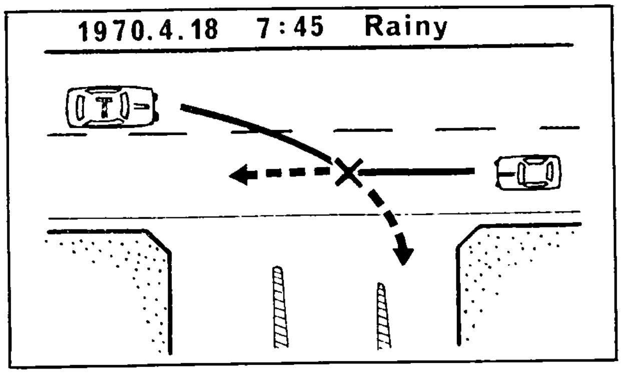


Figure 21

This is the place of this accident. Flat, straight, wide enough, no obstruction, not so bad was the view.

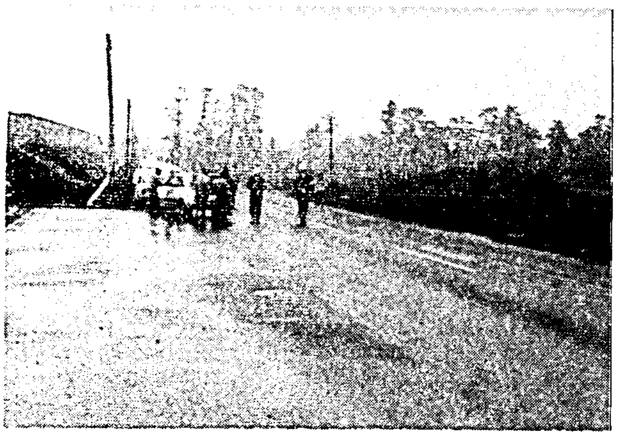


Figure 22

This is the car of Mr. T.

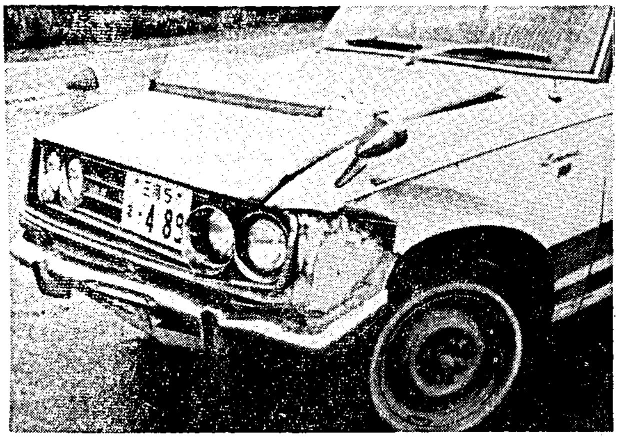
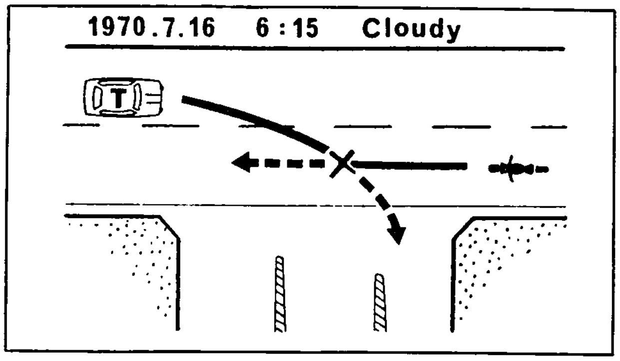


Figure 23

This is the opposite car.

Figure 24

About three months later, Mr. T. experienced the same kind of accident, at the same place, at 6:15 in the morning of July 16th. The weather was cloudy. The



opposite was a motorcycle this time. He was turning to right and judged he could clear before the opposite would come to his way and went on. But he could not and collided.

Figure 25

This car is Mr. T's. He had borrowed this car from his brother.

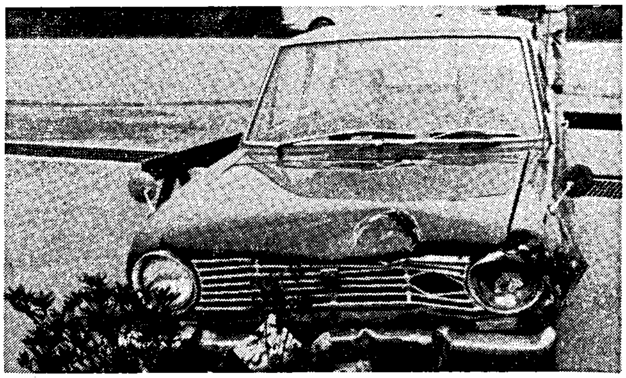


Figure 26

This is the opposite motorcycle.

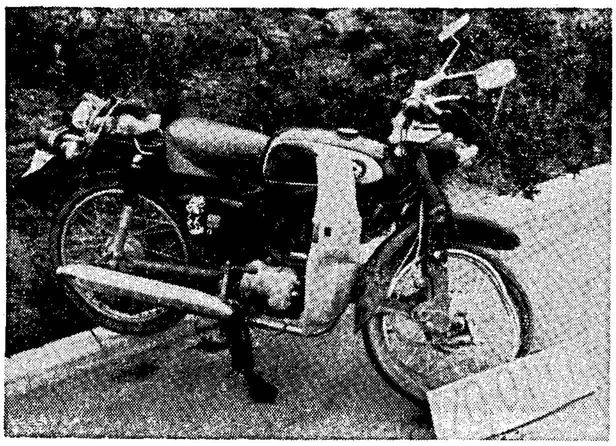
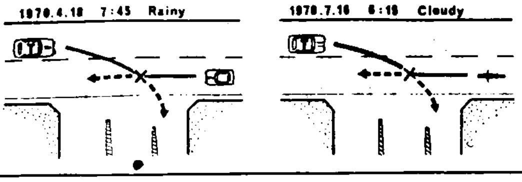


Figure 27

The general evaluation by his psychological aptitude test was pretty good, but in regard to the mental switching and forecast-ability the data showed inferior to average. The physiological aptitude test result evaluated him unsuitable for vehicle operation, and especially

THE PERSON Mr.T. (19years old. Driving career 1 year)

Physiological Aptitude Test (Unsuitable)	Sensibility to Visual Depth	4.25 (3.25)
Psychological Aptitude Test (Pretty Good)	Mental Switching Ability	-4 (-4)
	Forecastability	-14 (-10)

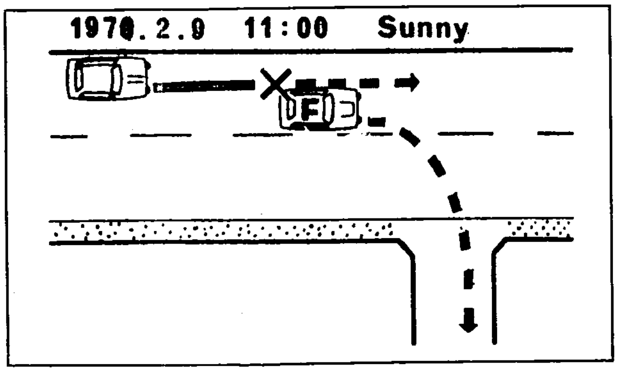


his sensibility to visual depth was so bad.

The parenthesized numbers in the table of this figure are the lowest permissible values decided by the developers of these testing procedures.

Figure 28

The next episode is of Mr. F., 22 years old and three years of operation career. About 11 o'clock in the morning of February 9th in 1970, his car was bumped



from behind by following car. At that time, he had been decelerating the car by braking, with the turn signal lights on, intending to turn to the right at the next corner.

Figure 29

This is his car collided. The tail lamps are covered crosswise with Scotch tape on purpose.

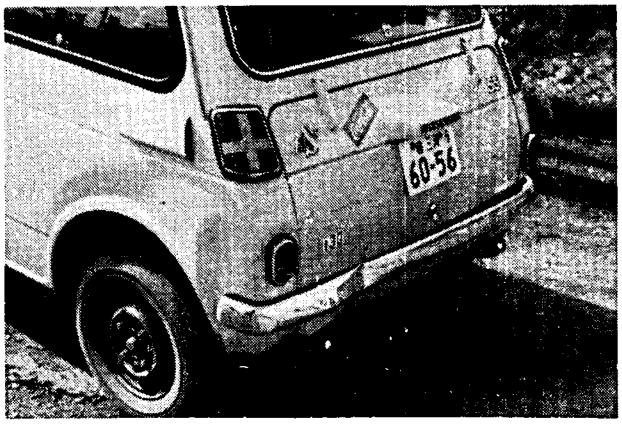


Figure 30

About three months later, he experienced another accident again. He was going out to turn back from the parking zone along the curb pretty rashly, then a motorcycle coming from behind could not stop and bumped against the side of his car.

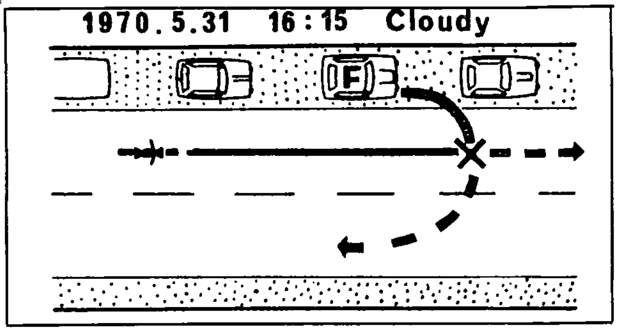


Figure 31

This is his car collided at that time. Front bumper had been taken off, and head lamps were also covered crosswise with Scotch tape. It was the very fashion of racing car in a racing circuit, just as Touring car class I. He was one of the young men mistaking the public highway for the closed racing circuit.

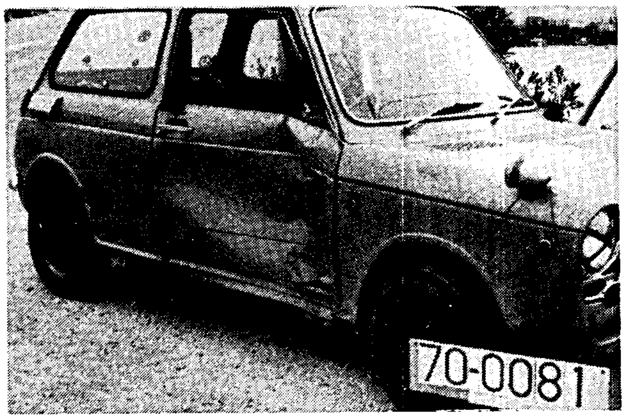
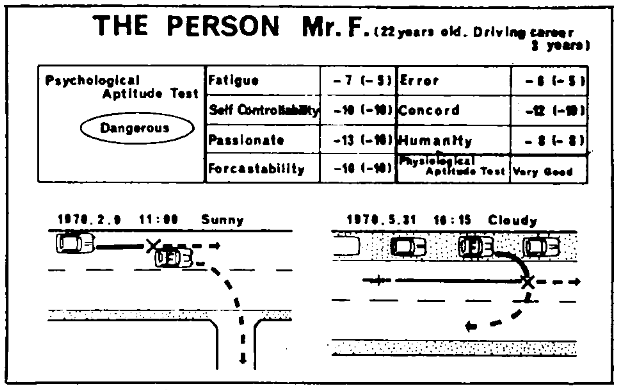


Figure 32

The result of his psychological aptitude test showed that he was extremely liable to be fatigued, to be passionate, to be uncooperative and to fall into an error. And also, in regard to self controllability, forecast-ability and humanity, he was just on the boundary between permissible and not permissible for vehicle operation.

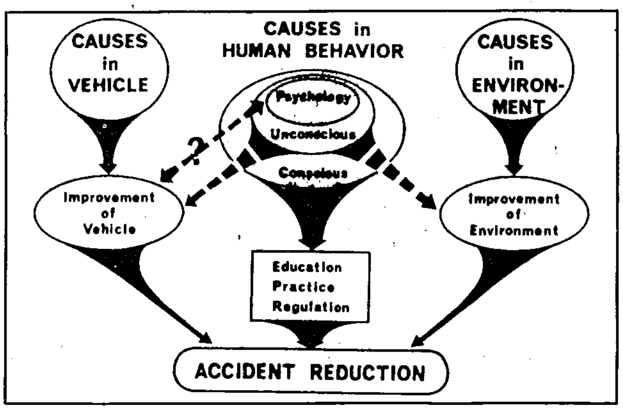
The general evaluation of psychological aptitude was indicated "dangerous."



On the other hand, his physiological aptitude for vehicle operation was evaluated very good. He brought forward the new problem that the combination of psychological unfitness and physiological excellence, like him, often leads to rash and unreasonable driving, especially when he operates the car of good performance. That seems as if the performance of the car agitates his psychological unfitness.

Figure 33

Through the investigations of our employees' accidents for one year, the contributing factors to accident occurrence were made clear to some degree. But still there remains so many things unknown. They are often concerned with the psychological black box concealed deep in human beings.



This diagram shows the accident reduction system that can be conceived at this stage.

The causes belonging to vehicle or environment, should be removed by their respective improvements.

The problem is the treatment of the causes in human behavior, and yet it is most important for the accident reduction. There are two conceivable solutions of this problem.

One is the compensative improvements of vehicle and environments, and another is the improvements of human beings itself, by due education, practice and strict observance of regulations.

The next problem for us is to what extent the compensative improvements of vehicles should be done, or in other words, to what extent the effect of education and practice could be expected. There might be no answer to this question.

So we considered as follows.

The human behaviors consist of conscious behaviors and unconscious ones. Though the division is not always clear, as to which behavior a certain cause should be attributed to, we tried to divide the human causes investigated into the two categories. In its consequence about 60% of direct causes belonged to unconscious behavior and 40% to conscious behavior. The causes in conscious behavior cannot be removed by the improvement of vehicle. They could be removed only by education practice and strict observance of regulation, because they are products of very "will" of operator.

Accordingly, the improvements of vehicles should aim at the elimination of causes in unconscious behaviors, in a cooperative manner to education, practice and regulation.

Now, still remains another problem.

The problem is the interaction between human psychology and vehicle performances.

The psychologically low developed person with excellent physiological aptitudes, such as Mr. F. in this film, is apt to like the sporty version with good performance of vehicle dynamics, and to attempt and enjoy an extremity of the performance. In other words, his psychological unfitness is excited by the improved vehicle performances, such as steering, braking, passing and so on.

We have no conclusive solution yet about this problem.

Figure 34

Now let me show the conclusions of our investigation briefly.

No. 1: More than 90% of direct causes and more than 70% of indirect causes were attributed to human beings.

CONCLUSIONS

1. More than [90 % of direct / 70 % of indirect] Causes;
attributed to Human Behaviors.

2. Most numerous situations before accident;
Lack of mutual Communications

3. Remarkable Psychological / Physiological Unfittness;
Forecast-ability, Positiveness for work,
Humanity, Observance of Rules,
Self-controllability,
Sensibility to Visual Depth,
Complex Reaction Time.

4. New problem;
Interaction between Human Psychology
and Vehicle Performance.

No. 2: The most numerous situation before accidents was the lack of mutual communication among vehicle operators.

No. 3: Psychological and physiological unfitness of accident involved drivers could be seen in forecastability, positiveness for work, humanity, observance of rules, self-controllability, sensibility to visual depth, and complex reaction time.

No. 4: The interaction between human psychology and vehicle performance should be studied hereafter.

Epilogue

The results of our investigation were almost as had been expected by most people concerned in Japan. But the rate of human factors to the whole causes for accidents was pretty higher than expected.

As mentioned before in our movie film, we think that the psychological refinement of drivers by education or any other way is most important to eliminate the human causes for accidents, and we should aid or support them with various improvements of vehicle.

The elevation of crashworthiness or occupant protection performance of vehicle can be looked effective as the supplementary or alternate improvements for the difficult elimination of accident causes, and actually, now it is the most urgent task for us car makers to fulfill.

However, crashworthiness cannot reduce the number of accident occurrences. (And it might rather increase accidents and number of injured people, because it would alleviate the fear against accidents from vehicle operators.)

Considering the results of our investigation, the most effective improvements of vehicles to accident reduction seems to be equipment of warning or alarming devices that work against vehicle operator or other vehicles when the operator falls into dozy, fatigued, or excited condition.

We studied also that no perception of information by drivers was mostly for the reason because they did not look, and not because they could not look. So the effort to be made for excessive improvements of direct and indirect visibility would not be so much rewarded as expected. Of course we don't think that the results of our investigation are common to other countries, where such conditions as traffic administration, traffic environment, drivers education, and other customs and manners are much different from those in Japan.

So these kinds of investigations in other countries would be highly appreciated.

Thank you very much.

APPLICATION OF RADAR TO AUTOMOBILE CONTROL AND SENSING

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Abstract

A description of two new experimental radar driver aids is presented. One adds longitudinal control to existing automobile speed controls to automatically operate both throttle and brakes in response to traffic flow. The second radar system acts as a rear vision aid.

Summary

The continuing increase in the automobile population, coupled with advances in roadway construction permitting higher speeds, has led to the need for sophisticated methods of automobile control beyond the capability of the human driver. Accidents involving several automobiles are no longer subjects for headlines – they are too common.

Radar, because of extensive use in aerospace systems, is a natural choice for development as a driver aid. Modern solid state technology has progressed to the point where low-cost subsystems are now feasible. Two systems are currently under development at Bendix: Adaptive Speed Control adds automatic headway (or spacing) control to existing speed control devices; Automobile Rear-End Warning provides a radar aid to rear vision.

Speed control devices have been available as options on most American cars for some time. They permit a car to hold any desired speed without driver control of the throttle and thereby are a desirable convenience to drivers. When moderate to heavy traffic is encountered, the convenience feature of speed control becomes marginal. The driver is constantly forced to override the system to avoid potential collisions. Adaptive Speed Control is a first step toward making the longitudinal control function automatic. The initial use will provide added driver speed control convenience. Later, as car-highway and car-to-car cooperation becomes possible, fully automatic highway control can become a reality.

Figure 1 shows the characteristics of the present system. The system automatically holds a driver-set speed unless the car overtakes leading traffic. When the system detects leading traffic, the throttle and brakes are automatically adjusted to achieve and maintain safe headway.

- ADDS HEADWAY CONTROL TO BENDIX AUTOMATIC SPEED CONTROL
- MAINTAINS SELECTED SPEED ON OPEN HIGHWAY
- ACHIEVES AND MAINTAINS SAFE HEADWAY ON LEADING VEHICLES THROUGH THROTTLE AND BRAKE CONTROL
- RESPONDS ONLY TO CARS IN OWN LANE
- DISREGARDS OVERPASSES
- DOES NOT REQUIRE COOPERATION FROM OTHER CARS
- BUILT-IN SELF TEST FOR TRANSMITTER AND RECEIVER

Figure 1

Figure 2 shows a block diagram of the complete system. The components below the dotted line comprise the basic speed controller. The components above the dotted line are the elements that provide automatic headway control. The driver initiates operation by pushing a speed-set button. The speed controller memorizes this value and signals the actuator to set the proper throttle position. If changing road grade causes speed errors, the throttle is commanded to adjust as required.

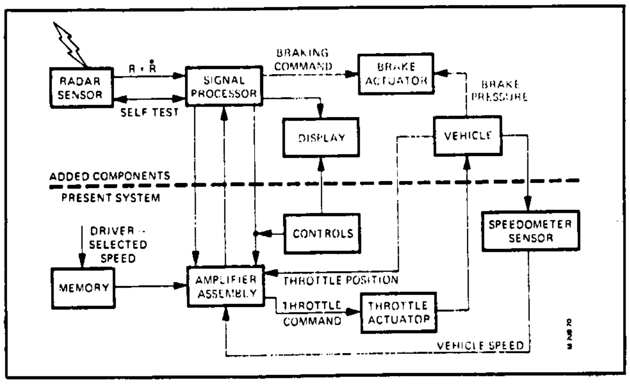


Figure 2

In the event a car is overtaken, the radar measures and sends the relative velocity and range to the signal processor. The processor combines this data with an input of own car speed and determines whether throttle or brake actuation is required. The system will continue to follow as long as the lead car stays under the driver-set speed of the radar-equipped car. The car will never exceed the driver-set speed. Of course, the driver can override the system at any time by manually applying the throttle or brakes.

Prior to fabrication of the first system, a detailed mathematical model was developed and used as a design aid. To achieve a near real time model, a hybrid computer was used in the system simulation. Each function subsystem was modeled. These models were (for a single following vehicle case):

1. Headway-mode Control Law
2. Brake Law
3. Accelerator-Pedal-Actuator
4. Lead-Vehicle Throttle
5. Speed Controller and Signal Processor
6. Radar Sensor

The headway mode control law defines the points at which commands are sent to the throttle and brakes. A brief discussion of the law is pertinent to understanding system operation. This law is:

$$E = (R - R^*) + 3\dot{R} \qquad (1)$$

$$R^* = 50 + V \qquad (2)$$

where

E = Control Voltage Level
R = Measured Range in Feed
R^*= Desired Range in Feet
$\dot{R}$ = Measured Relative Velocity in MPH
R = Equipped Vehicle in MPH Expressed in Feet (1 MPH = 1 Foot)

The control voltage level is at zero when the system is at desired headway. A positive voltage indicates acceleration is required. A negative voltage initiates throttle back-off; at a high negative level, braking is initiated.

The simulation proved to be a valid representation of the system performance and was of major benefit in design of the experimental system. Figure 3 shows a simple diagram of the control areas. The range rate is plotted versus range between cars. The range rate is opening above the abcissa and closing below. The desired headway, as stated before, is a function of the absolute velocity of the radar car (see equation (2)). The car represented by the trajectory plotted in Figure 3 enters the throttle control region and is slowed by only throttle deceleration to the desired headway. A faster closing velocity would have required proportional braking or, at very high closing velocities, maximum braking to achieve proper headway.

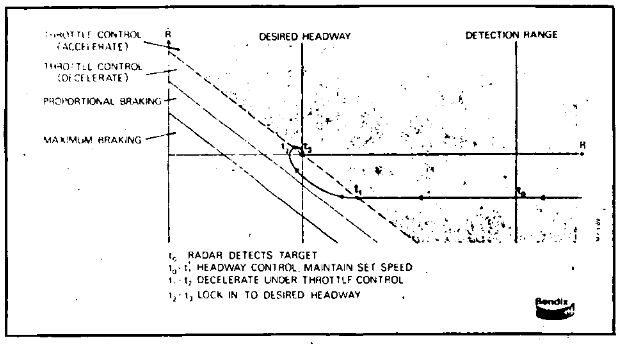


Figure 3

The design of a low-cost radar suitable for automobile headway control received considerable study. Both range and range rate measurements are required. A two-frequency CW approach[1] was selected over pulse or other CW modulation techniques after a cost/performance study.

The radar block diagram is shown in Figure 4. The transmitter is switched between two closely spaced frequencies. Each of the doppler-shifted return signals is gated into a separate channel. The range is a direct

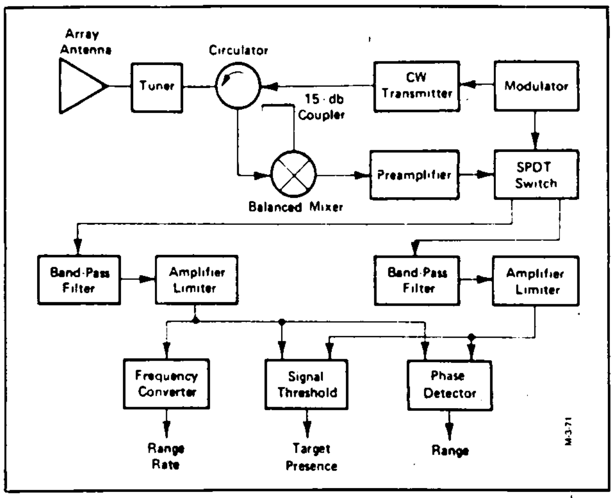


Figure 4

function of the relative phase between the two doppler signals and is extracted at the phase detector. The range rate is derived from one doppler channel. A third output is a threshold level measurement to assure acceptance by the processors of good signal-to-noise ratio data. The threshold level, therefore, determines the maximum system range.

The selection of a two-frequency radar approach presented two system problems. Since doppler is required to obtain range, no information is available at optimum headway when range rate has been reduced to zero. Also, the system lacks range resolution and can suffer from multiple target effects. Our experience to date has shown that the signal processor can overcome these obstacles when provided with memory and smoothing.

The first radar operated at 16 GHz with 50 milliwatts of transmitter power. The operating range was 200 to 400 feet depending on the size and shape of the car involved. As might be expected, small foreign cars were at the low end of the range.

A simple self-test feature is built into the radar. In the absence of a target, the signal processor periodically commands the modulator to audio modulate the oscillator. The system detects this modulation through leakage. If the leakage exists, it passes through the amplifier and is detected. Failure to detect this response lights a fail light and disconnects the system. It is felt that this technique is valuable to assure that the transmitter-receiver is operative. Further attention is being given to this important area to determine the best fail-safe approach for a final system.

The antenna and microwave section are shown in Figure 5. A standing-wave waveguide-array antenna was employed to simulate an automobile grill. The remaining components are standard microwave packages including a circulator, mixer, coupler, and isolator. The transmitter is a Gunn oscillator. Figure 6 shows the system mounted on a Continental Mark III. Tests to date have proven the feasibility of Automatic Headway Control.

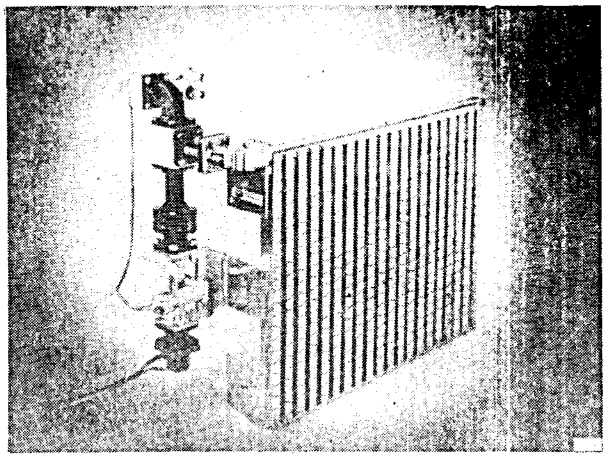


Figure 5

The second radar application to cars is in a rear vision aid. Dunlap and Associates[2] recently completed a study on motor vehicle rear vision for the National Highway Safety Bureau. The report noted that rear vision is one of the important areas requiring action. The actual proportion of accidents attributable either to lack of adequate rear vision information or to design of the rear vision display was difficult to determine. However, the general conclusion was that blind spots are a contributing factor in many accidents involving cars going in the same direction. Our rear warning system is designed

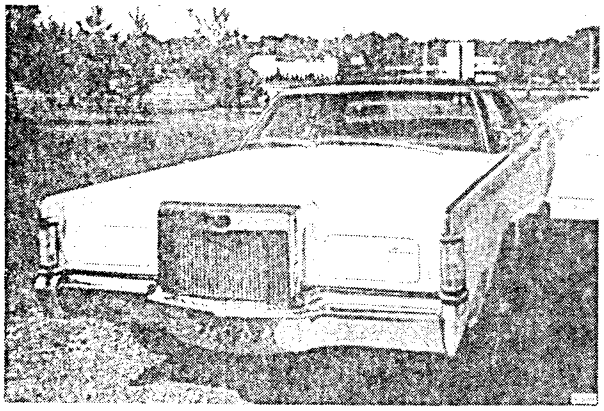


Figure 6

to alert the driver of the presence of traffic in his blind zones.

The system is composed of two lane-changing sensors and back-up sensor. Each sensor is a CW homodyne radar. Figure 7 shows the approximate coverage of each sensor. The antennas for the lane-changing sensors can be mounted adjacent to the automobile tail lights. The antenna patterns intersect adjacent lanes to illuminate the blind areas and to warn of the presence of approaching automobiles with a light or audible signal. The radars are instrumented to ignore roadside objects. The maximum range of these sensors is 50 to 70 feet on cars, with a minimum range response down to the center door post to cover the entire blind zone.

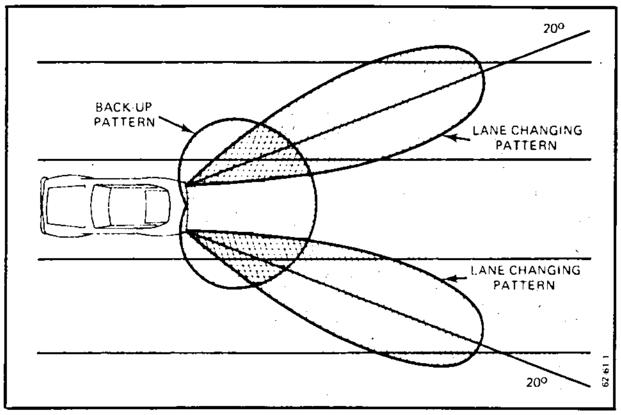


Figure 7

The antenna for the back-up sensor can be integrated into the rear bumper. The sensor is inoperative until the automobile is in reverse gear. Visual and audible warning is activated in the presence of obstacles such as humans, bicycles, posts, etc. The antenna pattern is centered on the road surface at a distance 10 feet behind the automobile. The sensor range is 0 to 30 feet.

Figure 8 shows a picture of a car equipped with the three sensors. The engineering tests to date have shown that this type of warning can be a valuable aid to drivers.

Figure 8

References

1. W.D. Boyer, "A Diplexing Doppler Phase Comparison Radar," *IEEE Transactions on Aerospace and Navigational Electronics ANE 10*, No. 1, pp. 27-33, March 1963.

2. Charles R. Kelley, et al., "Motor Vehicle Rear Vision." Final Report, Contract No. FH-11-6951, U.S. Department of Transportation, August 1969.

A NEED FOR RESEARCH

Mr. Francis A. DiLorenzo,
ESV Program Office

Part I – Introduction

Ultimately, the National Highway Traffic Safety Administration will levy vehicle handling standards on all motor vehicles sold in the U.S. The present schedule shows research activity through 1973; however, the ground work for even the issuance of an NPRM must begin now. It is to the common interest of both Governments and industry for all involved to supplement research efforts so that in the total picture, no major facets of the work are left undone, and the subsequent standard(s) that are issued have safety relevance and criteria that can be measured.

Closed-Loop – Open-Loop Terminology

Terminology such as subjective testing, objective testing, and man-vehicle response, have been used in the literature to describe vehicle dynamics testing techniques and while to date this has not presented a problem in written or verbal communication, for this discussion only the terms "closed-loop" and "open-loop" will be used. Open-loop disregards the feedback the driver gets from the vehicle, while closed-loop allows continual driver corrections based upon vehicle actions. Both techniques are presently used. At the risk of being unctuous, it would be well to consider that all earnest experimenters are objective in their task and that differences lie in the chosen techniques.

Neither the use of closed-loop, when referring to man-vehicle test, nor the use of open-loop response, when referring to machine-vehicle test, precludes other possibilities of testing techniques that already exist. As an example, when a driver is instructed to put in a given amount of steering or a steering input at or above a given rate without regard to the subsequent vehicle behavior, the test is considered an open-loop test because the driver makes no further inputs to the vehicle regardless of the vehicle's performance. By the same token, if a machine is refined to the extent it can maintain a vehicle on a prescribed path with a preset velocity, the test is considered a closed-loop test because the machine provides inputs based upon vehicle response. For the present state-of-the-art, some tests such as the transient yaw response in the ESV specification use drivers but are considered open-loop testing. The HSRI, in their report titled "Vehicle Handling Test Procedures," utilized a machine to perform their open-loop test maneuvers. Ultimately, if such a machine could be designed to comprehend vehicle "feed-back" in the same manner a driver does, we would have an ideal closed-loop testing technique.

For the present, however, the NHTSA is faced with the task of implementing and testing conformance to, vehicle handling standards in the near future, without having the benefit of this ideal testing technique. This can only imply, due to the large number of vehicles and testing agencies involved, that for compliance tests, the open-loop responses will be used, at least initially. Further, only a machine could produce the desired repeatability of combination braking and steering maneuvers. The momentous problem confronting us as members of Governments and industry is to correlate open-loop test results with closed-loop test results if, as stated earlier, the first handling standards are to have safety relevance and measurable criteria.

Part II - Program Plan

This part of the discussion describes schematically one way in which a program or number of programs could be integrated and produce the results necessary for solving the problem described in part I. Figure I shows the total flow of information, beginning with accident investigation results and culminating in handling standards. The input and output of each box will be given in

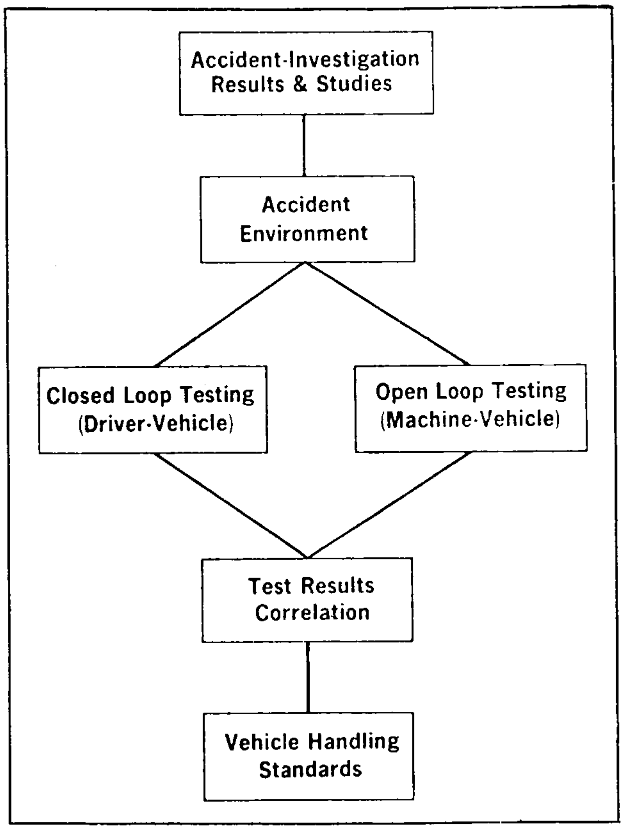


Figure 1

detail; however, as a brief overview of the picture, it can be seen that the information flow must begin with data obtained from the accident investigation results. From these data, the complete accident environment is defined providing the information necessary to design the two test programs: closed-loop performance tests and open-loop performance tests. The results of both programs are brought together for the correlation study. From the correlation study, viable handling standards are generated.

Figure II - Going back to the first category of work and into more detail, the NHTSA has some 16 investigating teams located throughout the States who report on some 700 accidents each year. We are currently modifying the accident investigator's report format such that more of the accident avoidance type data may be obtained from each investigation. As an example of the information obtained from these investigations, the investigator may quiz the driver on topics such as: How far away were you when you first perceived the other car, etc.? Did you attempt to steer or brake, steer and

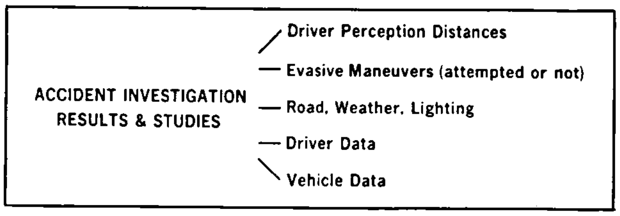


Figure 2

brake, etc.? The investigator would also determine the feasibility of a proper and possible evasive maneuver that may have avoided the accident. Many other vehicle, driver, and environmental factors such as visibility limitations, road conditions, etc., are already being recorded. The intent of a revised accident investigation format is to aid in the design of realistic closed- and open-loop tests.

Figure III - With the results of an adequate number of investigated accidents, the complete accident environment may be defined. There will also be statistical information on the relative frequencies of each accident

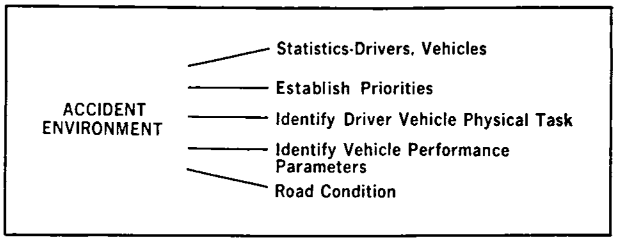


Figure 3

so that priorities may be established. We would know, as an example, the manner in which drivers of various ages behave in the accident environment. Figure III lists some of the representative data, much of which is being recorded at present.

Figure IV - The next step in this process is to design the test programs. There are always restraints in time and budget that must be considered; however, foregoing that for this discussion and considering the driver and vehicle or closed-loop performance test first, man-task maneuvers are created which simulate the environments discussed in the previous step. Also, we select drivers and

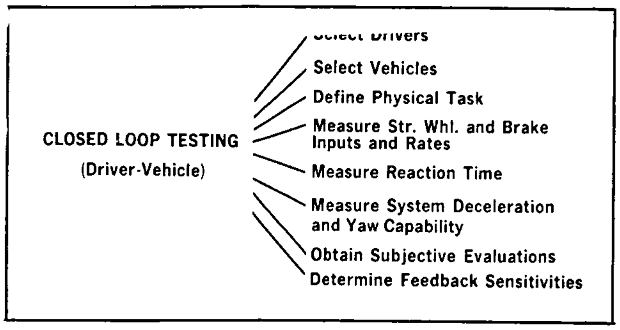


Figure 4

vehicles that represent the population. The output of this program would be quantification of such system parameters as: What is the maximum displacement a steering wheel is turned? What is the maximum steering wheel rate of input? What is the driver-vehicle reaction time, etc.? The testing group could also obtain certain information from the drivers concerning their subjective evaluations of vehicle handling and vehicle feedback.

Figure V - Parallel to this effort, the machine-vehicle or open-loop test would be conducted, designed to simulate as closely as possible the accident avoidance environments described above. Inputs to steering,

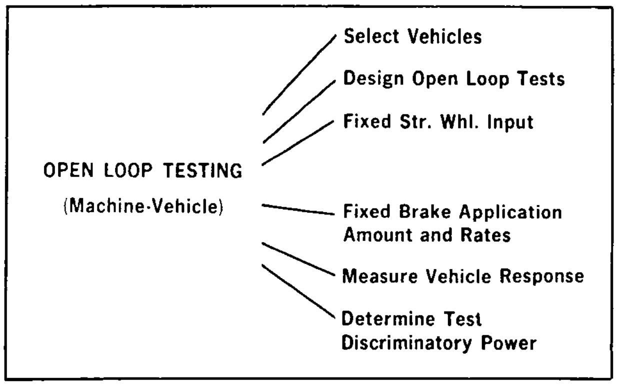


Figure 5

braking and throttle would be programmed and by definition, there would be no feed-back considerations. The conventional dynamic parameters such as yaw, yaw rate, response time, etc., would be recorded for each test. The spectrum of tests involved here should include the low lateral "g" realm as well as the "limiting" value of "g" maneuvers.

Figure VI - As soon as data are available from both test programs, correlation work should begin. Three of the prime purposes for this correlation are: (1) to validate the sensitivity of the open-loop performance tests as they relate to closed-loop performance tests, (2) to define minimum open-loop performance

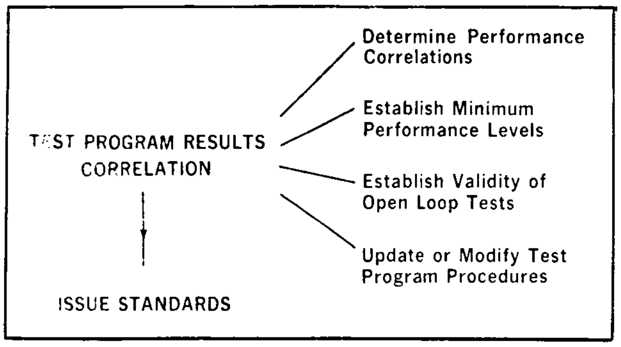


Figure 6

based on closed-loop test results, and (3) to aid in the selection of modification of future test procedures. The outputs of this effort would be the information necessary to write the first handling standards.

As a total program, this effort, beginning with accident investigation results, is not considered a one-time venture. It will require continual attention as a deeper understanding of each facet is gained through experience. Many problems will be surfaced that may or may not be obvious at the onset of the program. One that comes to mind immediately is the selection of drivers. Should they be professional or just experienced. If experienced drivers are chosen, their "learning curve" or adaptability to these kinds of tests will have to be taken into account. Conceivably, car A could be superior to car B for a particular maneuver; however, should the naive driver drive car A first, as a man-vehicle system, his performance may be below that of his later performance as a man-vehicle system using car B since he has had a chance to acclimate to the tests. The alternative to that, which is to use professional drivers, also has serious drawbacks from the standpoint of a professional driver's ability to make a poorly performing vehicle look acceptable by applying his own skills. This is one of many problems which will require tradeoffs in technical data, time, funding, safety, etc.

Part III - Conclusion

Undoubtedly, many, or all, of us have been, or are, active in many portions of this suggested plan. Through formal studies, intuition, etc., vehicle testing maneuvers, both closed-loop and open-loop, have evolved, and the production cars of today reflect the results of that effort. Certainly the automotive industry uses both modes of testing for developmental work, relying perhaps on the closed-loop methods for arriving at final production configurations. The NHTSA, through contracts with HSRI and Bendix Research Laboratories, has completed two years of research in vehicle dynamics, focusing attention on mathematical modeling and open-loop testing. Tentatively, we plan to initiate closed-loop testing in F/Y 1973 (July 72 – July 73) and, because it is a starting point for us in that field of research, we can expect many problems. Today, in light of forthcoming standards with potential maneuvers involving both steering and braking that are too complicated for even professional drivers to repeat consistently, it is time to reassess the problems of quantifying vehicle dynamics.

The program plans described above are intended only to stimulate interest in an area that needs research and does not necessarily reflect or imply the final methods by which the National Highway Traffic Safety Administration will arrive at vehicle handling standards.

SECTION 4

PART 5 VEHICLE BRAKING

PERFORMANCE SPECIFICATION FOR ANTI-LOCK SYSTEMS

Mr. R. Cochrane, Girling
Girling Ltd.

It is generally accepted that safety vehicles should be fitted with some form of anti-lock brake system. Many such systems are being developed and their benefits have been demonstrated. Genuine claims of significant improvements in stopping distance and controllability have been made. Nevertheless, the fitting of an anti-lock system, unless correctly specified, may well introduce additional hazards.

An anti-lock system, like air-bag restraint, is an entirely new concept in vehicle design. It is not a development of an existing braking system. It is an entirely new system which is additional to all those currently fitted to vehicles. But the most important feature is that it is the first major vehicle system capable of making a decision to oppose a driver's demands if it believes his decision to be incorrect. In this way it is different to air-bag restraint which can make decisions, but does not actually oppose the driver. It is therefore as essential to prove that it can always make the correct decision, as it is to prove that an air-bag will only inflate at the correct moment.

There has been very considerable discussion over the consequences of using air-bag restraint, yet little attention has been given to the requirements and testing of anti-lock systems. I therefore propose to introduce briefly some relevant points.

The braking targets that have been specified in the various ESV programs provide little incentive to brake system designers. For instance the VDA specification for German ESV's requires .75 utilisation coefficient, laden or unladen, on surfaces from .2 to .8 friction coefficient. This could be achieved now with a good load-conscious apportioning valve.

At present no specification appears to have been issued that will force anti-lock designers to work towards an objective giving a more positive contribution to safety, by testing braking performance while steering.

The requirements of an anti-lock system are dependent on the country and environment in which they are used. For instance in the United States a much larger proportion of road accidents occur on highways, freeways and expressways, than occur on motorways in the United Kingdom. Any vehicle deviating from its lane involves other cars travelling in the same or opposite direction. A large number of accidents in the United States could therefore be prevented by adopting a system giving stable straight line stopping during emergency braking.

However, in the United Kingdom relatively few accidents occur on motorways, but a much larger proportion occur in situations in which the ability to take evasive action could reduce the severity of the accident, or avoid it completely. The requirement therefore, in countries such as the United Kingdom, is to provide a system capable of giving both steering and braking ability.

	UK	USA
PEDESTRIAN & PEDAL CYCLISTS	1.6	
OTHERS	2.0	2.7
TOTAL	3.6	3.35

Figure 1

Figure 1 highlights the extent to which pedestrians and pedal cyclists are involved in fatal accidents in the United Kingdom, against similar figures for the United States. During the same period less than 2½ percent of fatal accidents in the United Kingdom occurred on motorways.

The relevance of showing improvements in stopping distance is limited. Many factors outside the control of the system designer influence the results of such tests. For instance the characteristics of tire to road friction, or choice of basic brake system, are both very significant.

The results of typical tests being carried out by Girling to assess the relative performance of different systems are shown on the accompanying graph (Figure 2). A conventional mass-produced saloon car was braked from various speeds whilst straddling surfaces of two different friction levels. In this example the tests were

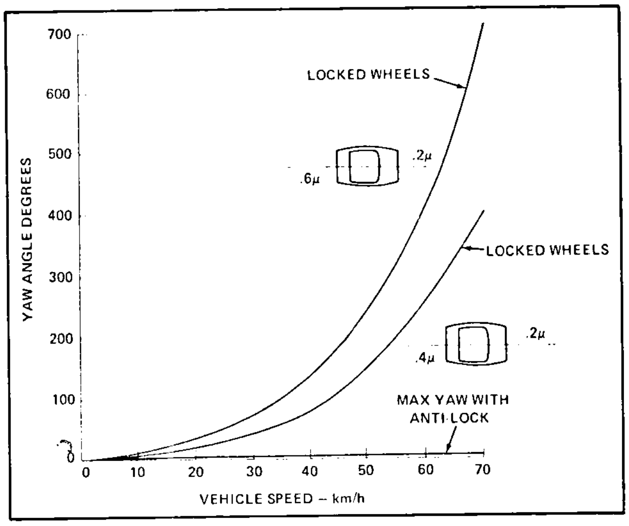


Figure 2

carried out twice – first on surfaces of about .2 and .4 friction coefficient, and then .2 and .6 coefficient.

With locked wheels an unstable condition is set up and the car starts to yaw. This condition becomes rapidly worse as speed rises. The car will continue approximately in its original direction provided that the wheels are kept locked. Even then it will tend to move across to the higher friction surface as it revolves.

A good rear axle anti-lock system makes the car stable and reduces yaw angles until they are almost negligible from any speed. This type of test is therefore of great importance when assessing systems designed to reduce highway accidents. The next stage is to devise tests to assess combined cornering and braking.

The application of braking forces, when cornering forces already exist, will alter the resultant force acting on a wheel. This can alter the handling characteristic of a car and the driver must adjust his steering demand to compensate. If the car is already on the limit of cornering adhesion the change in resultant force can make the car unstable. On a low friction surface this instability can cause some vehicles to spin rapidly. For a safety system this result must be unacceptable. Tests of this kind should therefore be included in ESV specifications, together with target levels.

It is worth mentioning here that the solution to such a problem may lie with the vehicle designer as well as the designer of the anti-lock system.

I have already drawn a parallel between anti-lock systems and air-bags. It has been shown that a large number of tests are required to prove the satisfactory operation of air-bag systems. Similarly a large number of tests are required to prove that anti-lock systems are capable of reliably making correct decisions.

In a system which by design must introduce into the brake lines additional complex devices capable of adjusting individual brake pressures, every possible consideration should be given not only to its normal operation, but also to designing in the best possible fail-safe characteristics.

ESV specifications require certain braking performance levels in the case of partial brake system failure. If an anti-lock system is to be a genuine safety device then any specification must ensure that, in a similar way, partial failure does not make it a dangerous system.

I hope the message is clear. Methods of testing are available which will assess the qualities, and highlight the imperfections, of anti-lock systems. Therefore suitable specifications must be formed if we, as designers, are to be adequately challenged in the development of safer vehicles.

A PROCEDURE FOR EVALUATING VEHICLE BRAKING PERFORMANCE

Mr. Francis A. DiLorenzo, ESV Program Office

Introduction

The research work for this paper was performed by the Highway Safety Research Institute (HSRI) at the University of Michigan under contract with NHTSA. The purpose of the program was to establish and verify analytical and test procedures for evaluating the braking capability of a vehicle and to determine performance figures representative of today's braking systems. The effort was initiated by the NHTSA to define portions of the braking specification for the 4000-pound Experimental Safety Vehicle. To date, the HSRI has completed the test portion of the program and is currently working on the final results.

The analytical methods described deviate from the classical definition of braking efficiency by isolating and evaluating the braking system performance separate from the tire-road performance. The results of the methods described provide a more accurate method of calculating Braking System Efficiency and comparing to known standards.

Analysis

Braking efficiency is typically defined as:

$$E_B = 100 \times \frac{A_{av}}{\mu} \quad \text{where:}$$

E_B – braking efficiency
A_{av} – average sustained deceleration
μ – road surface coefficient of friction

This definition implies that the coefficient of friction is constant for all velocities, an assumption that is often valid for dry surfaces, but totally unrealistic for wet surfaces. As indicated in reference (1), the peak coefficient of friction at 60 mph can be less than half the value it is at 30 mph for a wet asphaltic concrete surface. However, these changes in μ and peak μ with velocity are not completely evasive and, in fact, cross plots of μ-slip curves indicate that peak μ can be represented as a function of velocity* by a polynomial, i.e.:

$\mu = AV^2 + BV + C$ where:
V - tire linear velocity
A,B,C, - appropriate constants for curve fitting**
Since μ is readily represented as
$\mu = a/g$ where:
a - deceleration rate
g - gravitational acceleration

*If, as in the case of many dry surface tests, there is no dependency between peak μ and velocity and load, then an average peak μ is used for calculating ideal stopping distances. **The method of Least Squares was used for curve fitting.

$$\text{then:} \frac{a}{g} = AV^2 + BV + C$$

$$\text{or:} \quad \frac{1}{g}\int_{o}^{V_i} \frac{VdV}{AV^2 + BV + C} = \int_{o}^{D_i} dx \qquad \text{where:}$$

D_i – stopping distance (ideal)

Characteristically, a tire sliding on a wet paved surface at constant velocity has values of μ that rise quickly from 0% slip, peak off between 5% and 20% slip and then drop off as slip approaches 100%. If a braking system could hold the tire at the percentage of slip where the peak μ occurs for each velocity, an ideal stopping distance could be achieved for that particular tire, surface, loading, etc.

Using this ideal stopping distance and the actual stopping distance achieved by the vehicle, using the same tire, a Braking System Efficiency may be calculated from the formula:

$$E = \frac{D_i}{D_A} \times 100 \text{ where:}$$

E – Braking System Efficiency
D_i – Ideal stopping distance
D_A – Actual vehicle stopping distance

It should be emphasized that this calculation does not consider the tire-road performance, but only measures how well a driver or anti-lock system has utilized the available tire-road friction characteristics. To fix the tire-road performance to a common, readily acceptable reference level, ideal stopping distances for the ASTM tire (ASTM E-249) were determined and the test tires were evaluated against this standard by the following formula:

$$F = \frac{D_i\,(\text{ASTM})}{D_i} \qquad \text{where:}$$

F – Tire Factor
D_i – Ideal stopping distance for the test tire

The product of the Braking System Efficiency and the Tire Factor then yields a number defined as the Brake Rating or:

R = EF where:
R - Brake Rating

The value of "R" will vary around 100 depending on the relative magnitudes of E and F which are independent variables. For the better performing tires, F will be greater than 1.0 and E should always be less than 100% and never greater.

Finally, a comparison of wet to dry performance is made for test vehicle by ratioing its change in performance to the change in performance of the ASTM tire.

This may be expressed as:

$$M = \frac{\left[\frac{D_i\,(\text{wet})}{D_i\,(\text{dry})}\right] \text{ASTM}}{\left[\frac{D_A\,(\text{wet})}{D_A\,(\text{dry})}\right] \text{Vehicle}}$$

and M is defined as the Wet to Dry Performance Rating.

It may be shown that:

$$M = \frac{R\text{ wet}}{R\text{ dry}}$$

It should be pointed out that the changes in ASTM tire performance from wet to dry is due only to changes in the tire-road interface and no changes may be attributed to the braking system. This is because, as explained earlier, the stopping distances calculated for this tire are based on peak values of μ as generated on μ-slip curves and by definition are ideal and represent a 100% brake system. This is not so for the case of comparing vehicle performance from wet to dry surfaces. In these cases changes may be attributed to both the change in the tire-road interface and the ability of the braking system to adapt to a different surface. It is possible to isolate and examine each factor separately, i.e., obtain an M_1 for the tire-road interface performance, an M_2 for the braking system adaptability wet to dry, and then M from the formula:

$$M = M_1 \times M_2$$

The formulae for M_1 and M_2 are:

$$M_1 = \begin{cases} \left[\dfrac{D_i\,(\text{wet})}{D_i\,(\text{dry})}\right] & \text{ASTM} \\ \left[\dfrac{D_i\,(\text{wet})}{D_i\,(\text{dry})}\right] & \text{Vehicle} \end{cases}$$

$$M_2 = \left[\frac{E\,(\text{wet})}{E\,(\text{dry})}\right] \quad \text{Vehicle}$$

For this paper M was calculated directly from the ratio of R wet and R dry since it is the final number to be used for comparing vehicles. A designer, researcher, or trouble shooter, however, may be interested in evaluating both M_1 and M_2 to analyze the specific problem.

Test Program

Two vehicles equipped with 4-wheel anti-lock systems were chosen for the test program and the HSRI mobile tire tester[2] was used to generate the μ-slip curves. One vehicle was a 1971 Chrysler Imperial equipped with a production 4-wheel anti-lock system with the trade name "Sure-Brake" and the second vehicle was a 1971 Buick Riviera equipped with a prototype 4-wheel anti-lock system by GM. Both cars used Goodyear Polyglas tires with disc brakes on the front and drum brakes on the rear. Vehicle running gear was maintained per the manufactuers' specifications throughout the tests.

All tests were run at the Willow Run Airport in Michigan on a concrete surface that was resurfaced with asphalt. To achieve the low coefficient of friction surface, a portion of the asphaltic surface was coated with a sealer and sprayed with water by a sprinkler system. The ASTM skid numbers for the high and low coefficient of friction surfaces were 85 and 23 respectively. Due to the physical layout of the test area, the mobile tire tester was unable to test above 45 mph on the wetted surfaces and due to the limited power in the test tire drive mechanism no μ-slip curves could be generated for the dry surfaces with test tires at velocities above 30 mph. This necessitated extrapolating the wet surface data out to 60 mph which introduces some uncertainties into the calculation of ideal stopping distances. However, the data appears to behave as a continuous mathematical function; therefore, there is little concern over this potential loss in accuracy.

The brake pedal applications were controlled by a hydraulic device that acted directly on the brake pedal. The rates of pedal application were set at 30 inches per second with a displacement of 3 inches. This rate was derived from driver "spike" application tests run at HSRI and the 3 inch displacement was ample to develop brake line pressures that could take full advantage of the maximum torque capability of the brakes.

Test Results

All test points were repeated 10 times in order to determine scatter and obtain a sample that would lend itself to a meaningful statistical analysis. The statistical uncertainty in data scatter was coupled with the precision and accuracy of the instrumentation and data reduction to provide the net expected deviation in calculating Braking System Efficiency.

Figure I is a sample of the data taken from one vehicle run. The time trace runs right to left with a time

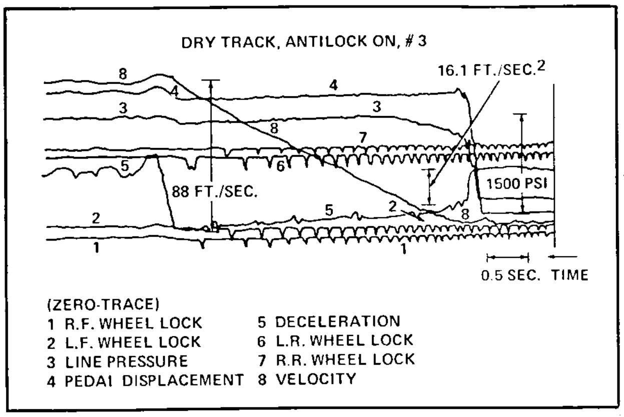
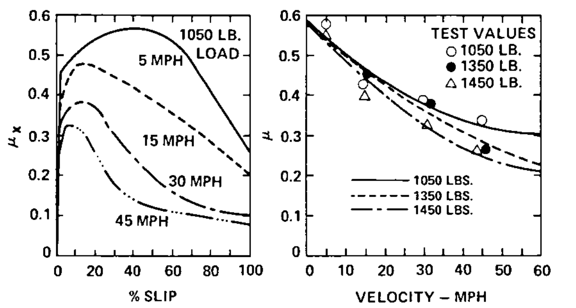


Figure 1

zero on the right hand side at the point where pedal displacement begins. Time final is at the point where the acceleration trace drops to zero. It may be noted that the velocity trace behaves quite linearly throughout most of the test with a slight upward curve due to the small but continuous change in deceleration. The periodic perturbations in the acceleration curve are due to the 4-wheel anti-lock cycling behavior. It appears the deceleration trace follows the hydraulic pressure trace quite well for the first two seconds of the test and thereafter the hydraulic trace remains constant while the deceleration trace increases slightly. This is perhaps most likely due to slight changes in the tire's frictional characteristics. Also, for these runs, the individual wheel speeds were monitored by the four lines with vertical "blips." The blips indicate one revolution and become more separated as the vehicle slows down.

Figure II illustrates typical wet surface μ-slip characteristics as generated by the mobile tire tester and also



μ–SLIP CHARACTERISTICS

Peak Tire-Road Interface Friction Coefficients on Low-Coefficient Surface

Figure 2

illustrates a typical plot of peak μ versus velocity used to obtain the mathematical relationship. The left side curves show significant changes in peak μ with changing velocity. In the right hand curves the effects of tire load are not relatively great on dry surfaces, however, on wet surfaces they become significant.

Tables 1 to 4 summarize all the test data and calculated results for this test program. In table I, the stopping distances are shown for both vehicles with the

TABLE I
Stopping Distance Data

Track Condition	Loading Condition	Corrected Mean Stopping Distance	One Standard Deviation σ	Three Standard Deviations 3σ	Mean $+1\sigma$	Mean -1σ	Mean $+3\sigma$	Mean -3σ
VEHICLE A								
Dry	40%	183	3.8	11 11.4	187	179	194	172
Dry	60%	184	3.6	10.8	188	180	195	173
Dry	100%	194	6.7	20.1	201	188	224	174
Wet	40%	419	20.6	61.8	440	398	481	357
Wet	60%	421	12.5	37.5	434	409	458	384
Wet	100%	385	17.4	52.2	402	368	437	333
VEHICLE B								
Dry	60%	180	6.4	19.2	186	174	199	161
Dry	80%	181	5.7	17.1	187	175	198	144
Dry	100%	193	6.6	19.8	200	186	213	173
Wet	60%	535	32.7	98.1	568	502	633	437
Wet	80%	498	18.8	56.3	517	479	554	442
Wet	100%	528	20.6	61.8	549	507	590	466

statistical analysis of that data. It may be noted that the 3 values for the two vehicles are quite different, with vehicle B on the average having considerably more scatter than vehicle A. Since testing techniques were the same for both vehicles, it would appear that the repeatability characteristics are largely within the vehicle.

Table II summarizes the mean peak values of μ from the tire-road interface tests which have been formerly referred to as μ-slip curves. Voids in the data presented are, as explained earlier, due to limitations of the test equipment. The values for the mean peak values of μ on

TABLE II
Summary of Mean Peak Values from Tire-Road Interface Tests

Tire	Speed (MPH)	Track Condition	Loads, In Pounds 800	850	1000	1050	1200	1250	1350	1450	1500	1600
L84-15	10	Dry		1.04								
	15	Dry	0.91		0.92					0.82		
	30	Dry		1.00								
H78-15	10	Dry		1.00								
	15	Dry		1.07		1.00		1.03		0.98		
	30	Dry		1.04								
ASTM	5	Dry				1.03						
	15	Dry				0.90						
	30	Dry				0.81						
L84-15	5	Wet				0.55				0.49	0.51	0.51
	15	Wet				0.47				0.38	0.41	0.43
	30	Wet				0.42				0.33	0.34	0.40
	45	Wet				0.34				0.28	0.32	0.31
H78-15	5	Wet				0.56			0.54	0.55		
	15	Wet				0.43			0.46	0.40		
	30	Wet				0.38			0.38	0.33		
	45	Wet				0.34			0.27	0.26		
ASTM	5	Wet				0.44						
	15	Wet				0.38						
	30	Wet				0.34						
	45	Wet				0.25						

the dry surface remained basically unchanged with load and speed, at about 1.0, precluding the need to establish a μ-velocity relationship, while similar runs for the wet condition show considerable variation with speed.

Table III is a summary of the statistical tolerance on the calculation of the Braking System Efficiency. For dry surface, the standard deviation of E is about the same for both vehicles. The standard deviation of the actual wet stopping distance for vehicle B appeared

TABLE III
Tolerance On Braking Systems Efficiency Calculations

DRY ASPHALT SURFACE

Vehicle	Tire	C Percent Capacity Load	D_a Ft.	σD_a Ft.	μAV	$\sigma \mu AV$	E %	σE %
A	L84-15	40	183	3.8	0.95	0.06	68.8	4.6
"	"	60	184	3.6	0.95	0.06	68.5	4.2
"	"	100	194	6.7	0.95	0.06	65.0	4.6
B	H78-15	60	180	6.4	1.02	0.05	65.5	4.5
"	"	80	181	5.7	1.02	0.05	65.2	4.4
"	"	100	193	6.7	1.02	0.05	61.1	4.0

LOW COEFFICIENT OF FRICTION SURFACE

Vehicle	Tire	Percent Capacity Load	D_a Ft.	σD_a Ft.	D_i Ft.	σD_i Ft.	E %	σE %
A	L84-15	40	419	20.6	407	50	97.2	5.0
"	"	60	421	12.5	377	50	89.6	2.7
"	"	100	385	17.4	377	48	97.8	4.4
B	H78-15	60	535	32.7	400	46	74.8	4.6
"	"	80	498	18.8	425	60	85.4	3.3
"	"	100	528	20.6	455	82	86.1	3.4

significantly greater than that for vehicle A. In the higher load conditions, the standard deviation of the ideal wet stopping distance for vehicle B was also higher than that for vehicle A, indicating that the tire on vehicle B was not as repeatable as the tire on vehicle A.

Table IV summarizes the test results and calculation for the program. Examining the column labeled Brake System Efficiency, both vehicles, especially A, have considerably higher efficiencies on wet surfaces (Lo-Co) than on dry (Hi-Co) surfaces. This correlates well with the stopping distance data which show for dry surfaces, that a vehicle stops about as well or better with the anti-lock system off as with it on. Conversely, on wet surfaces, the stopping distance with the anti-lock system on are clearly superior to those with the anti-lock system off. The column labeled Tire Factor is obtained by dividing the ideal stopping distance of the ASTM tire by the ideal stopping distance of the vehicle tire. As the numbers indicate, the vehicle tires provide shorter ideal stopping distances relative to the ASTM tire. The differences in performance are not as great under wet conditions, in fact the vehicle B tire at 100% capacity weight actually falls below the ASTM tire. The product of these two columns yields the value for the next column which has been arbitrarily termed Brake Rating. This rating provides a composite number that describes the combined Brake System Efficiency and the tire-road interface performance relative to the ASTM tire, thereby allowing a comparison of vehicles. From the data, both vehicles have about the same rating on dry surfaces, however, on wet surfaces, vehicle A comes out considerably higher than vehicle B.

TABLE IV
Summary of Test Results and Calculations

Vehicle	Test Surface	Percent Capacity Weight	Actual Stopping Distance, Ft.		Ideal Stopping Distance Ft.	Brak. Sys. Eff.	Tire Factor	Brake Rat.	Wet to Dry Pref. Rating
			Antilock On	Antilock Off					
A	HI-CO	40	183	178	126	68.8	1.25	86.0	
"	"	60	184	183	126	68.5	1.25	85.6	
"	"	100	194	198	126	65.0	1.25	81.3	
"	LO-CO	40	419	770	408	97.2	1.09	106.0	1.23
"	"	60	421	744	377	89.6	1.18	106.0	1.24
"	"	100	385	889	377	97.8	1.18	115.0	1.42
B	HI-CO	60	180	163	118	65.5	1.33	87.1	
"	"	80	181	175	118	65.2	1.33	86.7	
"	"	100	193	187	118	61.1	1.33	81.3	
"	LO-CO	60	535	803	400	74.8	1.11	83.0	.95
"	"	80	498	657	425	85.4	1.04	88.8	1.02
"	"	100	528	682	455	86.1	0.97	83.5	1.03
ASTM Tire	HI-CO				157				
ASTM Tire	LO-CO				443				

From a safety standpoint, it can be disastrous for a driver who is acclimated to excellent braking capabilities on dry surfaces to suddenly find that on wet surfaces, his braking capability has been seriously reduced. The last column on the right provides a quantitative method of comparing the change in performance when going from a dry to a wet surface. This Wet to Dry Performance Rating is obtained by dividing the wet Brake Rating by the dry Brake Rating. As explained in the introduction, this number is a comparison of the wet to dry performance change of an ASTM tire on the test machine relative to a wet to dry performance change of a vehicle using conventional tires. If the ratio is 1.0, the changes were equal, if greater than 1.0 then the vehicle performance changed less than the ASTM tire which is desirable. Conversely, at a ratio less than 1.0, the vehicle experiences more change than the ASTM tire and this is undesirable. With the exception of one point both vehicles exhibited less change than the ASTM tire. Clearly, however, vehicle A more readily adapts to a wet surface than vehicle B. The same conclusion may be reached by noting the significantly longer stopping distances produced by vehicle B for the wet conditions.

Conclusions

The test procedures and the analytical methods described provide a viable and realistic method of measuring vehicle braking capability relative to a standard reference. The use of a machine for brake pedal application eliminates driver repeatability error and increases overall accuracies. The error analysis which is not described in this paper but will be in the final reports, also lends credence to this approach. The test data are still relatively new and have not been examined in detail yet, however, it would appear that for a given set of vehicle operating conditions, both the Brake Rating number and the Wet to Dry Performance Rating are applicable to a brake specification. Specific recommendations concerning the magnitude of the Brake Rating and the Wet to Dry Performance Rating are not given at this time pending the release of the final report.

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SECTION 5

Part 1 — Summation

Mr. Albert J. Slechter, *Associate Director, Experimental Safety Vehicle Programs Office, National Highway Traffic Safety Administration, United States Department of Transportation*

Part 2 — Concluding Remarks

Mr. Douglas W. Toms, *Administrator, National Highway Traffic Safety Administration, United States Department of Transportation*

Part 3 — Concluding Remarks

Mr. Helmut Wagner, *Ministerial Director, Federal Ministry of Transport, Federal Republic of Germany*

Part 4 — Concluding Remarks

Mr. John A. Edwards, *Associate Administrator for Research and Development, National Highway Traffic Safety Administration, United States Department of Transportation and Chairman of the Second International Technical Conference on Experimental Safety Vehicles*

SECTION 5

PART 1 SUMMATION AND CONCLUDING REMARKS

Mr. Albert J. Slechter, Jr.
Assistant Director,
Office of Experimental Safety Vehicle Programs,
National Highway Traffic Safety Administration,
United States Department of Transportation

Good morning again to you all. Yesterday afternoon we participated in two technical seminars; one on crashworthiness or passive safety, and the second on accident avoidance or active safety. We would like this morning to summarize these sessions and, as contributors from the pilot ESV country, give further perspective, if we can, to the areas of concern to the technical participants. We will have time for comments or questions from the delegation after the summary is completed.

We recognize that in this four-day period a tremendous amount of technical information has been presented, and there has been little time to digest it and to react from one delegation to the other. That, of course, is going to now be the job of all of us when we leave Stuttgart. Many opinions on specifications and priorities have been outlined in the seminars and in the technology outlines presented earlier this week. We need to consider these opinions carefully in order to assure that the best inputs from all experts throughout the world are obtained. Each of the countries represented here have road situations and safety problems that have a high degree of commonality. Yet in some cases, specific differences do exist. On a personal basis I became more familiar last weekend with the German road environment in a drive on the Autobahn to Ulm, then on down to Garmisch, west to Lindale, then on back to Stuttgart. The importance stressed in Germany on accident avoidance. particularly vehicle handling and braking, was particularly noted. It is sufficient to say that the sense of priority on accident avoidance in Europe and Japan is well understood by the United States delegation. Of course, the higher priority of crashworthiness emphasized by the United States in car designs recognizes that so long as normal people drive, and until the driving process is totally automated. many crashes will inevitably occur. I won't expand further on this thought since I believe it is well documented by now. I will now briefly highlight some of the more critical problems and concerns that have been brought forth during the conference. The order is not significant.

First, I believe dummy fidelity, the ability to obtain repeatable results in tests with anthromorphic dummies, has been clearly indicated as a concern by all the delegations. Our Safety Systems Laboratory in the National Highway Traffic Safety Administration is very actively pursuing the standardization of the dummy. For the United States ESV program we have arbitrarily, although with the best information we now have available, opted to use a modified Alderson 50th percentile dummy, at least for our prototype tests. As improvements in dummy design become available, we will, of course, take advantage of them.

Second, the General Motors delegation pointed out the extreme difference between designing for just 50th percentily dummy performance vs. designing for the full range of dummies, from the 5th percentile female to the 95th percentile male. General Motors also pointed out that designing a system which uses belts, whether active or passive, and of course ESV is a passive restraint car; but designing for belts is a much different problem than designing for airbag restraints.

Third, the French delegation continues to indicate agressiveness as a serious problem in the front end design of an ESV, and we agree with them. We believe this is probably one of the most significant trade-off situations that we face, the trading off of agressiveness against crashworthiness. In order to make this trade-off properly, as the ESV program matures, we must have better data on what happens on the road – what kinds of accidents occur and the speeds at which accidents occur. That brings up the "mixed traffic" situation, which has also been indicated as a problem; we may be overemphasizing the fixed barrier collisions in performance specifications at the expense of the mixed traffic situation of car-to-car car-to-pedestrian, and car-to-cycle crashes.

One common thought must be shared by us all as a result of this meeting. That is all of us must recognize the need to maintain flexibility in our thinking as we explore feasible, practical designs of subsystems and vehicles. For example, the United States ESV specification from the beginning stressed safety in barrier crashes up to 50 mph, together with other difficult specification challenges. We are not unalterably fixed to these requirements. Many, in fact, most appear to be feasible, but we believe all ramifications should be explored regarding these specifications. Without setting such a tough goal at the outset, we couldn't hope to focus the automotive engineering experts of the world on a very substantial increase in safety performance. The cost effectiveness of such specifications has not yet been determined, but is a critical analysis that must be performed by all countries, and exchanged between countries when available. Of course, as everyone who has ever tried to perform such analysis should know, data from on road accidents is critical to the analysis. It has been my experience that one never finishes such an analysis to complete satisfaction, because data are never totally complete. Nevertheless, we are increasing our research efforts in the United States to obtain the best data that we can on the speed of accidents, type of accidents, and their consequences. We expect that reasonable data will begin to be available from these programs in the 1973-74 period. It will then be coupled with the safety performance feasibility information from each of the international ESV projects. This coupling will then form the basis for first recommendations by the ESV research group of the National Highway Traffic Safety Administration, to the rulemaking bodies of the National Highway Traffic Safety Administration. Substantial lead time is anticipated to allow manufacturers time to tool up to ESV levels of performance. It is my intent here to emphasize that the ESV program is an evolutionary, exploratory program; it is not bound rigidly to a final specification at this time, but instead seeks to use the initial specification as a basis for:

1. Exploring the feasible upper limits of safety performance that can be designed in the vehicles of various weight classes,
2. Evaluating the cost and effectiveness of solutions at these specified levels,
3. Optimizing specifications for cost effectiveness, and
4. Final demonstration of feasibility through systems tests.

Some of the ESV projects are now involved in the first element; demonstration of feasibility and/or identification of more obvious trade-offs. By our next meeting, this step for the larger class vehicle should be well along.

I would like to touch just briefly on what we see as a possible optimization, not in detail, just an indication of some of the thinking that is going on in the United States program. I'll speak most specifically to the crashworthiness specifications.

1. We are seeing, in the United States' ESV programs, that the "no damage" requirement at 10 mph in front and rear is causing a severe weight penalty in some designs, and this is particularly true in the rear end designs. We feel possibly that a relaxation will take place ultimately in that requirement.
2. Dr. Appel, yesterday, spoke of the 50 mph moving barrier and the 75 mph car-to-car requirement in rear collisions; and we agree that even though we are not at all sure of the details of the data presented and the accuracy of that data, the trend should be to lower this requirement. Again, a weight reduction can be obtained.
3. I mentioned earlier the pole impact requirement at 50 mph. We feel that here again we should take a very careful look at the 50 mph pole requirement, with a view toward a possible reduction in this requirement.
4. We recognize that we have been binding our contractors very rigidly to a three-inch intrusion specification for all crash modes. It is now rather clear to us that intrusion, which is not safety related, can take place in the passenger compartment. We believe, therefore, that in optimization, we can allow increased intrusion just so long as that increase is controlled in the structure. Again, obvious weight savings can be achieved.

You might obviously recognize that all of these comments bear heavily on the weight problem. Perhaps, we have appeared a bit mysterious in announcing weight figures specifically for the United States prototype cars. I hope it is understood that the Fairchild and AMF competition situation precludes our saying too much in this area until the cars are delivered and evaluated. We admit both prototypes are over the weight specification at this time. However, some of the items I have just mentioned as possible optimization candidates can work towards getting our cars into a weight class that is practical for the United States full-size car market. We believe, similarly, that on a percentage basis the weight of a smaller car can be maintained at a practical level.

Thank you.

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PART 2 CONCLUDING REMARKS

Mr. Douglas W. Toms
Administrator, National Highway
Traffic Safety Administration,
United States Department of Transportation

I would like to compliment the presenters. I feel that in every instance the people who participated in this conference did an outstanding job. Obviously, we now have a worldwide effort on experimental safety vehicles. Practically every auto producing nation and every automotive manufacturer is working on some aspect of the ESV project. In the United States we look favorably on this point and feel that this worldwide participation assists us, and we are convinced that it will benefit all the peoples of the world.

We recognize that at this conference there was a clear expression of a difference of opinion and we feel that this is a healthy situation. Make no mistake, at no time do the people involved in the United States feel that we have all of the answers or that the paths that we are following are the best ones. I would like to emphasize that the specifications for our experimental safety vehicle project were, at that point in time, our best judgment. We clearly expected that as more research took place and further experience was gained that changes would be necessary. In this regard, I would like to solicit the comments of all the auto producing nations and the comments of every manufacturer on how they feel our ESV specifications could be improved. These are not sacred, we're open-minded about them, and we must move towards the best possible set of requirements.

We should emphasize that the reason we are developing ESV, is to save lives and reduce injuries. We have repeatedly said that our priorities in the National Highway Traffic Safety Administration are first, to save lives, second, to reduce injuries, and then to concern ourselves with property damage. When we talk about certain kinds of restraints, or crashworthiness goals we do consider all three elements, but if there are trade-offs to be made then the savings of lives must receive the highest priority.

We are much encouraged by the worldwide auto industry's commitment of dollars and resources to the ESV project. This conference clearly shows that a massive amount of money and large resources have been poured into the ESV program. We are very pleased to see this and hope that we can all work together to truly come up with requirements, worldwide, that will save lives – not just on the roads of America but on the roads of the world.

A comment needs to be made about the amount of information that was presented at this conference. Mr. Edwards said that we would have a report to you in 90 days. As you review and think through the information that was presented during the conference a great deal of new information will come to light. During the first few days as I listened to the presentations, it was clear to me that some old ideas were rejected; some ideas reflected a difference of opinion, and new solutions had been found to many continual problems. This conference has been good, in pointing out that progress has really and truly been made.

I would now like to comment briefly on the systems approach to the rulemaking requirements of the United States. A crashworthiness performance requirement, a handling performance requirement and perhaps a few other performance requirements would be issued in lieu of the specific requirements called out today. In terms of timing, it would be my judgment that we would be moving towards such a rulemaking approach within the next year or two with an implementation date in the late 70's.

It is essential that both industry and government work together. I do not mean this in terms of the automobile industry and the United States Government. I mean it in terms of all governments working together and all segments of the industry working together. This begs the question of anti-trust. Certainly we want to be sure that no situation exists where portions of the auto industry may collaborate to withhold products or information that would benefit the public. One of the ways that we assure that such collaboration does not occur, is by inserting the government into the proceedings. Much of the conversation that has gone on at this conference and many of the meetings that have taken place are in direct violation of our anti-trust laws if it were not for the presence of the government representatives. So this is a device where the governments work together so that they are able to provide for the exchange of information without violating the laws.

The concept of agressivity came up repeatedly and I would like from a National Highway Traffic Safety Administration policy viewpoint to make a comment. From what I have heard at this conference and from the information that has been presented to date, it appears clear to me that an agressivity index is in order. Whether or not we will make the large car, through a softer structure, accommodate the small car remains to be seen. The evidence appears to partially support this approach. Clearly the small-large car relationship is a tough problem, and we must find solutions. The laws of physics are such that if we do not have some sort of an agressivity index the small cars are going to get the short end of the deal in every crash. So some kind of solution must be found and so far it appears that an agressivity index is the best solution. Possibly in the next year or so other solutions will be found.

A lot has been said about cost benefit ratios – the relationship of performance to cost. In my judgment, neither industry nor government has been particularly skilled in this area, however, I must insert a disclaimer. Certainly every manufacturer knows exactly what it costs him to produce a car, but trying to translate these costs to benefit to the public at large is difficult. I don't believe that any manufacturer would be willing to agree with his competitor as to how his car benefits the public in relationship to his competitor's car. I'm sure that every manufacturer feels that his car is a better value than his competitor. Therefore, the cost benefit relationship is difficult, and this is where the government can help. We are going to have to be more open about costs and perhaps it will be the role of the government to determine what the benefits are and to priority-rate these benefits. Then maybe we can really begin to talk openly about cost benefit relationships.

Last year, as Secretary Volpe commented, we experienced a reduction of 1,100 lives lost on our highways – a substantial reduction in our death rate per 100 million miles traveled. This year it does not look as good. We are embarking on a massive campaign in November and December to try to bring down the number of lives lost. One of the complicating factors is that each year there are more cars sold and therefore more miles driven. This year we are experiencing an excellent reduction in our death rate, but the numbers of deaths are not coming down. Consequently the cost is still going up. The projections indicate that in direct costs we will exceed 18 billion in losses this year. Including direct and indirect we will experience losses in excess of 40 billion dollars. I'm sure it is the judgment of the United States Congress and United States Government that these losses are too large. I want to emphasize that the reason that we are here and the reason that the National Highway Traffic Safety Administration exists is to reduce these losses. That commitment is total and absolute.

This has been an excellent conference, and I invite each of you, one and all, government and industry to come to Washington for TRANSPO 72. The third ESV conference will be held in Washington in conjunction with TRANSPO 72. The dates of the conference are May 30, 31 and June 1, 1972.

My sincere thanks to each government that participated. Without your participation there would have been no conference. So to my counterparts and my colleagues of each government, a special thanks.

To the automobile industry, as much as you may not love us, my sincere thanks. I know that each member of the automobile industry worldwide put a lot of work into this conference, not only in the presentation of papers, preparation of materials, but in the extension of resources. We feel the attitudes have been good. We feel that the top people have participated and so we thank you, all of you in the auto industry for making this conference the success that we feel it has been.

A special note to Daimler-Benz. I think this has been a magnificent facility, I don't think anyone could come to this meeting without looking around and saying "pretty neat," "very nice." The refreshments, the lovely girls, the excellent surroundings, and by no small measure, I would like your recipe for your sun dance. The weather has been superb and at this time of year this is no small feat. I don't know how we at TRANSPO 72 are going to duplicate your castle. We have thought of the Library of Congress, the White House and I don't think that we can top that. An extra special thanks to Daimler-Benz for being the host industry, a great job was done and we're most appreciative. So to each of you who came, to each of you who participated, to each of you who worked so hard, my special thanks, we look forward to seeing you all at TRANSPO 72.

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PART 3 CLOSING ADDRESS OF THE REPRESENTATIVE OF THE FEDERAL MINISTER OF TRANSPORT

Mr. Helmut Wagner, Ministerial Director,
Federal Ministry of Transport, Federal
Republic of Germany

Mr. President, ladies and gentlemen,

Please, allow me to add three observations to what the previous speaker has said.

We have all heard with admiration which wealth of material industry have prepared to promote the idea of traffic safety, but we have also seen that in each country millions of monetary units have been spent for investigating the same things. This fact gives rise to the question whether we cannot unite in our work, at least in those fields where we have common interests, where we are not competing with one another, in order to achieve by joint work what can be so achieved. This refers firstly to research work, to biomechanics, which can be examined in the same way everywhere. Is it possible to distribute research projects? Can time and costs be saved in this way? It concerns secondly the statistics, the function of which is to prepare a programme, which must be incorporated into the current statistical programmes – a rather difficult job – and which should be as much as possible the same for all those participating so that comparable results may be obtained. Finally, there are the test methods with which to ascertain, whether this or that technical characteristic prevails. All this we can achieve through the cooperation, which has been proposed here, above all by the American delegation.

Then there is the second item: We have in Europe a multitude of national legislation, which all have their own – and different – technical regulations. This means for industry that they have to go to great expense, in order to adapt themselves in each individual case. The idea of standardization suggests itself, and this idea has been the determining factor in our work here at this conference.

We shall be compelled to standardize, when the safety vehicle will have been created. We shall be forced to harmonize the regulations, and so eliminate an obstacle to trade, which at present still swallows up a lot of money without adequate advantage.

I want to express my thanks to the members of the American delegation with their leader, Mr. Toms, in the first place because they have devoted themselves to these problems and because they are prepared to cooperate with us.

I also want to thank you, Mr. Chairman, for the excellent way in which you have presided over this conference and have made it a full success.

It is also my wish to thank all the gentlemen from industry for the share they have had in this quite outstanding event, either by their scientific contributions or in its organization. All these accomplishments fill me with confidence that the next meeting will bring new progress, and I can only recommend that in the meantime industry and the competent authorities in every state consult each other, in order to find ways how to ensure that the next conference will lead to further progress.

Thank you, gentlemen, thank you, Mr. Chairman, and many thanks to the American delegation.

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PART 4 CONCLUDING REMARKS

John A. Edwards
Acting Associate Administrator
for Research & Development
Research Institute,
National Highway Traffic Safety Administration

As your chairman, I would like to make a few closing comments. We have had a very effective coming together here at Sindelfingen. Clearly, we identified limitations on current statistical data and dummy response. We demonstrated considerable concern for vehicle producibility and cost benefit factors. We also collectively recognized that the ESV specifications we are working with today are actually maximized and that ultimately we must optimize these specifications based on our developmental experience, and on the real world mix of large and small cars. We also require time because of the complexity of the project.

I'd like to make a personal observation. It is all too easy for us to become disillusioned, by the obstacles confronting us. We must not be dissuaded from our goal. I believe this challenge of improving road safety is one that we can accomplish. I believe the ESV program is a major milestone along the way.

I want to further comment on the genuine and honest openess that is clearly developing between delegations in this ESV program. There is an obvious commitment by all delegations to truly attacking and solving the road safety problem. This perhaps was the hallmark of our conference. I am honored to have been able to serve as your chairman, and at this point I now declare the Second International Technical Conference on Experimental Safety Vehicles, closed.

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