Patricia F. Waller (1972). North Carolina Symposium on Highway Safety (Vol. 6). Crashworthiness: Safety through Automotive Design. Chapel Hill, NC: University of North Carolina Highway Safety Research Center.

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chapel hill, n. c.

spring 1972 • volume six • edited by Patricia F. Waller

Crashworthiness: safety through automotive design

Edwin A. Kidd
John A. Edwards
Richard A. Wilson

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safety through automotive design

North Carolina Symposium

on highway safety

volume six

Crashworthiness:

safety through automotive design

Edwin A. Kidd — *Cornell Aeronautical Laboratory, Inc.*

John A. Edwards — *National Highway Traffic Safety Administration (NHTSA)*

Richard A. Wilson — *General Motors Proving Ground*

NORTH CAROLINA SYMPOSIUM ON HIGHWAY SAFETY

Raleigh, N. C.

Volume six **Spring 1972**

The University of North Carolina Highway Safety Research Center
Chapel Hill, North Carolina 27514 • B. J. Campbell, Director

a few words about the symposium topic . . .

Newer cars are safer than older cars, presumably because improvements in design are making them more crashworthy. Few dispute the benefits of the energy absorbing steering system and interior padding in injury reduction during the second crash or the efficacy of producing bumpers that can sustain low-speed crashes without damage to the vehicle. In fact, so-called design improvements are heralding a new era in automotive safety, and the groundwork is being laid today. Three men—representing the coordinated efforts of government, industry and private research organizations—address themselves to innovations in vehicle crashworthiness and occupant protection that may eventually culminate in mass-produced safety vehicles. While no one views a safer vehicle as a panacea, few deny its potential contribution to highway safety.

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About the Center . . .

At the request of the Governor of North Carolina, the 1965 North Carolina State Legislature provided for the establishment of the University of North Carolina Highway Safety Research Center. Dr. B. J. Campbell, then Head of the Accident Research Branch of Cornell Aeronautical Laboratory, was invited to return to his alma mater to direct the new Center. He accepted, and in 1966 the Center officially began operation. Since then the staff has grown to more than fifty, representing skills in experimental psychology, clinical psychology, mathematics, transportation engineering, computer systems, journalism, library science, biostatistics, graphic arts, epidemiology, experimental statistics, general engineering, human factors engineering, and health administration. The University of North Carolina Highway Safety Research Center is the first institution in the South devoted exclusively to research in highway safety.

About the Symposium . . .

The North Carolina Symposium on Highway Safety is a semiannual event sponsored by the North Carolina State University School of Engineering, the University of North Carolina School of Public Health, and the University of North Carolina Highway Safety Research Center. First held in the fall of 1969, the symposium has three major purposes. First, it is designed to attract students to acquaint them with the problems and possibilities for research in the field of highway safety.

Second, it is a means of bringing together professional workers in the greater North Carolina area whose interests are related to this field.

And, third, the published papers from the symposium will provide on a regular basis major positions and summaries of research in the field of highway safety. It is hoped that these volumes will provide ready resource material for persons interested in this field.

INTRODUCTION

The problem of highway safety has three interacting parts, namely, the highway, the vehicle, and the driver. While none can be considered in isolation from the others, the consensus of experts in the field is that the greatest short-term payoff can be realized by concentrating on the vehicle. In any one year the new crop of vehicles constitutes approximately 10 percent of the total vehicle population. Consequently, the safety impact of vehicle improvements stands to be felt almost immediately. Because work in crashworthiness holds great promise for quick payoff per dollar invested, the federal government has placed high priority on the development of an experimental safety vehicle—a task of such magnitude that it has involved the combined efforts of private and public organizations on an international scale.

Our spring 1972 symposium focused on the status of research and development of crashworthy vehicles—that is, vehicles that will absorb the impact of a crash in such a way that the occupants are likely to survive without serious injury.

The push to develop a safer motor vehicle has involved the combined efforts of industry, private research, and government. Our speakers were chosen to represent each.

Dr. Edwin Kidd, representing private research, describes three major areas that can be modified to increase occupant protection, namely, the structure of the vehicle exterior to the compartment, the interior structure, and the occupant restraint system. Of course, none of these can be considered independently, since each affects the performance of the others.

Studies of accident data indicate that to protect occupants in two-thirds of all accidents, it is necessary to provide adequate protection at speeds up to 40 mph. To achieve a two-thirds reduction in fatalities, adequate protection must be provided at speeds up to 60 mph. Accident data can be used to provide a basis for determining the speeds at which protection is necessary to achieve a given improvement in injury experience. Separate determinations should be made for each accident type, e.g., front, side, rear, and rollover.

The question of occupant restraint is frustrating. Improvements in door latches and side structure have been made on the basis of injury data that indicate occupant ejection is much more likely to result in serious injury than confinement to the vehicle. Occupant restraint systems were therefore developed to prevent not only ejection, but also the second crash of the occupant into the interior of the vehicle. Although data indicate that the combined use of lap and shoulder belts provides protection that is possibly the equivalent of that provided by air bags, nevertheless seat belts are beneficial only when the driver, acting on his own cognizance, fastens himself in—and the vast majority of the motoring public does not buckle up. Consequently, it has been deemed essential to continue research and development of passive restraint systems. The primary passive restraint system under consideration is the air bag.

The development of adequate occupant protection depends to a large extent on information from actual crashes. Because it is often difficult to determine exactly what precipitated a crash, methods are being developed whereby information can be fed into a computer and used as the basis for reconstructing the accident. This after-the-fact computer simulation provides great promise for establishing objective data that can be used as the basis for accident investigation.

Representing government, Mr. Edwards provides an overview of the efforts being made to develop a more crashworthy vehicle. The United States federal government has contracted not only with domestic firms, but also with automobile manufacturers in West Germany, Japan, Great Britain, Italy, France, and Sweden. This program is part of NATO's efforts to solve environmental and social problems through its Committee on the Challenge of Modern Society. The major purpose is to speed up the development and exchange of new safety technology.

The first emphasis in the development of an experimental safety vehicle is on a five passenger family sedan, chosen because of its popularity and wide use. Prototypes of these sedans are now being tested and evaluated. Because of the involvement of the foreign automobile manufacturers, it will be possible to give immediate attention to the problems of the small cars and how they fare in "big car-little car" crashes. There is reason to believe that small cars can be made to provide much greater protection than is now the case.

Mr. Edwards emphasizes that mechanical design is not seen as a panacea for the problem of death and injury on the highway. It is seen only as part of the total system, which includes driver behavior, the driving environment, and economic and societal factors. However, mechanical design is seen as the part of the system that is likely to save the most lives in the shortest period of time.

Representing private industry, Mr. Wilson provides a brief history of crashworthiness research. He points out that while the major emphasis has been on the characteristics of the vehicle, it is also appropriate to consider the crashworthiness of the highway and the crashworthiness of the human body. (Indeed the latter changes as a function of age.)

There are four major variables which can be manipulated by crashworthiness researchers, namely, impact area, stopping distance, velocity change, and mass. In each of these it is necessary to reduce the number of uncontrollable factors and to reduce the injury potential of the controllable factors. For example, because serious injury and death frequently resulted from ejection of the occupant, and because the objects the ejected occupant struck were largely uncontrollable (pavement, trees, rocks), efforts were made to reduce the frequency of occupant ejection. Compartment intrusion, however, negates the injury-reducting effects of interior improvements that help prevent ejection. Thus, efforts are being made to minimize such intrusion. Because unrestrained occupants are not helped by many vehicle design changes, it is necessary to develop restraint systems that will be used.

While one may study the crashworthiness of the human body, it is not possible to make rapid changes in it. Consequently, crashworthiness researchers must work with human tolerance levels as they now exist. The crashworthiness of the road system is another matter. Although highway changes are often slow and laborious, it is possible to replace signs and poles with breakaway versions. It is possible to design bridge abutments that control the angle of vehicle impact. It is possible to remove certain hazards from the highway shoulder. There is much that can be done to improve the crashworthiness of the highway.

Mr. Wilson describes the three main kinds of crash testing used to determine crashworthiness. First is the full-scale test in which a complete car is crashed under controlled conditions to determine the crush properties of the structure. A second method is impact sled testing which can be used to study the occupant to interior dynamics.

A third approach, component testing, can be used to test individual assemblies such as the instrument panel-knee impact area. Data are collected through electronic transducers mounted on the vehicle and on the dummies and by high speed cameras placed onboard the vehicle or beside the test area.

Turning to the question of what we ought to do as opposed to what we can do, Mr. Wilson outlines some of the constraints placed on the development of a crashworthy vehicle. For example, the efforts to date to develop an experimental safety vehicle have resulted in a considerable increase in vehicle weight. Furthermore, it has been demonstrated that even with present day cars larger vehicles are more crashworthy than smaller ones. Yet problems posed by the population explosion and the serious questions of fuel resources and air pollution have led to the recommendation of the use of smaller cars. How can we resolve the environmental benefits of the smaller vehicle with the increased risk of injury or death? We must also face the question of whether we should be aiming to prevent a small number of serious injuries or focusing on larger numbers of less serious injuries. We need to recognize that as we make progress we will be faced with the law of diminishing returns. At some point it will require an enormous effort to achieve a miniscule return in safety. How should we define the level of cost-benefits that is appropriate? There are also tradeoffs in safety features. While the use of seat belts clearly reduces the overall injury experience, there are certain kinds of crashes in which seat belt usage may increase the probability of injury. There are no simple answers. Working policies cannot be established by researchers alone but will require the combined efforts of responsible persons from government and the private sector.

Our three speakers have provided a vivid description of what is an exciting cooperative effort to combat a major social problem. The data they have reported will have a major impact on the vehicles we will be driving in the next decade and, for some of us, may make the difference between life and death. We feel fortunate to have had them share with us the advances that are taking place in the development of a more crashworthy vehicle.

Patricia F. Waller

Section I

Research In Automobile Crashworthiness And Occupant Protection

Edwin A. Kidd

EDWIN A. KIDD

Since 1963, Dr. Kidd has been engaged in transportation research at Cornell Aeronautical Laboratory, Inc. As head of the Transportation Research Department, he has been concerned primarily with driver behavior measures and computer simulation. A breakdown of the department's research includes crashworthiness studies and full-scale tests; impact mechanics; restraint mechanics, including computer and impact sled simulation; and other areas of applied research. From 1948 to 1963, Dr. Kidd was involved in aircraft research at CAL; before joining the CAL staff, he was a research engineer for Lockheed Aircraft Corporation and a flight test engineer for the U. S. Air Force. He received the Ph.D. degree in experimental psychology in 1969 from the State University of New York at Buffalo.

RESEARCH IN AUTOMOBILE CRASHWORTHINESS AND OCCUPANT PROTECTION

By Edwin A. Kidd

Crashworthiness is the capability of an automobile for protecting occupants from injury during impact. This protection may be provided by proper design of three areas of the vehicle: the interior structure, the occupant restraint systems, and the structure exterior to the compartment. These individual components cannot be considered independently, as the performance of each affects the requirements of the others. Thus, concern for the complete protection package is necessary to the development of proper solutions for occupant protection.

Research on systems to provide occupant protection begins with the definition of the environment in which such systems must operate. Automobile accidents occur in a variety of ways, and the resulting impact loads on the structure and the decelerations imposed on the occupants can be from any and all directions. However, it is not practical to provide on-board vehicle systems that will give complete protection from injury in all accidents at all speeds for all vehicles. Therefore, the assignment of protection levels and the determination of priorities for research are essential. Information on which to base these levels and priorities can only be obtained from actual accident data. Appropriate interpretation of accident statistics will define the operating environment within which the occupant protection package must work.

The Accident Environment

Numerous accident analyses have indicated that the most frequent direction of impact is from the front. Although accidents are often classified as head-on, intersection or rear end accidents, each of these types includes at least one vehicle that suffers a frontal impact. In a rear end accident, the car behind suffers a forward impact. In a side impact, intersection accident, the striking vehicle is again experiencing a forward impact. With the addition of head-on accidents and frontal impacts with objects in single vehicle accidents, the frequency of frontal impacts approaches 50 percent as shown in Figure 1.

IMPACT DIRECTION	PERCENT*
FRONT	46.5
SIDE	19.4
REAR	17.1
SIDESWIPE	9.1
ROLLOVER	1.6
NOT CLASSIFIED	6.3
	100.0

* BASED UPON PRELIMINARY CALCULATIONS, UNPUBLISHED RESULTS, CAL TRI LEVEL ACCIDENT STUDY

FIGURE 1. *Distribution of accident impact directions*

This distribution of accident types was obtained from a sample of all reported accidents involving current model vehicles in the eight county Western New York area surrounding Cornell Aeronautical Laboratory (CAL) during the period from November 1969 through November 1971.[1] Eighty-two percent of the vehicles involved were passenger automobiles, with the remainder consisting of multi-purpose vehicles, trucks and buses. Over 60 percent of the vehicles involved were 1969-1971 models. This summary is based on preliminary calculations; however, the overall ranking of accident types by frequency of occurrence should not be affected by subsequent data refining.

Distributions of accident samples that include only injury producing accidents give rollover accidents a higher proportion and rear impacts less than the data of Figure 1, reflecting the greater severity of rollover accidents.

Speed at impact is an important consideration in establishing the environment for occupant protection. Usable speed information is difficult to come by in most accident samples, and most statistical studies of accidents bypass the speed question entirely. However, somewhat better sets of data on which to base accident reconstructions are being collected by professional accident investigators. These professionals base accident reconstructions on physical evidence and employ engineering techniques. Computer simulation is a promising new development in the reconstruction of accidents and in the provision of speed estimates at impact. A research program[2] aimed at providing aid to researchers involves a form of computer simulation that will reconstruct the accident based on information provided by investigators at the scene.

This accident reconstruction model (McHenry, December 1971) is an outgrowth of earlier research in which a well-validated model of the vehicle, roadway, objects struck and the driver was developed[3] (McHenry and DeLeys, July 1971). The capabilities of this model can best be illustrated by a recent effort to design an automobile thrill show stunt in which a full-sized automobile rotates 360 degrees in the air and lands on a receiving ramp (Figure 2). Design of the ramps was accomplished entirely from parameter studies with the mathematical model. This accurate prediction of the effects of approach speed, friction coefficient, etc., provides considerable confidence that an accident reconstruction model can be developed that will bring

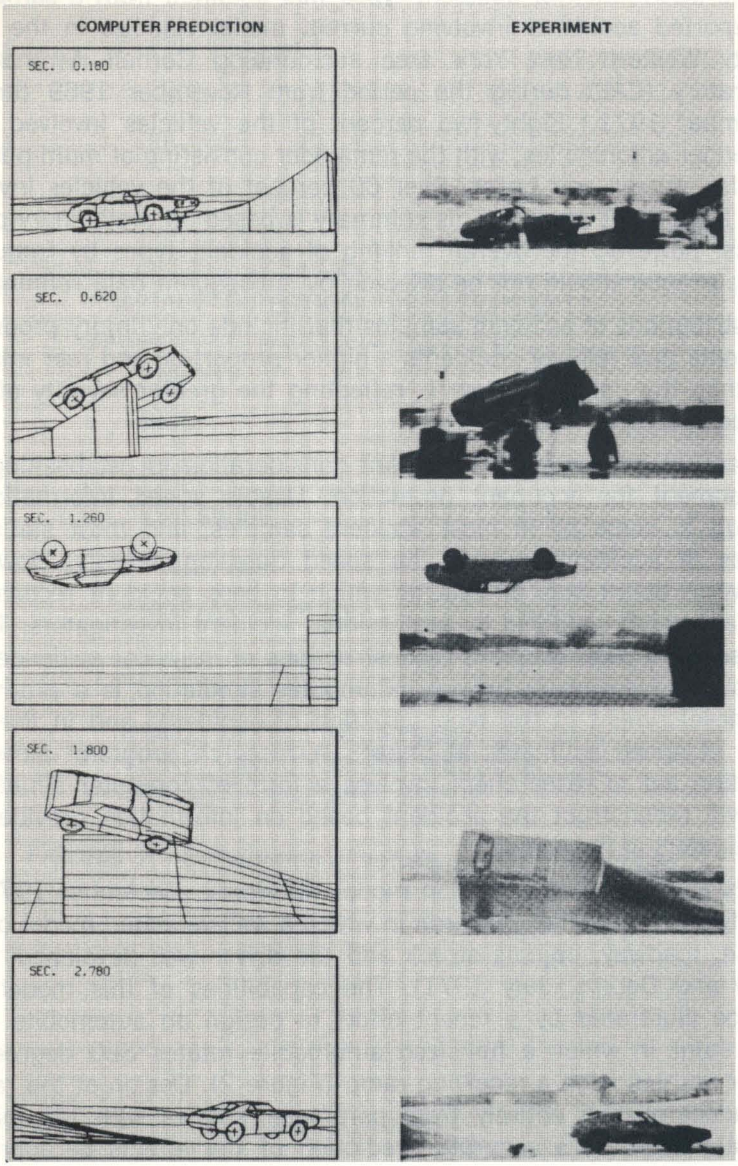


FIGURE 2. *Spiral ramp jump*

uniformity to impact speed estimates and overall accident reconstruction by accident investigators. Development of the accident reconstruction adaptation of this modeling approach is continuing with applications to staged and actual accident investigations.

At present, we can use only what data are available on accident speeds. Distributions of occupants exposed to injury and of occupants injured or killed is presented in Figure 3 for a sample of rural accidents in Utah (Kihlberg, May 1969). Although this particular data sample may not be completely representative of the accident population as a whole (because of possibly different distributions of accident types, vehicles, driver age, etc.), it does serve to indicate how the maximum speed requirements for occupant protection is affected by the criteria for protection.

For illustration, it will be assumed that the overall objective is to provide occupant protection in two thirds of the accidents. To protect two thirds of all occupants suffering any reported injury would require that appropriate protection be provided at speeds up to something greater than 40 mph. If the concern is the reduction of fatalities only, in similar amount, then the appropriate protection speed becomes approximately 60 mph.

The data summarized in Figure 3 are for all accident types and for unrestrained occupants. Use of these pooled data was for convenience (to the author) only. Any such decisions on maximum speeds for protection should be done for each particular accident type—front, side, rear, rollover.

Another parameter essential to an adequate definition of the accident environment is a description of the objects struck. Automobiles strike or are struck by other vehicles, fixed objects, or rollovers, in that order. In the CAL Western New York data sample referred to earlier, a preponderance of these reported accidents included vehicles striking other vehicles (90 percent). However, the 10 percent single vehicle accidents produced more than 30 percent of the severe injuries.

Adding to the total picture of the environment for occupant protection systems in automobile accidents is the variation in vehicle dimensions—interior and exterior—and the structural elements contiguous to the occupant. An example of the range of current vehicle dimensions pertinent to frontal impact protection is given in Figure 4.

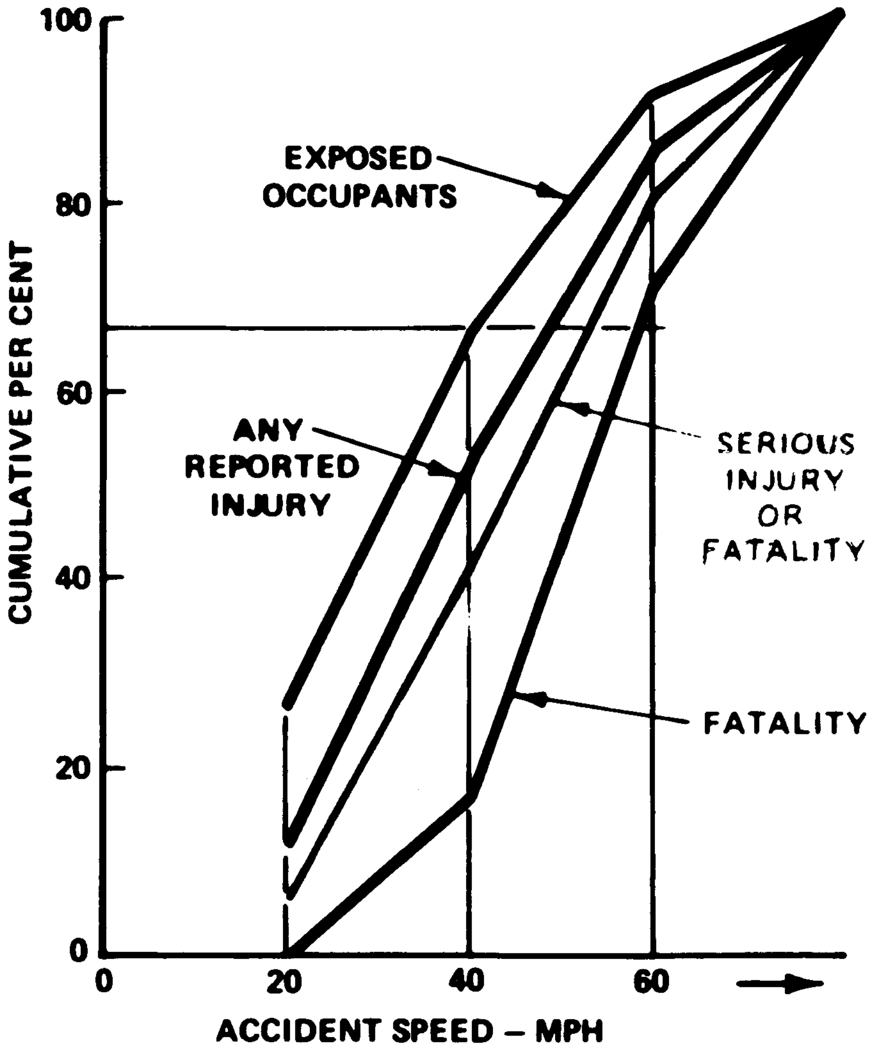
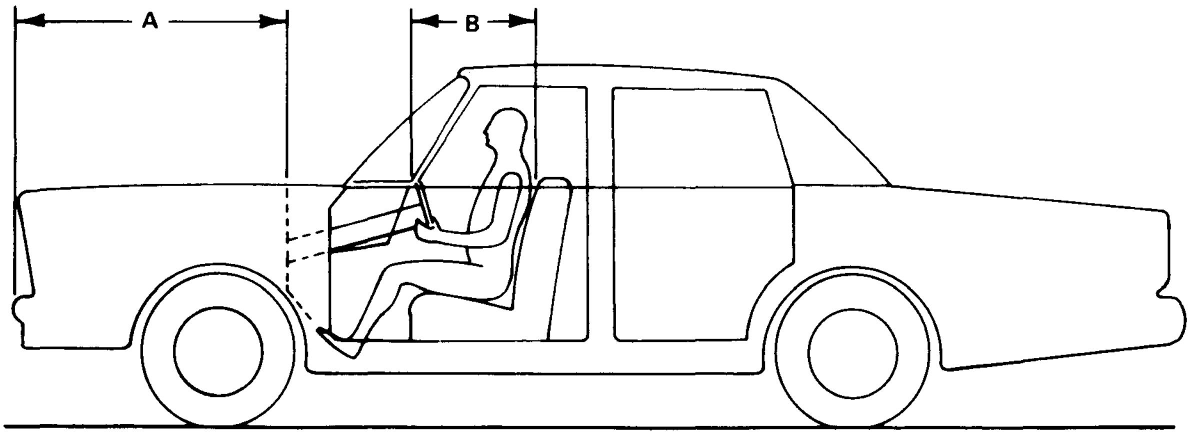


FIGURE 3. *Injury distributions with accident speed*



DESCRIPTION	FOREIGN SUB-COMP.	AMERICAN SUB-COMP.	AMERICAN COMPACT	AMERICAN STD. SIZE
DIM A – CRUSH DIST. BUMPER TO FIREWALL	35.5″	44.0″	47.5″	58.0″
DIM B – INST. PANEL TO SEAT BACK	26.0″	27.5″	29.5″	32.5″

FIGURE 4. *Automobile dimensions relevant to crashworthiness and occupant protection*

There is also the variation in occupant size and the many possible seating positions (driver, front passenger, rear passenger). Not to be overlooked are the dimensions and characteristics of the seats themselves—both bucket and bench.

Even this brief statement of the characteristics of the protection environment presents a complex picture of variables for which to design a total vehicle crashworthiness and occupant protection system. Logically, a step by step, inclusive solution of the problem should be forthcoming. The research on crashworthiness that is in progress is directed toward this goal; and this statement of the problem, in all its complexity, provides a background from which to evaluate this research.

Occupant Restraint

Early efforts to improve occupant protection were concerned with the solutions to specific aspects of the total problem as each was identified as a contributor to injury. For example, ejection and windshield and side glass were among the first injury producing elements to be identified in research on causes of injury (Tourin, 1958; Schwimmer, Seymour and Wolf, 1962; Campbell and Hopens, December 1964; Garrett, May 1962). From these came safety door latches, seat belts and laminated glass as solutions. The effects of these initial safety measures can be examined in a variety of references (Kihlberg, May 1969; Garrett, December 1964; Fargo, Garrett, May 1969; Garrett, July 1970). Meanwhile, the effects on injury of vehicle interior design, in particular sharp edges and protuberances, were identified (Anon., August 1963; Gensler and Campbell, September 1964; Transportation Research Department, July 1969). Smooth surfaces, padding and grouping of instruments in seldom struck areas evolved as solutions. Similarly, the steering column as an injury producer was identified from accident data (Shoemaker and Narragon, November 1963; Garrett, January 1970) and the non-penetrating column became a requirement. Historically, the steering column has generally provided protection for the driver as compared with the right front passenger (Kihlberg, November 1965). This occupant position has been further improved by the installation of collapsible steering columns on many automobiles (Levine and Campbell, November 1971). Additionally, strengthened doors have been added to improve side impact performance, and a requirement has been made for torso restraints.

With proper occupant restraint, protection of occupants from at least severe injury is possible in forward impacts with no external (to the compartment) structural modification of intermediate size vehicles at speeds up to 40 mph. However, the present occupant restraints—lap plus shoulder harness—appear marginal at 30-40 mph impact. A recent research study (DeLeys, Segal, Patten, December 1971) using one of the available tools, the CAL Two-Dimensional Occupant Simulation (Figure 5) offers some insight as to the interactions of the various pertinent parameters that define the available occupant protection including types of occupant restraint, forward structure deceleration-crush characteristics, and impact speed.

In this study, five idealized deceleration-crush characteristics of the vehicle ahead of the compartment were assumed. Each of these waveforms, as shown in Figure 6, was based on the assumption of 24 inches of vehicle crush for a 40 mph impact; that is, each represents the same amount of maximum energy.

Waveform #1 is a square wave with a constant deceleration (27.7 g's over the entire 24 inches of crush) and represents optimal energy dissipation. Waveform #2 is roughly characteristic of the force deflection properties of existing vehicles, where the lower force level corresponds to the crush of sheet metal and the higher level represents the resistance of the engine-transmission and suspension structures.

Waveform #3 represents a vehicle that is capable of developing high resistance forces for the first four inches of deformation with the load then dropping off as the structural members collapse. The maximum deceleration allowed for the initial portion of the force-deflection curve is 60 g's.

Waveform #4 is an increasing ramp and was chosen since it is known to produce excessive belt loading (Martin and Kroell, January 1967), and therefore would represent the upper limit of the injury indices. Finally, case #5 is a waveform representing a vehicle with a very soft forward structure that would cause an occupant to move forward under the action of a small decelerating force, thus reducing the spacing between himself and the interior, and thereby taking advantage of ride down effects.

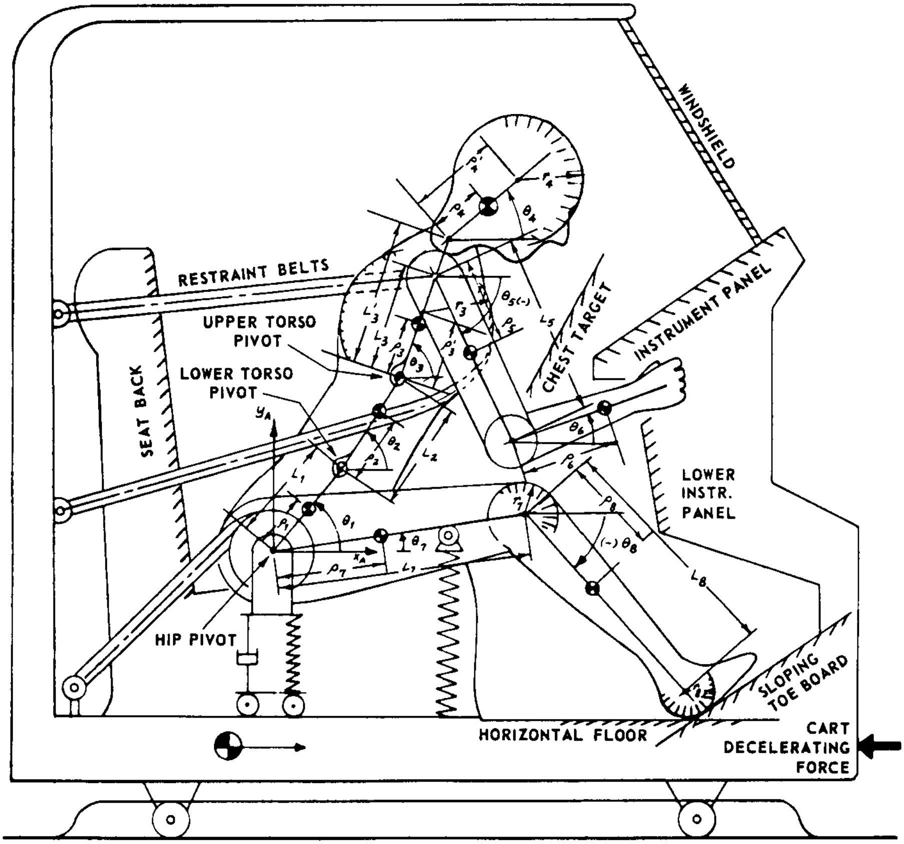


FIGURE 5. *Mathematical model of human body and restraint system on test chart (11 degrees of freedom)*

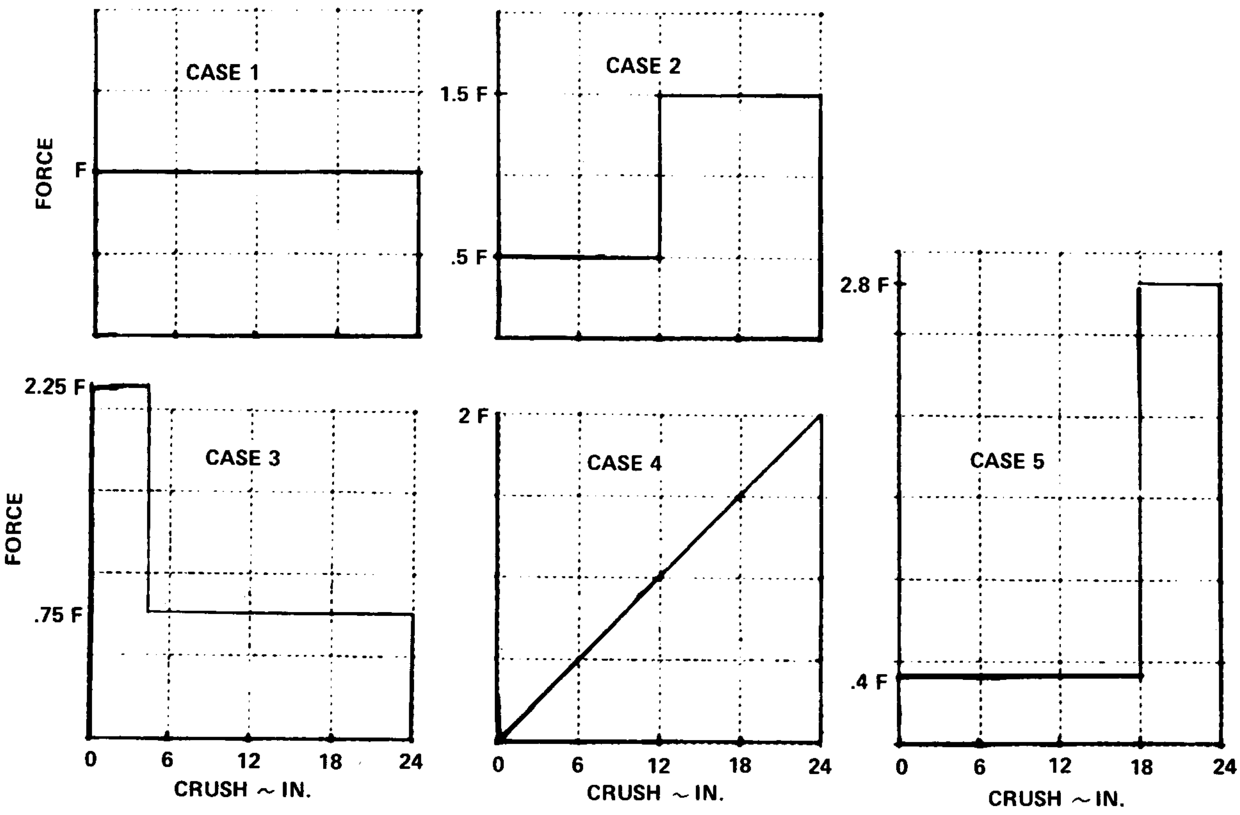


FIGURE 6. *Idealized deceleration—crush characteristics of vehicle*

For a 50th percentile occupant restrained with lap and torso belts and in a 30 mph impact, waveform #3 provided the lowest values of injury indices (Figure 7). The severity indices reported are Gadd numbers (SAE Head Severity Index) as based upon resultant head accelerations. Parameter studies with these model simulations such as the one discussed here are most appropriately used to make relative comparisons between specific parameter values. Interpretation of the results in terms of absolute values is appropriate only in the gross sense. However, there is the indication that a three-point harness system coupled with a representation of conventional structural deformation characteristics, waveform #2, would provide protection at impact speeds near 25 mph (using the present HSI limit of 1000).

Another utilization of mathematical simulations in determining protection requirements is a study conducted by the Ford Motor Company (Gruch, Henson, Ritterling, September 1971). Figure 8 (Figure 29 of the referenced report) presents estimated lives saved for various safety measures. An interesting conclusion from this figure is that utilization of an assumed constant force harness restraint system by greater than 40 percent of exposed occupants would provide the same overall protection for occupants (in reducing fatalities) as the assumed front and rear air bags with lap belts.

It should be emphasized that regardless of such conclusions, it has not been possible to induce occupants of automobiles to use available belt restraints more than 25 percent to 30 percent for seat belts and 2.5 percent to 4 percent for lap-torso belts (Council, October 1969; Nelson, January 1971).

A three-dimensional mathematical model of the occupant, vehicle interior and restraint systems (Bartz, July 1971) is being completed at present (Figure 9). Initial validations with impact sled and the laboratory tests are excellent, and this tool will be available shortly for studies on occupants and pedestrians in impacts of whatever type and direction. Sample comparisons between predictions and experiments are shown in Figures 10 and 11. In these experiments a 50 percent percentile Sierra 292-1050 anthropomorphic dummy was forced into a very general nonplanar motion by locating the dummy and belt anchor points in an unsymmetrical manner on the sled. The final dummy head position differed from that predicted as a result of neglecting belt-chin interactions. This comparison was made during the develop-

VEHICLE DECELERATION WAVEFORM	HEAD SEVERITY INDEX	
	20 MPH	30 MPH
1	693	1217
2	351	1695
3	728	1077
4	714	2001
5	254	1526

FIGURE 7. *Computer simulation results for 30 mph—lap and torso belt restraint—standard interior*

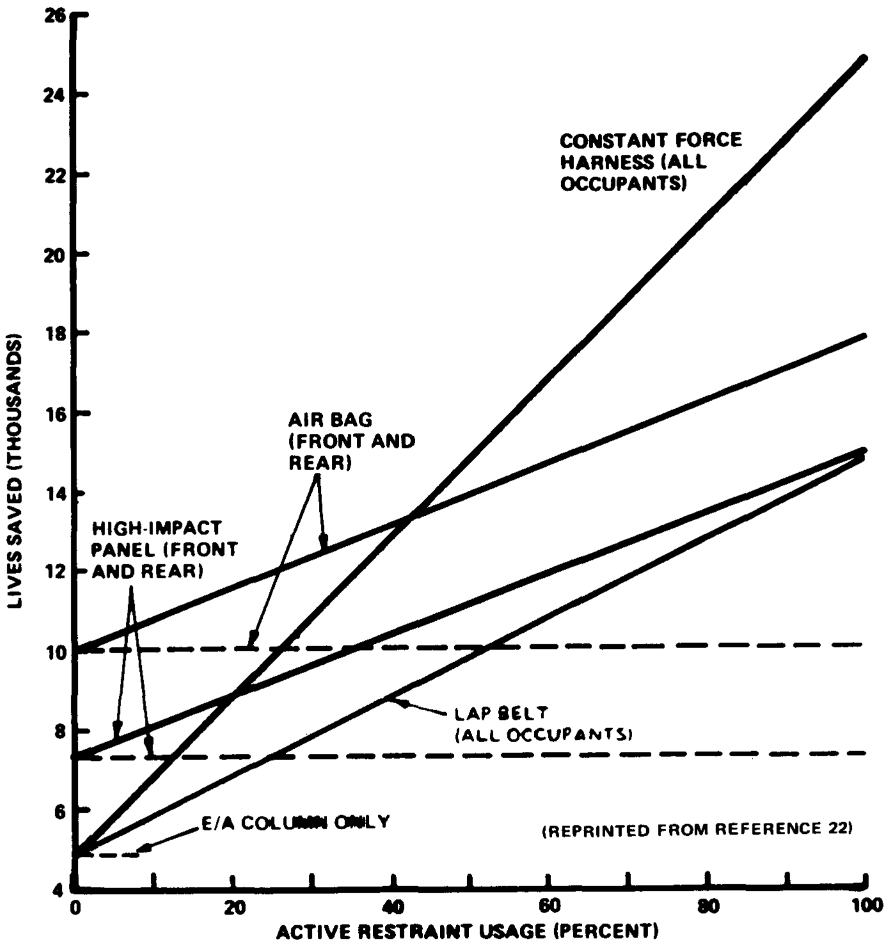


FIGURE 8. *Lives saved with various restraint systems as a function of active restraint usage*

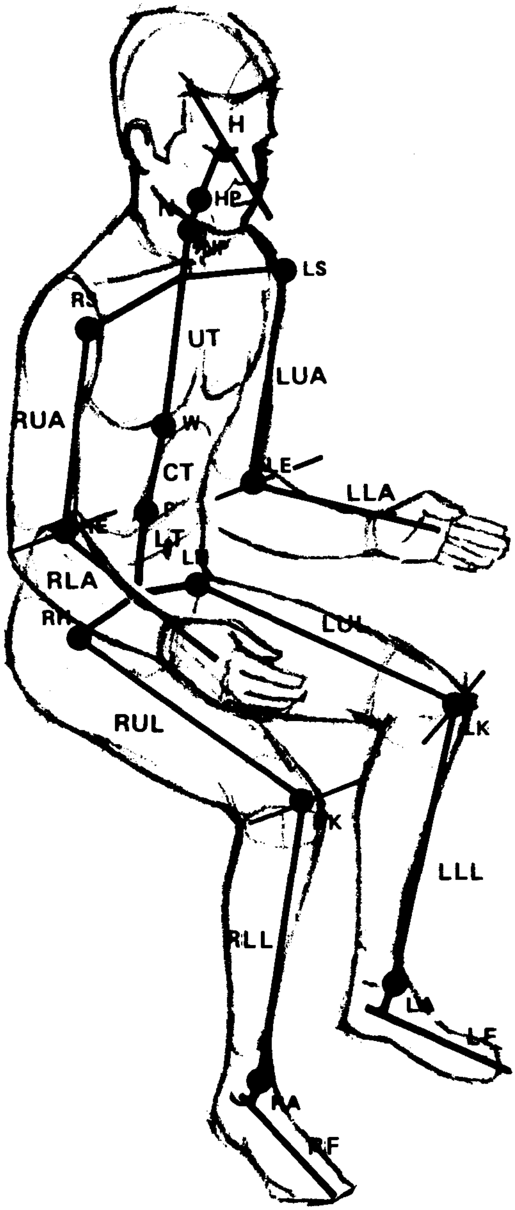


FIGURE 9. *3-D mathematical model of occupant/pedestrian*

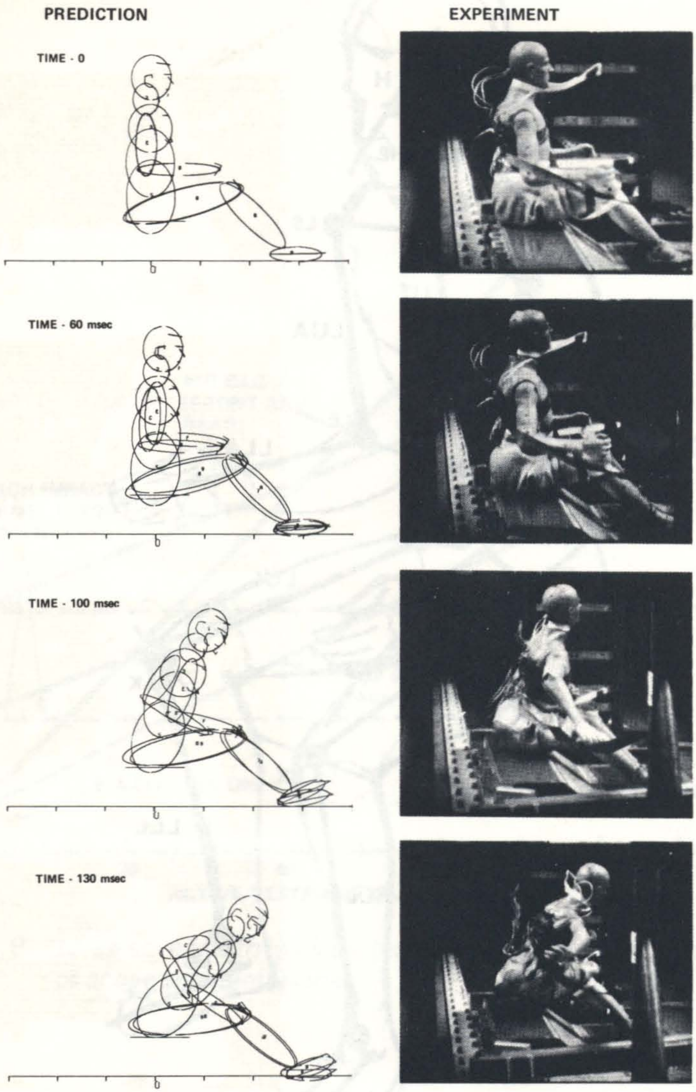


FIGURE 10. *3-D mathematical model validation—20 mph impact sled experiment, side view*

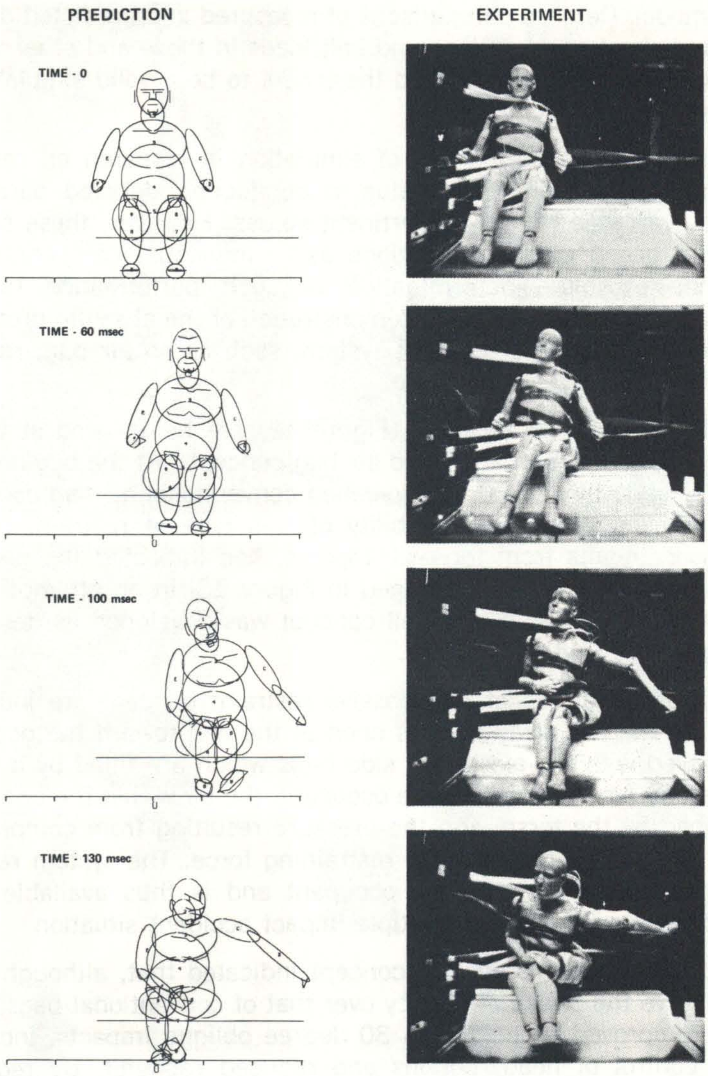


FIGURE 11. *3-D mathematical model validation—20 mph impact sled experiment, front view*

ment of this three-dimensional simulation and serves as a demonstration that the various degrees of freedom were appropriately excited in the model. Detailed comparisons of measured and predicted dummy head and chest accelerations and belt loads in these and other validation experiments have indicated the model to be a valid simulation of the physical systems.

These examples of the use of simulation in research on restraint systems demonstrates their value in conducting detailed parameter studies over wide ranges of pertinent values. However, these simulations are based upon assumptions as to individual component performance. Absolute determination of such performance requires physical experiments; and the demonstration of the absolute protection provided by a specific restraint system, such as an air bag, requires impact sled and full scale testing.

Such physical test facilities (Figure 12) are being used at CAL in the development of an advanced air bag concept.[4] At the beginning of this project in July, 1970, the so-called conventional air bag concepts, while demonstrating the feasibility of this type of restraint in protecting occupants from forward impacts, had indicated the need for improvement in the areas outlined in Figure 13. In an attempt to improve these features, a multicell concept was developed as described in Shoemaker, September 1971.

The basic features of this passive restraint concept are indicated in Figure 14. The array of cells open at the end toward the occupant is deployed with the aid of the side bags which are filled by a stored gas system. Upon impact by the occupant, the air within the open cells is trapped by the torso, and the pressure resulting from compression of the trapped air provides the restraining force. The system remains deployed after impact by the occupant and is thus available for a secondary impact or for a multiple impact accident situation.

Sled testing of this air bag concept indicated that, although it did not improve the stroke efficiency over that of conventional bags, it did provide improved protection in 30 degree oblique impacts, including better control of head motions and reduced rebound. By requiring considerably less inflation gas, it will also considerably reduce the over pressure within the compartment. These results, coupled with the improvement as regards multiple impacts, have indicated sufficient

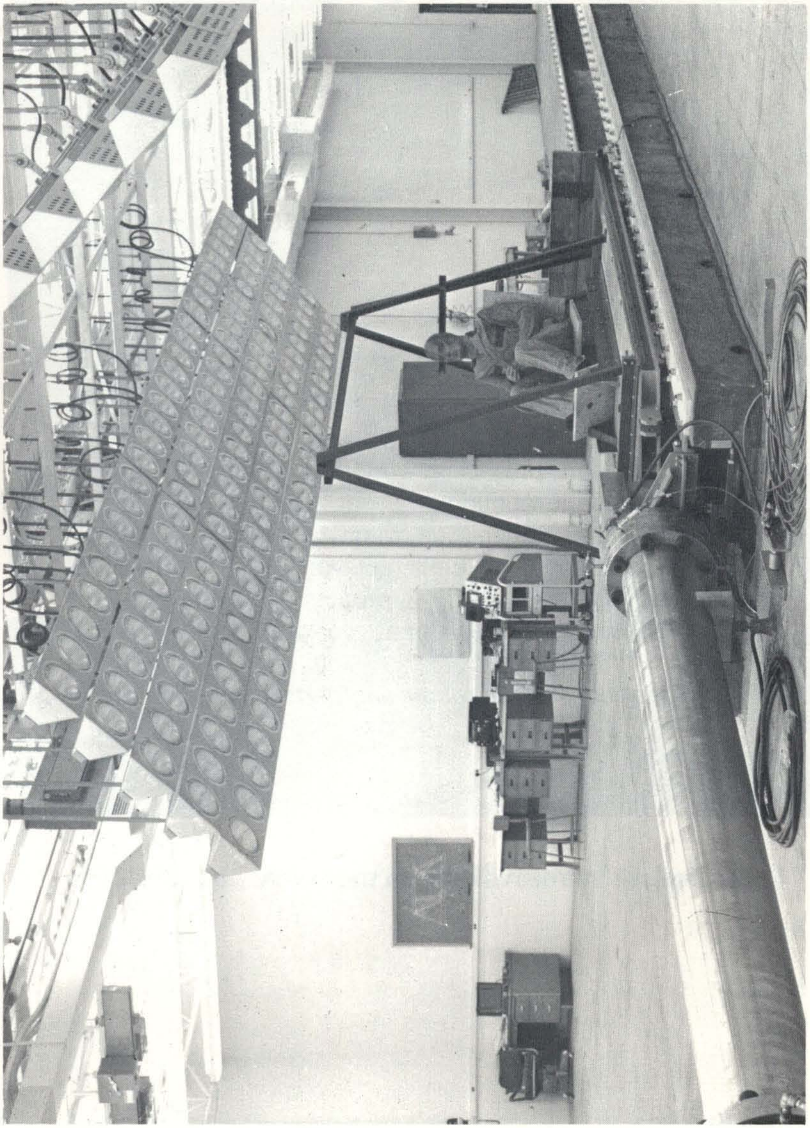


FIGURE 12. *CAL impact sled*

- Stroke efficiency
- Control of occupant head motions
- Occupant protection without lap belt
- Occupant rebound
- Protection in oblique frontal impacts
- Protection in multiple collisions
- Occupant to occupant impacts
- Passenger compartment over pressure

FIGURE 13. *Areas considered for air bag performance improvement*

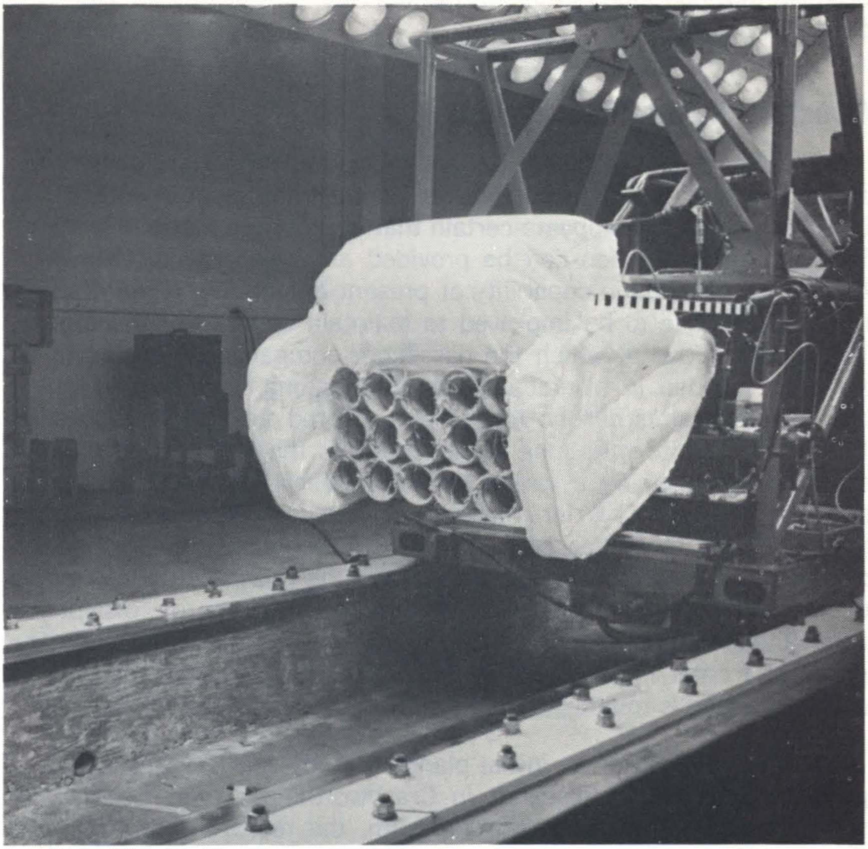


FIGURE 14. *Advanced inflatable restraint system—air 3*

promise that continued effort on the development of this air bag concept is in progress.

Structural Energy Management

Although these restraint system research programs have been aimed at protection of occupants in frontal impacts at speeds up to 30 miles per hour, it appears certain that appropriate restraint systems for occupant protection can be provided at higher speeds. However, the energy dissipation capability of present automobile forward structures would have to be improved to maintain compartment integrity. The impact speed at which the passenger compartment begins to be seriously invaded in frontal impacts defines one limit beyond which occupant restraints can no longer be expected to protect. Figure 15 (Mason and Whitcomb, June 1972) presents the range of permanent crush experienced by a variety of automobiles—subcompact to full size—in car-to-flat barrier and car-car impacts. With from approximately 21 to 31 inches of frontal crush available, depending upon overall bumper to firewall dimensions and the relatively undeformable engine dimensions, some approximation of the energy dissipation capabilities of automobiles can be made. Thus, from Figure 15, the range of frontal impact velocity for which compartment integrity is still maintained is roughly 30 to 40 mph.

In June 1968, after an initial planning study (Mayor, July 1968), a project titled "Basic Research in Crashworthiness" was begun with sponsorship by NHTSA. In this program, the research emphasis has been on the development and demonstration of practical structural collapse mechanisms to improve the energy dissipation characteristics of automobile structures. Structural collapse concepts have been developed for both frontal and side impacts of primarily intermediate or full-size vehicles. There has also been some effort on luxury and compact automobiles. Publications of this research include Miller and Naab, November 1969; (a) Miller and Mayor, November 1969; Mayor and Naab, November 1969; Miller and Greene, November 1969; Mayor, Theiss and Schuring, November 1969; (b) Miller and Mayor, November 1969; Miller, Greene and Culkowski, March 1971; Shoemaker, Segal, and Naab, July 1969; Naab, January 1972; Johnson, April 1972; Galganski, May 1972.

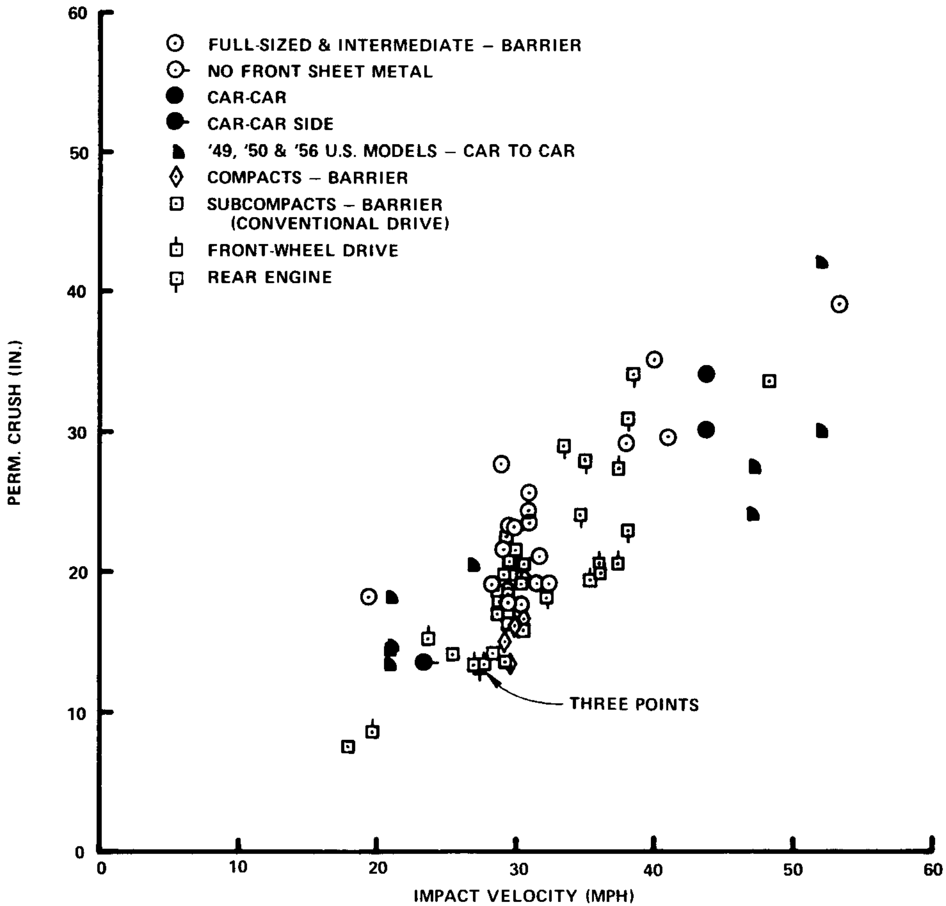


FIGURE 15. *Car-barrier and car-car impacts*

The overall design goal for performance in frontal impacts has been to obtain approximately a constant deceleration at a level of 40 g's. There is human tolerance evidence that a totally restrained occupant can survive 40 g for .100 seconds with an onset of approximately 500-600 g's per second (Anon., September 1967). As the impact duration at 60 mph is of this order of magnitude, this design level appears appropriate.

For side impacts, the design goals have been 20 g's at 40 mph in car-car impacts and 20 mph in pole impacts. The reduced acceleration levels for side impacts is necessary because of the lack of appropriate restraint and the necessity to allow for occupant impacts on the vehicle interior.

Side structure modifications were designed to meet the objectives listed in Figure 16. Modifications required to achieve these objectives are indicated in Figure 17 for a recent test vehicle. This side impact structure also provides protection against rollover accidents and contributes to the overall structural modifications required for frontal impacts. With the addition of Ensolite padding on the inside of the door and a Lexan window panel, the measured dummy head severity index was reduced from 1480 to 480 in pole impacts at 21 mph (Figure 18). Chest and pelvis accelerations were also reduced markedly.

Initial efforts on front structure modifications were directed primarily toward demonstration of feasibility of particular structural collapse concepts. For the intermediate size automobiles, two general approaches were taken. One involved modifications to the area ahead of the engine—greatly increased bumper stiffness plus structural mechanisms to provide control collapse over approximately the front two feet of the vehicle. The second approach utilized the entire front of the vehicle up to the firewall for bringing the compartment to a stop at impact speeds of approximately 60 mph. This "engine deflection" concept moves the engine beneath the passenger compartment during the impact and provides controlled collapse from bumper to firewall (approximately four feet).

In the earlier research, no special effort was made to reduce overall weight increases or to provide operable vehicles. After the initial demonstrations of feasibility, recent efforts have been directed toward the objectives of Figure 19.

1. IMPROVE OVERALL STRUCTURAL INTEGRITY OF OCCUPANT COMPARTMENT (PREVENT EJECTION OR CONTACT BY OUTSIDE OBJECT)
2. INCREASE LATERAL STRENGTH OF OCCUPANT COMPARTMENT TO PREVENT EXCESSIVE INTRUSION (OUTSIDE OBJECT OR ANOTHER VEHICLE)
3. AVOID EXCESSIVE "RIGIDIZING" OF THE COMPARTMENT TO LIMIT LATERAL ACCELERATION RESPONSE (HUMAN TOLERANCE)

FIGURE 16. *Objectives of side structure modifications*

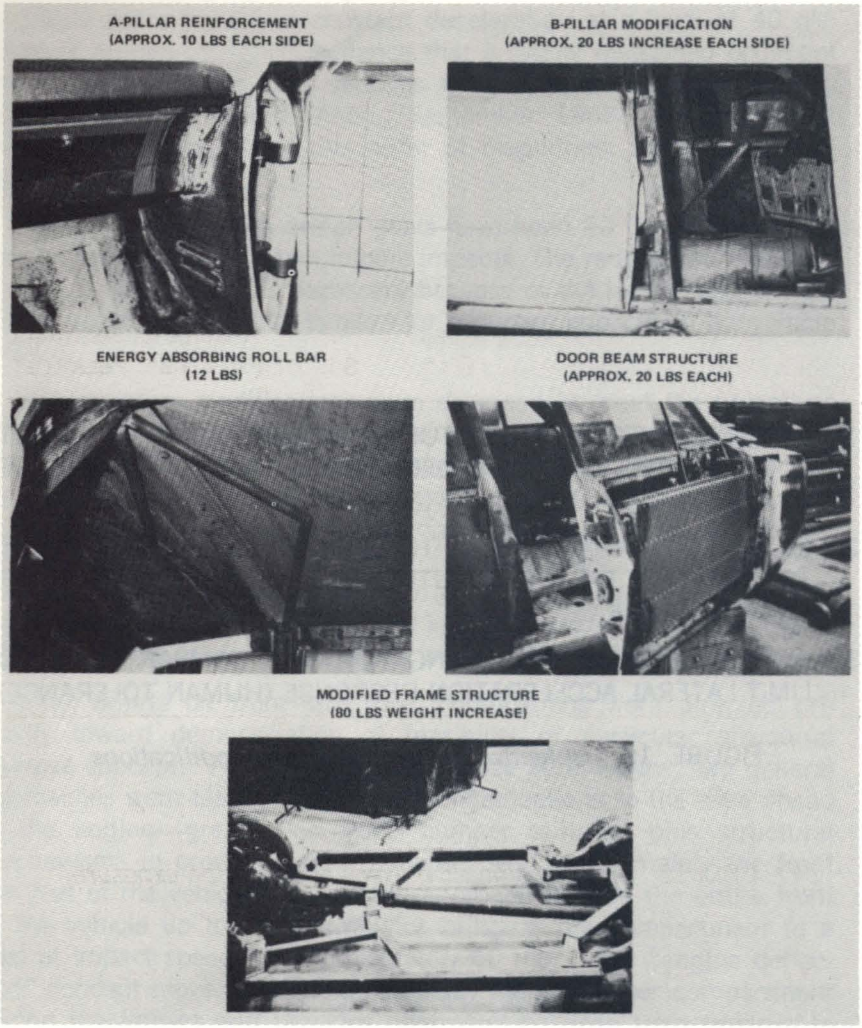


FIGURE 17. *Side structure modifications*

Test Configuration	Dummy Location	Head Resultant Peak G's*	Head Resultant S.I.	Chest Resultant Peak G's*	Pelvis Resultant Peak G's*
90° Side pole impact (mod 3E3, test No. 49)	Right rear seat	49	290	54	38
	Right front seat	59 (30)	480 (240)**	38	54
90° Side pole impact (base-line, test No. 46)	Right front seat	105	1480	65	92

* Peak magnitude for .003 second duration

** Secondary pulse

FIGURE 18. *Anthropometric dummy acceleration exposure*

- Reduction structural weight increase
- Integrate front and side structural modifications
- Compatibility with conventional automobiles during side impact
- Consider problems related to operational vehicles

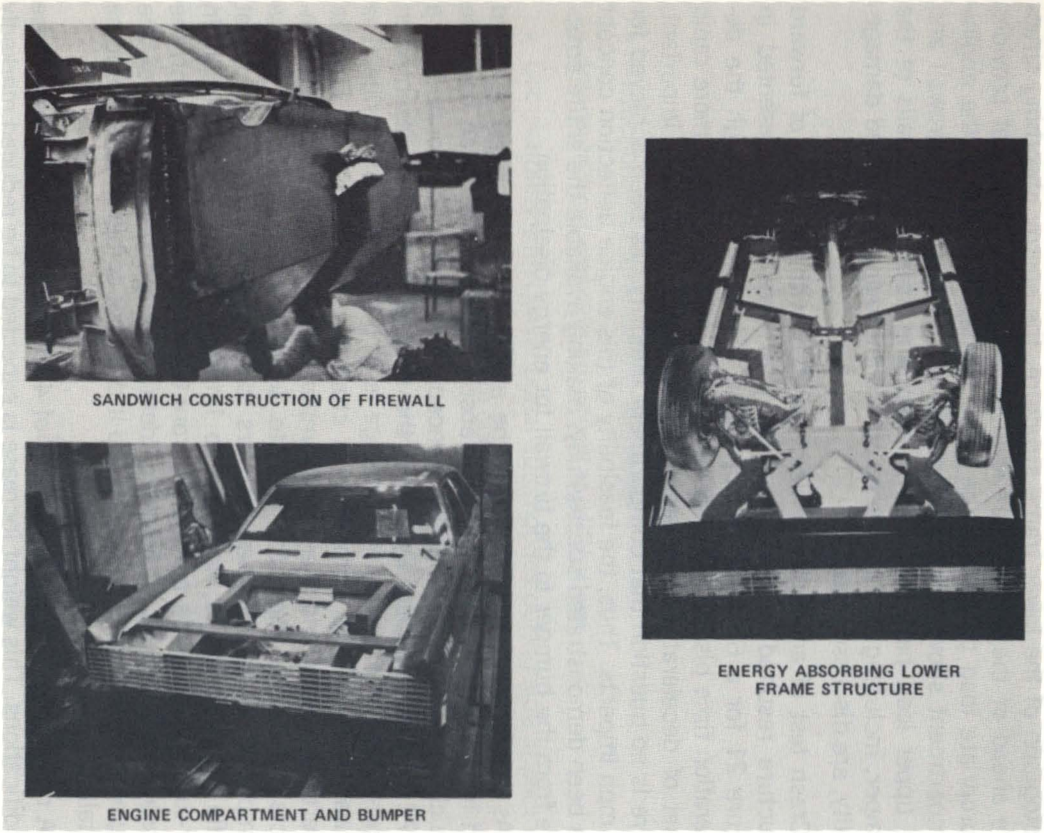
FIGURE 19. *Front structure development objectives*

Details of the forward structure for the engine deflection concept are presented in Figure 20 for a recent test vehicle. The firewall construction shows the engine deflection ramp which mates with a similar installation on the engine itself to insure proper separation. In the photograph of the lower frame structure, the energy absorbing structure ahead of the firewall is shown as is the structure that provides appropriate load paths into the basic frame. The view of the engine compartment shows the additional strengthening of the firewall and the upper load path and energy absorbing structure. Details of the bumper, including its Ensolite insert for improving low speed damageability, are discussed later.

Crash test of an earlier vehicle modified with this type of forward structure resulted in the time history of deceleration presented in Figure 21 for a 60 mph impact into a fixed pole. Although the deceleration time history does not resemble a square wave, a more rapid onset of deceleration has been achieved. Also, and most important, there is no question that compartment integrity has been achieved for 60 mph impacts. Thus, the feasibility of this engine deflection concept has been demonstrated successfully, making available the entire structure from the bumper to the firewall for energy dissipation.

As a first step in determining the actual weight increase required and in demonstrating this energy absorbing structure in an operable vehicle, the engine deflection concept has been incorporated in a 1972 Ford automobile. Details of the modifications are presented in Figure 22. The only "styling" change is in the bumper and grille. The forward face of the bumper is a channel section with an Ensolite insert between it and the fixed bumper component. In low speed impacts, up to nine mph, the Ensolite deforms with no damage to the bumper structure and then recovers to its original dimensions. A flat grille construction is employed to improve the load distribution in car-to-car impacts, in particular, front-to-inside impacts. Although the forward structure is difficult to identify in the photography of the engine compartment, it is there and it does not compromise the engine installation.

A net increase in vehicle weight of 475 pounds resulted from these modifications. This weight increase is expected to be reduced markedly when production tools and dies are utilized for structural components. Also, not all of this incerase is attributable only to the improvement of



SANDWICH CONSTRUCTION OF FIREWALL

ENGINE COMPARTMENT AND BUMPER

ENERGY ABSORBING LOWER FRAME STRUCTURE

FIGURE 20. *Forward structure modifications*

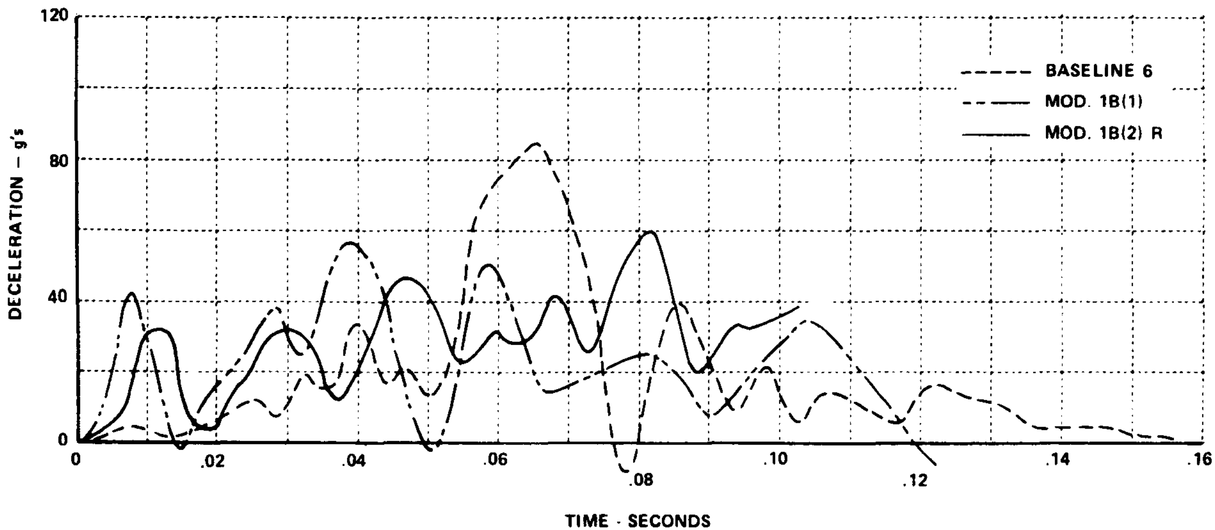
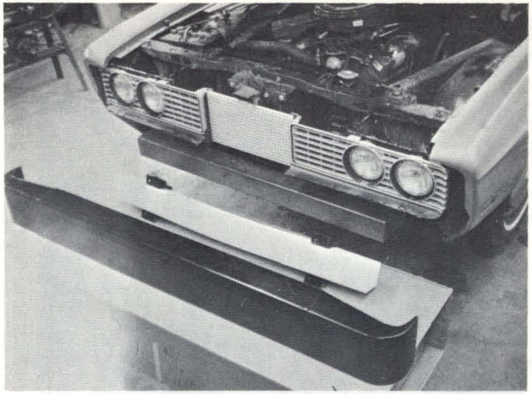
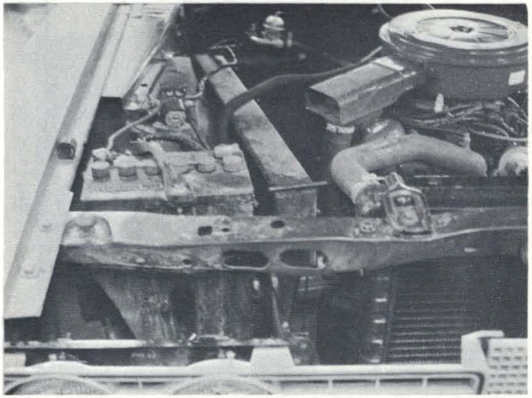


FIGURE 21. *Longitudinal passenger compartment deceleration data (mod. 1 series vehicles)*



BUMPER CONSTRUCTION

DRIVER STATION



ENGINE COMPARTMENT

3/4 OVERALL VIEW

FIGURE 22. *Crashworthy front structure in a 1972 Ford vehicle*

frontal impact performance. Some of the changes would properly be attributable to side impact performance improvement. Brief handling tests of the final vehicle in this series are planned to demonstrate any changes from the unmodified vehicle due to the increased weight and changed weight distribution.

Controlled energy dissipation for frontal impacts has also been demonstrated in compact automobiles for 60 mph impacts. For these vehicles, the design acceleration limits must be proportionally higher than those for the intermediate or full size vehicles. Car-to-car impacts between vehicles of different sizes will result in excessive deformation of the vehicle of smaller size unless the structural deformation characteristics are stiffer than those of the larger vehicles. Careful consideration of this vehicle to vehicle interaction is essential in establishing compatible maximum deceleration design goals. Also required is the design of vehicle interiors and restraint systems that are compatible with individual vehicle deceleration limits.

Recommended Continuing Research

An immediate area of concern should be the performance of small automobiles—compact and subcompact—in the environment of impact with larger vehicles.

Continuation of the development of crashworthy structures for intermediate size automobiles should emphasize overall integration of front and side structures in operable vehicles.

The development of mathematical models of structural collapse during impact should continue with concern for methods of weight minimization as well as the prediction of performance of candidate designs.

Comparative studies of competing energy management systems—e.g., both energy dissipating structures and hydraulic systems—should be conducted with concern for weight, cost and protection provided in the context of the total accident spectrum.

Studies to evaluate the interactions between energy dissipation systems, vehicle interiors and occupant restraint systems should be accomplished, directed toward optimization of the total protection package. Extensive use of mathematical simulation is envisioned with validation of specific predictions of performance by impact sled and full-scale testing.

Development of accident investigators' aids for reconstruction of accidents should continue with emphasis on continuing surveillance of adequate samples of accidents to provide feedback on effects of safety measures as introduced.

FOOTNOTES

1. On-going CAL Tri-Level Accident Study, sponsored by the National Highway Traffic Safety Administration and the Automobile Manufacturers Association.

2. Sponsored by the National Highway Traffic Safety Administration.

3. Sponsored by the Federal Highway Administration (formerly the Bureau of Public Roads).

4. Sponsored by the National Highway Traffic Safety Administration.

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Section II

The Experimental Safety Vehicle Program

John A. Edwards

JOHN A. EDWARDS

Mr. Edwards is the Acting Associate Administrator for Research and Development of the NHTSA, a position he assumed in 1969. His primary responsibility is to coordinate community and state research programs in highway traffic safety in accordance with the Federal Motor Vehicle Safety Standards. Research programs under his administration include studies of driver behavior, vehicle handling and vehicle crashworthiness, and development of an experimental safety vehicle. Before joining the Department of Transportation (the parent organization of the NHTSA), Mr. Edwards was associated with the National Aeronautics and Space Administration (NASA) as Director of Gemini Operations, Deputy Director of the Gemini Program, and Director of Apollo Operations, in that order. A graduate of the United States Military Academy, Mr. Edwards received the M.S. degrees in aeronautical engineering and instrumentation engineering from the University of Michigan.

THE EXPERIMENTAL SAFETY VEHICLE PROGRAM

By John A. Edwards

Good afternoon ladies and gentlemen. It is a distinct pleasure to have this opportunity to discuss with you the National Highway Traffic Safety Administration's Experimental Safety Vehicle Program as a part of this symposium on "Crashworthiness: Safety Through Automotive Design." Certainly, this is a subject which must be a special challenge to each of us, as I am sure that each of us has had, directly or indirectly, some personal experience, probably recently, with an automobile accident and its effects.

The Experimental Safety Vehicle Program is one of three priority programs now receiving the major portion of the administration's resources. All three were selected because of the high probability of near-term results. Possibly during the question period, we can discuss the other two priority programs.

My formal presentation this afternoon will be restricted to the ESV program and will cover:

(1) An overview of the ESV Program, its objectives and goals,

(2) A description of the initial ESV project—the family sedan—now well under way,

(3) A summary of the International ESV Program, the success of which has exceeded all of our expectations; and finally,

(4) A few comments about our future plans for the ESV program.

The Experimental Safety Vehicle Program: An Overview

The purpose of the ESV Program is to test, on an experimental basis, new ideas of automotive safety incorporated in a vehicle which has been designed, fabricated, and tested as a total system. The basic objectives of this program are to determine the technical feasibility of making significant safety performance improvements in motor vehicles, to stimulate public awareness of the long-term social and economic advantages to be gained from savings of lives and injuries resulting from advanced auto safety design, to encourage the industry to increase its efforts in auto safety design, and finally, to establish the technical base for the development of improved motor vehicle safety standards.

The ESV Passenger Car Program that we envision is designed to bring about the development of a number of vehicle classes which together span the spectrum of passenger cars on the road today. These vehicles will be designed to weight and passenger space configurations similar to today's production vehicles, so that the unique problems associated with each may be solved. The first vehicle class, five-passenger family sedan, is a project in full operation. This maiden project, under sponsorship of the U.S. government, is progressing well. Detailed progress and specifications for this project will be discussed in a few moments.

In addition to this project, three others are believed necessary to cover the full range of popular passenger cars. These are: the intermediate, the compact, and the subcompact class vehicles.

Each of these vehicle classes poses unique problems that must be investigated to assure the ultimate establishment of reasonable safety performance standards for all passenger vehicles. For each project, we would hope that the design concept would employ a total systems approach, and thus provide the optimum trade-offs between accident avoidance, crash-injury reduction, and post-crash factors in single car, as well as car-to-car crashes.

Obviously, however, the development of safe automobiles in these various vehicle classes cannot be accomplished without consideration of the interrelationships between the classes themselves. On the other hand, it was felt two and one-half years ago that development could not wait for the completion of a long series of highly complex "studies" before proceeding. The process is interactive, the technology was largely at hand, and the simple awareness and reasonable consideration of other weight class vehicles was considered sufficient for us to proceed. That this action was at least catalytic is evidenced by the development activity of such companies as Volvo, Volkswagen, Mercedes, Toyota, and Honda.

We have given consideration to the "big car-little car" crash in the development of our family sedan specifications—particularly in the specification for velocity proportionality in front collisions.

We have planned the passenger car ESV Program to meet the previously stated objectives through a series of steps which demonstrate significant progress at the earliest possible date. Accordingly, near-term goals have been selected that we believe are reasonable to achieve, yet represent potential substantial savings in highway losses based on our present accident experience.

We believe, at this time, crashworthiness must receive the highest priority in all passenger-type safety vehicle development programs, because of the overriding cost effectiveness advantage that is available from initial improvements in this area. As those of you who have reviewed our current specifications are aware, the emphasis in our family sedan program is on crashworthiness. A near-term goal of crashworthiness in a frontal barrier collision at 40-50 mph has been selected because our data indicates that approximately 85 percent of frontal injury-producing accidents occur at or below this velocity range.

For the family sedan project, current state-of-the-art vehicle handling characteristics have been selected as the immediate goal, because the potential for substantial savings in lives and injuries in this area has not been quantified to a sufficient degree. In addition, the lead time required for exploration of significant improvements in safe handling could compromise the short-term crashworthiness improvement program. Long-term goals do, without question, require improvements in this area. In other NHTSA research areas, a perceptible shift of emphasis into the area of driver performance and vehicle performance research is already under way.

Vehicle body style was a major consideration in the selection of near-term and long-term ESV goals. The family or standard sedan was chosen for initial investigation by the Department of Transportation because of its high usage rate in our country, and because conceptual studies indicated that a higher degree of safety could be demonstrated in the shortest design and development time.

The development and demonstration of the 40-50 mph family sedan will hopefully be followed by initiation of an intermediate class advanced safety vehicle project with crashworthiness capability from 40 to 50 mph. This vehicle will not be limited to a front-engine design. Indeed, it may be necessary to go to a mid-engine design to allow space in front for the required crashworthiness hardware. We anticipate starting initial design efforts in the immediate future.

A second major step in the ESV passenger car program is now underway by virtue of foreign developments in the lighter weight vehicle classes. These vehicles, while representing less than ten percent of the vehicles on United States roads, account for a number of traffic deaths and injuries. In addition, the number of small vehicles in the 1500-3000-pound weight class on American roads is rapidly increasing. Automobiles in this category are being introduced by both American and European manufacturers. Because of this, the special problems associated with providing safety protection for small car occupants will be prominent in our research and development activities during the seventies.

The trade-offs associated with the probable introduction of increasingly large numbers of small cars into the United States transportation system are being considered. We are all aware of some of the economic and ecological advantages of the small car from both the individual consumer and the general public's standpoint. However, these advantages must be weighed carefully against the inherent penalty that the small car occupant pays in reduced crashworthiness when he is involved in a collision with a larger vehicle. We are approaching the problems associated with the larger vehicles in our family sedan project and are hopeful that the design solutions resulting from that project will partially alleviate the small car's disadvantage in a big car-to-small car collision. This is being investigated through the incorporation of velocity sensitive front-end systems that reduce crash forces in the small car when struck by the larger car.

This concludes the ESV program overview and I would now like to move to the specifics of the family sedan project.

THE FAMILY SEDAN ESV PROJECT

In August 1967, proposals were solicited by the Department of Transportation for a program definition and preliminary design phase for the first Experimental Safety Vehicle. Contracts were awarded in March of 1968, and extensive conceptual and design trade-off studies were conducted for the Department in 1968-1969 period by three independent contractors. The results of these studies were analyzed by the ESV programs office, and an independent evaluation was further provided by another research contractor, the Battelle Memorial Institute. The primary conclusions were (1) that the department should embark first on a typical family sedan ESV project, in recognition of the popularity of this model, and (2) that crashworthiness (the minimization of injury to occupants in crashes) should be given top priority.

In mid 1970, after extensive review of proposals to design the safety car, contracts were awarded to AMF Incorporated, Fairchild Industries, and the General Motors Corporation for the development of prototype experimental safety vehicles of the family sedan weight class. In July 1971, the Ford Motor Company signed a similar contract. All of the contractors are designing to the same system performance specification which requires the application of total systems engineering to provide the optimum trade-offs between crash-injury reduction, accident avoidance, post-crash factors, and pedestrian safety. The principal contractors, plus their subcontractors, have a balance of experience which we believe is demonstrating that vehicles can meet the requirements of our specification and the overall goals of our program. General Motors and Ford are participating for the token sum of one dollar, while the contracts with AMF and Fairchild total about eight million dollars.

AMF Incorporated has extensive commercial and defense business experience and has, as major subcontractors, Mini-Car, Inc., The Bendix Research Laboratories, Pioneer Engineering and Manufacturing Company, Cornell Aeronautical Laboratories and the Eaton Corporation.

Fairchild Industries is one of America's major aerospace contractors and applies their significant technical knowledge and engineering skill to their design. Principal subcontractors to Fairchild are the Chrysler Corporation, Digitek, Bendix, Loewy/Snaith Incorporated and Eaton.

General Motors and the Ford Company, of course, need no introduction.

From the overall ESV program objectives previously discussed, more specific objectives were assigned the family sedan project. These objectives are:

(1) To demonstrate crashworthiness for front collisions into a fixed barrier at 40-50 mph velocities.

(2) To minimize injurious forces in side, rear, and rollover collisions.

(3) To provide riding and handling equal to or better than today's typical sedans, and

(4) To demonstrate advanced state-of-the-art braking, lighting, visibility, controls and display systems.

Design/Fabrication Plan and Progress

The schedule for the ESV family sedan project allowed one year to produce the final design which was completed in the summer of 1971. Prototypes from both AMF and Fairchild were delivered to the government in December 1971, or eighteen months after award of contract. Competitive testing of these prototypes is now in progress at Dynamic Science, Phoenix, Arizona, test facility. Based on the results of these competitive "drive-off" tests and evaluations, a follow-on contract for design optimization and fabrication of additional cars will be awarded to that contractor whose prototype demonstrates the best overall safety performance.

General Motors requested additional time to conduct more extensive design evaluations and development testing; therefore, GM is not scheduled to deliver their prototypes until October 1972. Ford, as mentioned earlier, did not sign their ESV development contract until July 1971; however, because of independent ESV work, their prototypes will be delivered in December 1972. Both the General Motors and Ford prototype ESV's will undergo a similar extensive testing program prior to prototype delivery.

The ESV Test Program

The ESV Development contracts required that all four contractors submit recommended test plans for prototype evaluations and for follow-on vehicle testing. These recommended test plans were received on schedule during December 1970. In conjunction with this effort by the major contractors, we had, as part of our supporting research project, contracted for independent work in devising a crash test plan. This input was also received in December 1970. With these five major test input recommendations, plus our own in-house work, a final test plan for prototype testing was developed, and a contract was awarded to Dynamic Science of Phoenix, Arizona, late in June 1971.

Dynamic Science spent the period from July 1971 to January 1972, upgrading their test facilities and conducting the necessary baseline tests in preparation for prototype testing. Testing of the 12 follow-on vehicles and the General Motors and Ford prototypes, plus follow-on vehicles from these contractors, will carry over into late 1974. However, during the testing period we will continuously assess the test results as they become available to determine what rulemaking recommendations are appropriate. There now exists the strong possibility that foreign-developed ESV's in the various weight classes will be available to participate in this test program.

International Technical Conferences on ESV's

The Second International Technical Conference on Experimental Safety Vehicles was a continuation of the International Exchange of Technical Information on Automotive Safety Developments initiated at the first conference held in Paris, France, in January 1971. At the Paris conference, which was sponsored by the U.S. Department of Transportation and hosted by the French government and the French automobile industry, all of the major automobile-producing nations of the world made technical presentations on current safety developments and participated in seminar discussions on vehicle ride and handling (braking, steering, suspension, drive train), crashworthiness (structures) restraint systems, interior safety design, and other accident avoidance factors (visibility, lighting controls and displays).

In November of 1971, just prior to the Paris conference, separate memoranda of agreements were signed by the United States with the Federal Republic of Germany and with Japan for the international development of ESV's and for the international exchange of technical information on these developments. In May 1971, similar agreements were signed by the United States with Great Britain and Italy. The French agreement with the United States was signed in October 1971, and the Swedish agreement in March 1972.

These international agreements between the major automotive-producing nations of the world now bring such names as General Motors, Ford, Chrysler, American Motors, AMF, Fairchild Industries, Daimler-Benz, Volkswagen, Opel, BMW, Ford of Europe, Toyota, Nissan, Honda, Fiat, Rolls Royce, British Leyland, Renault, Peugeot, Citroen, Saab, and Volvo, and their design and manufacturing expertise to the critical task of accomplishing a quantum jump in automotive safety through the application of total systems safey engineering.

The second ESV conference held October 26-29, 1971, was again sponsored by the U.S. Department of Transportation and was hosted by the Federal Republic of Germany and the Daimler-Benz A.G. in

Stuttgart, Germany. During this second conference, all four United States ESV contractors—AMF, Fairchild, General Motors, and the Ford Motor Company—made detailed technical status reports on their progress to date. The results of development tests were presented and design solutions discussed. Each of the signatory countries also presented their progress in ESV development, and seminar discussions were held on accident avoidance and crashworthiness developments.

This unprecedented international program for experimental safety vehicle developments is being spearheaded by the United States as part of NATO's broad attack on environmental and social problems through its Committee on the Challenges of Modern Society (CCMS) for the specific purpose of speeding up the development and exchange of new safety technology. To accomplish this transfer of technology, cooperating countries participate in a broad program of activity ranging from multilateral international meetings to the exchange of government-sponsored technical discussions and industry visits in the fields of: accident investigation, ESV, emergency medical services, alcohol driving countermeasures, vehicle inspection, and road hazard identification.

The Third International ESV Conference will be held in Washington, D.C., in conjunction with Transpo 72, and will be orientated toward the accomplishments of foreign governments in their ESV development.

FUTURE PLANS

Our present planning calls for a follow-on family sedan effort consisting of design optimization, as mentioned earlier, and fabrication of 12 additional ESV's from General Motors and the Ford Motor Company. All of these cars will undergo extensive testing so that quantitative engineering and test data will be available for the development of improved federal motor vehicle safety standards.

In fiscal year 1973, we plan to initiate definition and feasibility studies on an advanced state-of-the-art safety car project. This project will attempt to go well beyond the limits of conventional design and will investigate such advanced state-of-the-art safety design concepts as:

1. Crashworthiness vis-a-vis the ESV family sedan, the compact ESV and advanced energy management design concepts.

2. Producibility, maintainability, and reliability to determine what the technical base will support when these engineering disciplines are integrated with safety parameters into the overall design requirements.

3. Accident avoidance to determine what constitutes safety-related superior ride and handling as related to safety, what braking efficiency is possible, and are automatic systems feasible and practical.

4. Other advanced safety parameters including structures, restraints, visibility, lighting, human factors, controls and displays and engine pollution, etc.

All of these areas must be investigated considering the total transportation system including accident statistical data for the late 1970's and early 1980's.

In fiscal year 1974, the initial feasibility studies on a special-purpose vehicle project will commence. We plan to include in this project a safety motorcycle which is now under development by Honda, and a safety school bus effort which will investigate various safety possibilities when the school bus is considered as a total system. Some effort on trucks and recreational vehicles is also planned under this project. Of course, all of these vehicle classes must be investigated if we are to consider safety within the context of the total transportation system.

CONCLUSION

I would like to conclude my remarks today by repeating my invitation to all of you to join with us in the design and development of safer automobiles. Certainly, the challenge is a worthy one which warrants the very best effort from each of us. Today's technology has given us the necessary tools. We must put these tools to work to accomplish the design break-throughs which will reduce the numbers of accidents and injuries and help eliminate vehicle occupant deaths even in crashes at high speeds.

A caveat however: Please do not think that we espouse only mechanical design solutions. A true systems analysis and design optimization must consider: driver behavior; the driving environment; and, economic and societal factors. This program is a part of the whole—not the total solution.

We do feel in any case that the ESV Program will demonstrate technical feasibility and already has performed as a catalyst to bring together the major automobile producers of the world and their design and manufacturing expertise to seek solutions to this crucial problem of saving lives.

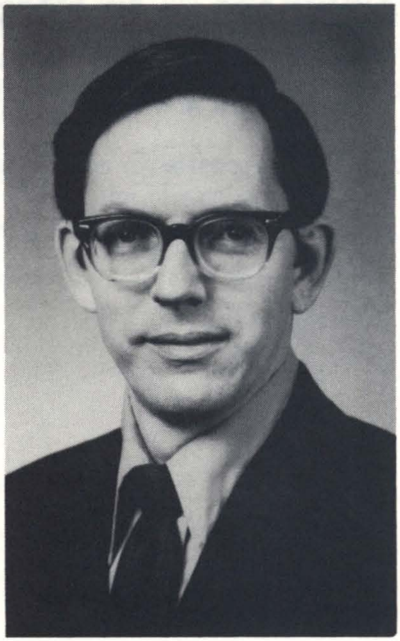
In 1970, the United States experienced a reduction of 1,100 lives lost on its highways. This is the reason and purpose for the existence of the National Highway Traffic Safety Administration.

Thank you very much.

Section III

Crashworthiness — In Perspective

Richard A. Wilson



RICHARD A. WILSON

Mr. Wilson joined GM in 1955 after receiving a B.A. degree in mechanical engineering from Bucknell University, Lewisburg, Pa. Presently, he is Engineer-in-Charge of the Safety Research and Development Laboratory at the GM Proving Ground, Milford, Mich. He was associated with GM's Noise and Vibration Laboratory until 1965 when he was assigned to the newly formed Safety Test Engineering Department. In 1968, the department was renamed Safety Research and Development Laboratory, and Mr. Wilson assumed the position of Staff Engineer for Impact Testing; in 1970, he was promoted to his present position. Mr. Wilson's background includes extensive research experience in structure dynamics, impact and vibration instrumentation, data analysis, and computer applications to dynamics problems.

CRASHWORTHINESS—IN PERSPECTIVE

By Richard A. Wilson

Automotive safety is one of the oldest of our current environmental problems. It has challenged automotive engineers ever since the first car took to the road and demonstrated that convenient transportation also entailed a responsibility for the people and property that touched upon it. An interesting advertisement appeared in many nation-wide magazines a few years ago. Humorously, the ad (Figure 1) pointed out the tragic inevitability that accidents become a by-product whenever humans operate machines. Certain combinations of circumstances produce unwanted events that were not intended to be normal operating conditions for the machine. For the case of automobiles, these unplanned situations very often involve the collision of one or more vehicles, producing damage to the car and, if the accident is severe enough, injury or death to the occupants.

The safety community has come a long way toward understanding this problem and dealing with it. Back in 1925, there were just under 22,000 traffic accident deaths (Figure 2). In the ensuing years, the number has slowly gone up to more than 55,000; however, the number of miles traveled has gone up much more sharply. In 1925, miles traveled totaled about 120 billion . . . and that has gone up to more than a trillion in recent years. Using these two references—the number of fatalities and total mileage—we can determine the death rate which, in 1925, was 18.2 fatalities for every 100 million vehicle miles. By 1971, the rate dropped to a record low of 4.7 deaths per 100 million miles. In particular, there was a 6 per cent drop in the death rate from 1969 to 1970 yielding 1200 fewer fatalities between those two years.

The Larger Picture

The vehicle-road-driver triangle has been used in many safety discussions to illustrate the three-sided nature of highway safety. More recently, our National Highway Traffic Safety Administration has expanded on this theme and has expressed the problem as a nine-cell matrix. This concept (Figure 3) not only indicates the important relationships existing between the driver, the vehicle and the external environment—before, during and after the accident—but also sym-

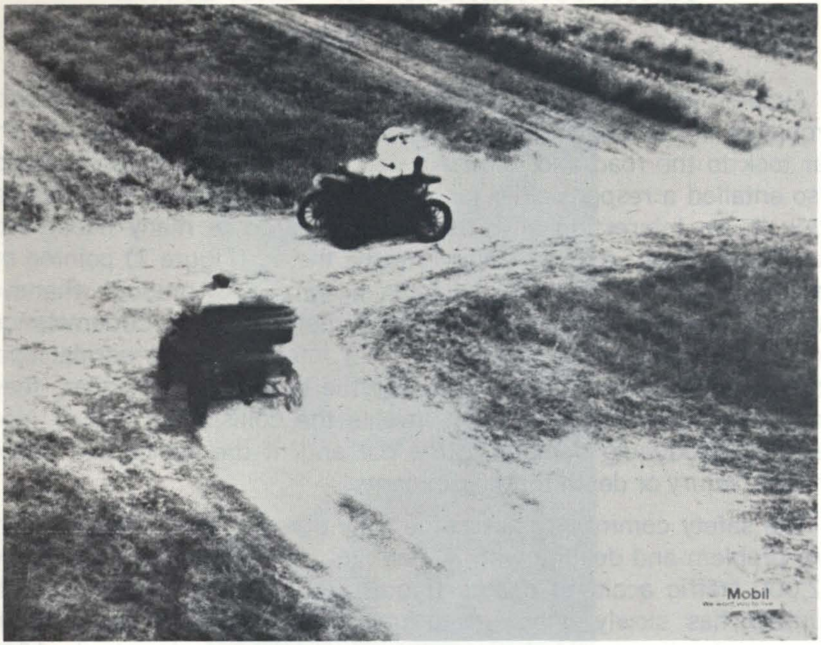


FIGURE 1. *In 1895 there were only two cars in Ohio. Guess what happened?*

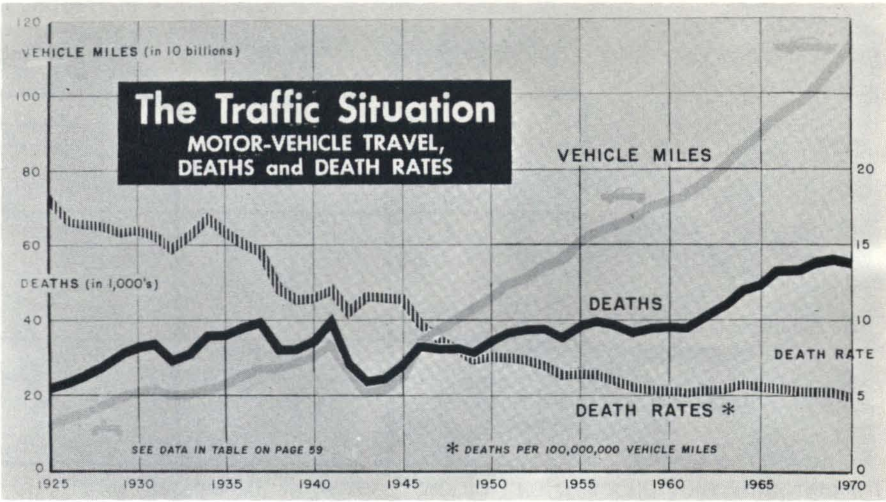


FIGURE 2. *The traffic situation*

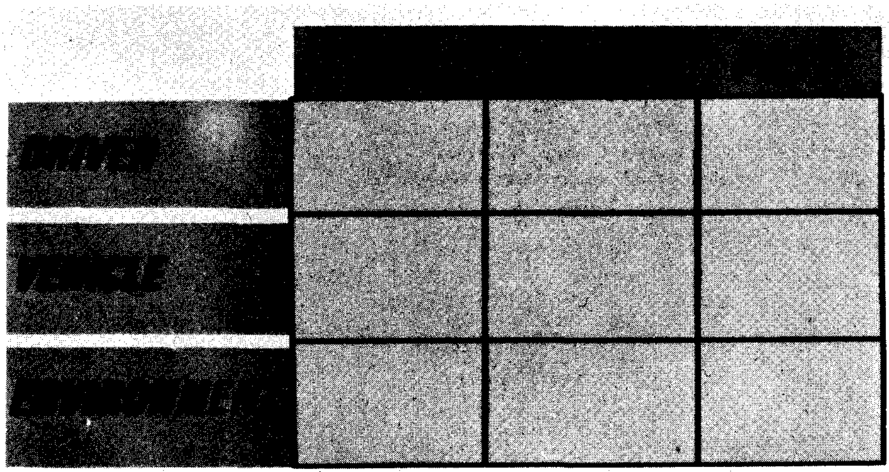


FIGURE 3. *Crash chart*

bolizes the need to move away from a fragmented approach toward a systems approach to highway safety research.

In earlier days, vehicle safety was associated primarily with creating the means of avoiding an accident. Brakes, steering, suspension, driver controls—such were the elements given primary consideration. However, these fall mainly into just one of the nine areas—vehicle pre-crash. Little attention in research was paid to the road, the driver, or the crash itself. The late 50's and early 60's saw an emergence of broader safety research. Human tolerance studies came about. Roadside improvements were tested and began to be implemented. Accident data began to be collected in more detail. Now the problem is being attacked from various fronts and further progress should follow as we gain knowledge in each facet of the matrix.

Crashworthiness

In this discussion, however, I would like to focus your attention on a specific area—crashworthiness. It has been nearly a decade now since industry, government and various private organizations embarked on what has been the most intensive safety research and development program in the history of the automobile. The initial emphasis during this period was placed on crashworthiness—an element of the highway safety matrix that was selected as having potential for fast and effective improvement.

What is crashworthiness? Simply put, it is a measure of the absence of crash injury. In the context of the nine-cell matrix, we can relate crashworthiness to those specific matrix elements involved in occupant trauma during the crash and post-crash periods. In other words, crashworthiness is a function of specific qualities and characteristics of the occupant, the vehicle, and the external environment which serve to minimize injury. Under this definition, we will find it appropriate to speak of not just the crashworthiness of a vehicle, but surprisingly, the crashworthiness of a bridge abutment, and even more surprisingly, the crashworthiness of the human body. Obviously, we are not free to alter all these elements, but we must understand each area and do what we can to relate them properly.

Given our definition of crashworthiness as a measure of traumatic injury, what can we say about our ability, as safety researchers, to reduce injury through design improvements? Let me begin by going all the way back (Figure 4) to a basic concept that traumatic injury is produced by excessive strain, in the mechanical sense. Not surprisingly, then, a first objective of crashworthiness research is to determine the human body's tolerance to excessive strain. Many studies have been conducted involving animal tests, human cadaver tests, and sub-injury volunteer tests—all directed toward providing biomechanical data needed for safety design.

Again from basic mechanics, we know that strain is a function of stress or pressure. And further, that stress and/or pressure are functions of force and area. Isaac Newton, one of the first safety researchers, found that force was a function of mass and acceleration. And going even further back, we can thank Galileo for first noting that acceleration was related to velocity and distance. Retracing this injury causation chain, we find that in order to reduce traumatic injury—by reducing strain, by reducing stress, by reducing force and acceleration—crashworthiness researchers have four major variables available for manipulation. And furthermore, that each of these four variables—impact *area,* stopping *distance, velocity* (or energy) change, and *mass*—can be divided into those factors which are inherently fixed and those factors which can be affected by engineering design. Thus, along with determining human tolerance levels, additional objectives of crashworthiness research are to reduce the number of uncontrollable factors and to reduce the injury potential of those factors which are controllable through careful engineering design.

Reducing the Uncontrollable Factors

Developments in vehicle safety illustrate the way that uncontrollable and undesirable factors have been made controllable, thanks to crashworthiness research. For example, the impact characteristics of materials external to the vehicle such as earth, rock, asphalt, steel and wood are uncontrollable with respect to the vehicle designer and usually undesirable with respect to an ejected occupant. Thus, a long line of crashworthiness improvements from the introduction of all-steel turret tops in 1935, to improved door latches, to lap and shoulder belts have all been aimed at reducing occupant ejections, thereby reducing exposure to uncontrollable, external impact surfaces.

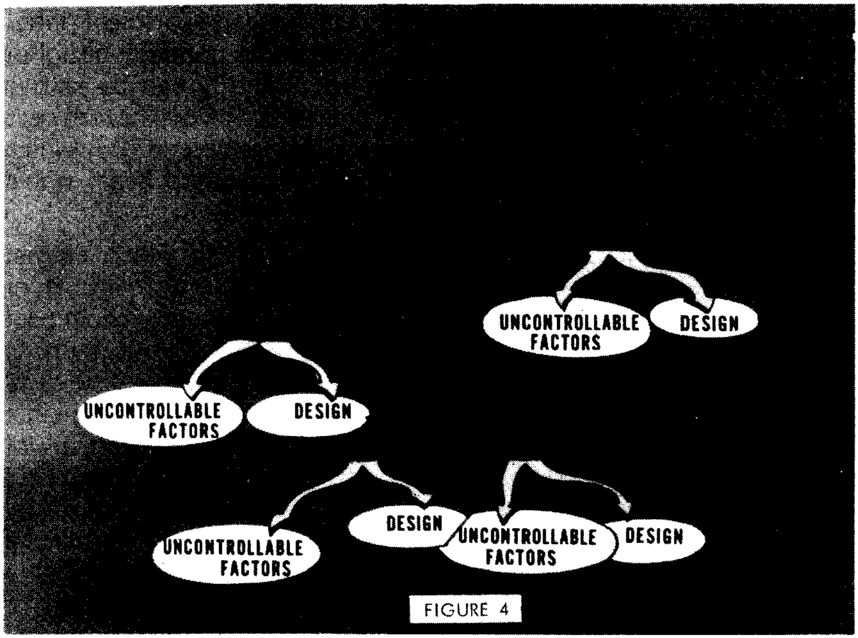


FIGURE 4. *Impact characteristics*

Similarly, the impact characteristics of vehicle interiors are, to a large degree, designable. However, if occupant compartment intrusion resulting from severe impacts occurs, then our carefully designed and controlled interior impact characteristics quickly can be shifted to the realm of the uncontrolled. Thus, one thrust of crashworthiness research has been toward design changes to the frame and body which attempt to minimize excessive intrusion. The side-guard beam would be in this category.

Another group of uncontrollable factors are those which do not respond to specific design changes. A good example of this is front structure force-deflection properties and their effect on the impact velocity and stopping distance of the occupant. To be blunt, there is no effect for unrestrained occupants. Their impact velocity and stopping distance are uncontrollable factors with respect to reasonable front structure design changes. One of the roles of occupant restraint systems, such as lap belts, shoulder belts and air bags, is to bring these factors within the control of front structure design. That is, by coupling the occupant to the vehicle, restraint systems permit the occupant to take partial advantage of the vehicle crush.

Stopping the Occupant

To clarify this point let me quickly review with you the dynamics of a frontal impact. Recall, if you will, that stopping distance is one of the four main variables available for manipulation by crashworthiness researchers. But just how much distance is actually available for stopping the occupant? To answer this question, we need to think about an important, but maybe not so obvious fact: the slowdown distance (Figure 5) the occupant actually has available to him is with respect to ground, not merely with respect to the vehicle. We see that the occupant travels a certain distance from the time the vehicle first touches the obstacle to the time he is stopped. We also see how this available slowdown distance can be divided into three separate categories: the interior crush, the initial free-space between the occupant and the vehicle interior, and the vehicle crush. Crashworthiness design must consider all three as we attempt to apply tolerable forces acting over as long a distance as possible.

This concept is more easily grasped if you will think of a passenger (Figure 6) looking down the aisle, while seated at the center of the

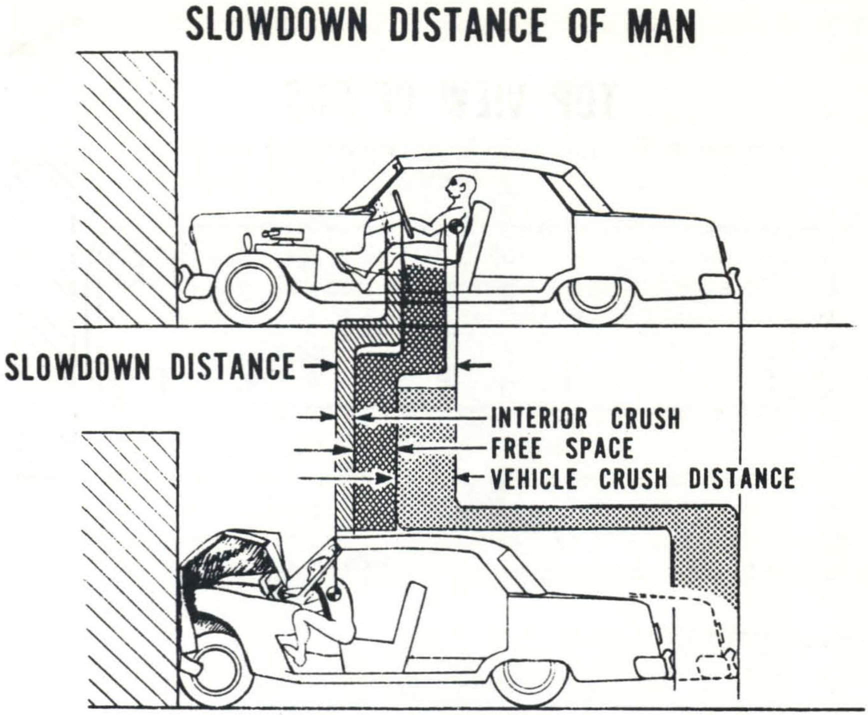


FIGURE 5. *Slowdown distance of man*

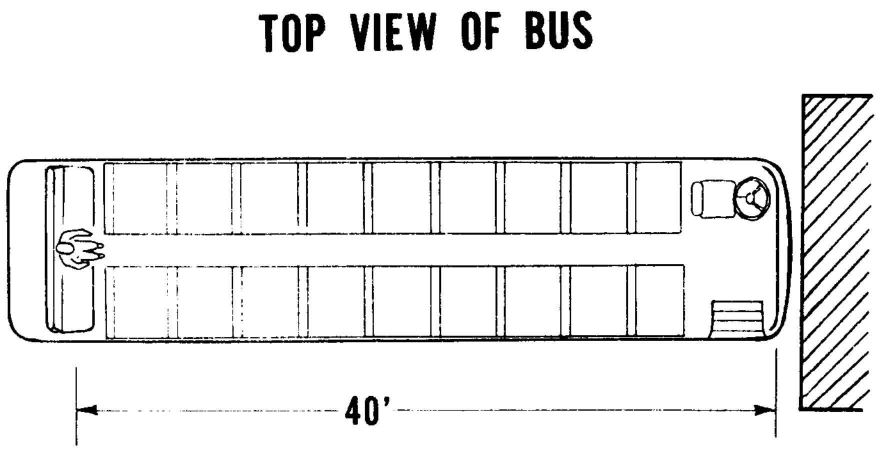


FIGURE 6. *Top view of bus*

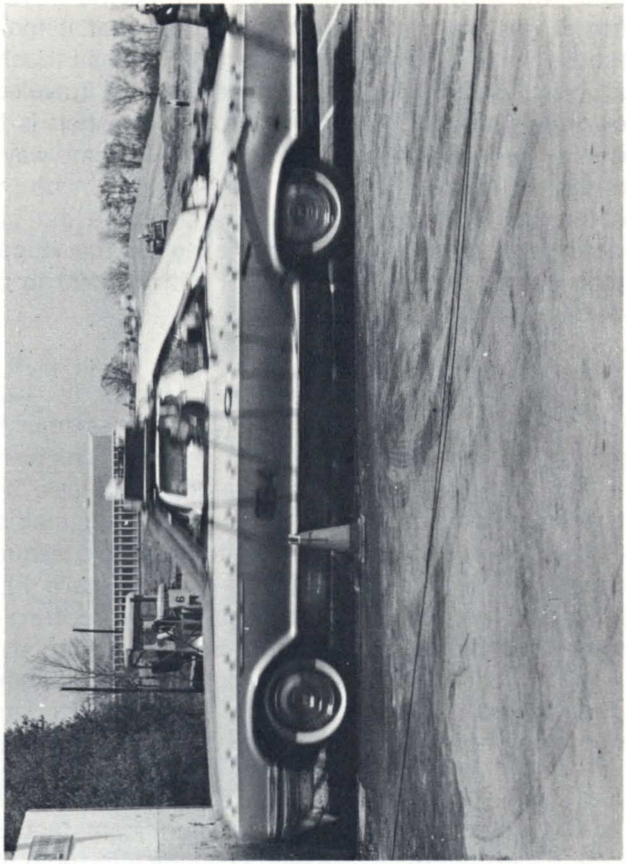


FIGURE 7. *Initial impact—rapid sequence photography*

rear bench seat on a 40-foot suburban bus. If the bus were to impact a rigid wall, it would stop in about one fourth of a second from 30 mph. The poor fellow on the rear seat keeps right on going and takes nearly a full second to reach the front of the bus, three fourths of a second after the bus has stopped. What was the useful stopping distance of this man? Certainly not the 40 feet he traveled down the aisle. And it was not the 41 inches of crush that it took to stop the bus, because the crush was finished before the man touched anything. We must have force acting through the distance traveled in order to slow down the occupant. The answer to the question is that the man stopped in a few inches of deformation, split in some way between the crush of the man himself and the "dent" he has made in the front of the bus interior. The crush of the bus structure did not affect the forces acting on the occupant. In other words, the stopping distance of the man was an uncontrollable factor with respect to possible front structure design changes in the bus.

Although the timing is closer, the same effect is true for unrestrained occupants in present day passenger cars, i.e.—the interior is essentially stopped by the time the driver or passenger traverses the free space. The occupant strikes an interior which is essentially stopped. You will not be surprised that this fact also holds true for lap-belt restrained occupants if you keep in mind that a lap-belt restraint does not slow down the upper torso. Rapid sequence photography can illustrate this point. At time zero (Figure 7), the vehicle and its lap-belt restrained dummy occupants are traveling at their initial speed and the front bumper is just contacting the immovable barrier. Notice the car and the driver dummy are both slightly blurred due to their speed. At this instant, the car begins to slow down and the driver dummy continues forward at his original speed.

The next sequence camera frame (Figure 8) was taken approximately 100 milliseconds later. A most significant fact is illustrated. The vehicle structure crush is essentially complete (note the sharpness of the vehicle image) before the driver dummy reaches the forward compartment (note that he is still blurred). The occupant strikes an interior which is essentially stopped, making the stopping distance of the man an uncontrollable factor with respect to front structure design changes.

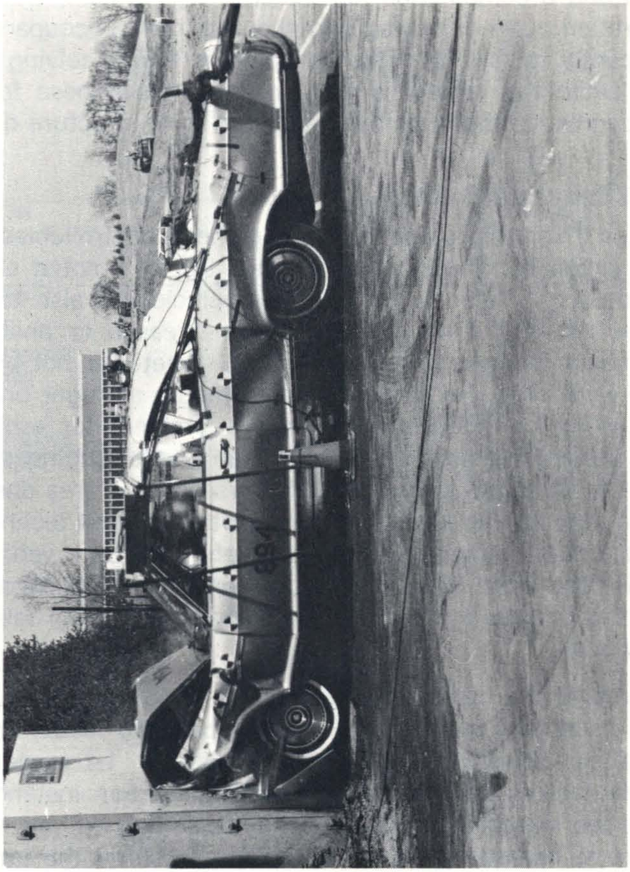


FIGURE 8. *One hundred milliseconds later—rapid sequence photography*

As mentioned earlier, one of the roles of occupant restraint systems is to make this particular uncontrollable factor controllable. Crashworthiness researchers usually refer to this as "ridedown." Looking at a series (Figure 9) of test dummy accelerations, experienced in 30 mph barrier impacts, using no restraint system, a lap belt restraint system and a combination lap-shoulder belt system, we see that the acceleration pulse of the lap and shoulder belted occupant has shifted significantly to the left. This occupant is now receiving deceleration forces while the vehicle is still crushing. Now these forces are, to some degree, controllable by changes in front structure design.

The Driver and the Road

So far I have discussed controlling the uncontrollables through design changes in vehicle related areas. But as I noted earlier, crashworthiness can refer to not just the vehicle but also to people and highway designs. Unfortunately, for one reason or another, our advancements in these other areas have sometimes not been as great as one would like. For instance, developing a stronger breed of injury resistant vehicle occupants is more a problem for evolutionary design—subject to natural selection—than it is for engineering design—subject to technical innovation. Of course, in this area one could think of good nutrition as an aid to crashworthiness and technological aids such as crash helmets can also be useful. But as a vehicle designer, there is little I can do to make your bones stronger. What I must do, instead, is to base my engineering designs on human tolerance levels as they exist.

Improving the crashworthiness of our road system is another area which sometimes seems to move at a pace no faster than evolution and natural selection. But improvements can be made and uncontrollable factors can be made controllable. For instance, we can't control the impact characteristics of trees, but we can remove those that are in hazardous locations. We can't control the impact characteristics of steel and concrete, but we can design guardrails which deflect vehicles rather than confront them. Similarly, we can't control the structural requirements of bridge abutments, but we can design systems (Figure 10) that effectively control their impact characteristics. Dr. Robert Hess, of Michigan's Highway Safety Research Institute, has estimated that any one of a half-dozen such systems

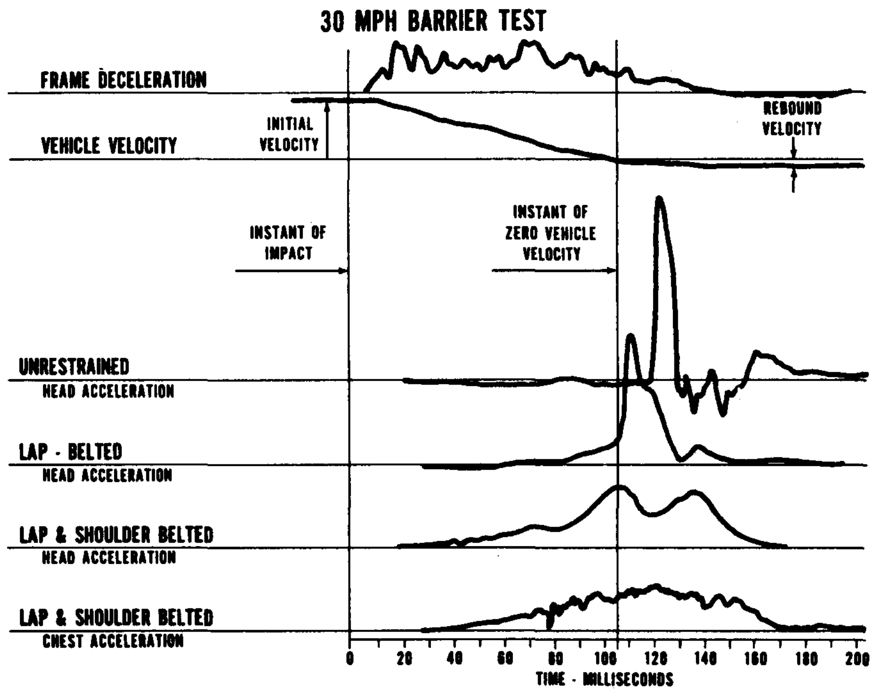


FIGURE 9. *30 mph barrier test*

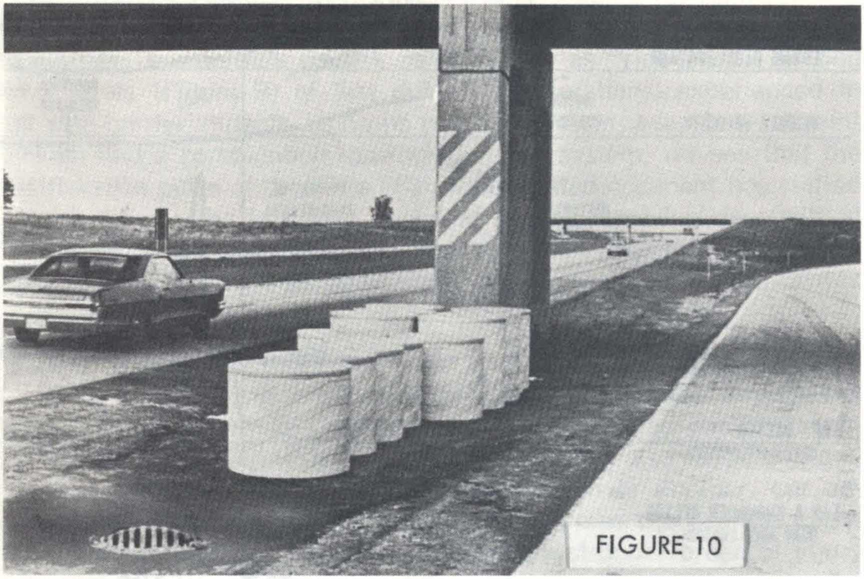


FIGURE 10. *Structural requirements in bridge abutments*

currently available could be installed in high-accident areas for less than $500 per installation. He has recommended that "... no less than 10 percent of Federal and State road funds be used to remove and/or protect obstacles, and to carry out purely safety oriented road projects." I believe such a program would be effective, especially so, for those older vehicles not having the benefit of newly developed safety systems. At the General Motors Proving Ground, where many of these ideas have been devised and put into practice, the overall rate of lost-time vehicle accidents is at least 25 times lower than that of the public highways.

Crashworthiness Tools

Now that I have described a few of the ways that safety researchers attempt to make the uncontrollable factors controllable, let me spend a bit of time discussing the ways in which these factors can be, and are studied, tested, and measured to improve crashworthiness.

Vehicle crashworthiness doesn't come about by speculation, second-guessing, or armchair quarterbacking. It takes good design, produced by good development programs and backed by good data; crash data that can be gathered only by controlled, instrumented tests and plain old hard work.

Crash testing can be divided into three main categories: full-scale tests, impact sled tests, and component tests. A full-scale impact using complete cars generally is required when the program involves the crush properties of the structure. If the study concerns only the vehicle crash acceleration and the occupant-to-interior dynamics, then the impact sled can be used. A component test is useful where very close control on impact speed and trajectory is required when testing individual assemblies such as the instrument panel knee impact area. Full-scale tests are or have been conducted on various kinds of vehicles in many different ways such as:

- frontal barrier tests
- rear moving barrier tests
- rollovers
- side impacts, and
- car-to-car impacts

At GM, most of this work is done in a large building which allows testing to proceed year around, relatively independent of the weather. Our two impact sleds reflect over eight years' experience with this type of collision simulator. GM pioneered this equipment, which has been adopted by many companies and institutions around the world. The impact is produced by a large compressed air cylinder and piston device which pushes the test sled with the same acceleration the vehicle would have received if it were in a full-scale test. Component testing covers a variety of things including:

- top structure tests
- front structure evaluation
- windshield glass tests
- instrument panel tests

Many of the Federal Motor Vehicle Safety Standards relate to tests that are of the component type.

Data Acquisition

Actually producing the impact is only half the story. The other half is documenting what went on during the crash. If effective safety designs are to evolve from impact tests, engineering data must be obtained. Forces, accelerations, trajectories, and other factors must be measured, recorded, and analyzed. We use two main methods for recording the impact event—electronic and photographic. Electronic transducers are mounted on the vehicle or in the dummies to generate electrical signals that can be wired to tape recorders. These recordings are then played back into a computer and finished plots are generated for our engineers to use during their development programs. High-speed cameras that can take 1000 pictures per second are placed onboard the test vehicle or alongside the test area to photograph the action of the occupants and the vehicle. The film is processed right at the Proving Ground so that the results are available for immediate study. Film analyzers can provide accurate measurements of vehicle crush or dummy motion and can punch computer cards so that machine-drawn plots are possible. Test dummies are a most important link in our data acquisition chain. Many of our test results are only as good as the dummy's ability to simulate a human. Although our dummy service area provides as good a dummy as we know how to obtain, basic limitations in biomechanics knowledge do not allow a complete evaluation of the injury potential of impact test situations.

Which Improvements? Where?

Up to this point I have presented you with a general overview of the four main variables available to crashworthiness researchers along with some of the tools utilized to measure and understand these variables. Let me now turn our focus slightly to what will certainly be the most interesting and controversial aspect of auto safety in the coming decade. Let us turn from the question of what we can do, to what we ought to do. Of the many potential safety improvements which could be made, which ones should be made and when? Which ones will pay dividends to society and which will not? Not merely in economic terms, although that is certainly important, but also in terms of factors which are difficult to quantify such as utility, convenience, psychological security, pain and suffering.

The issue is complex because crashworthiness research and vehicle design are subject to a wide variety of constraints, limits and trade-offs. To illustrate, let's look at a list (Figure 11) of several crashworthiness design "tools" along with some of the variables related to them. This list is by no means complete. It only demonstrates the concept I have been discussing. Design, control, mixing, or just thinking about these variables leads to many constraints and trade-offs. Some examples (Figure 12) are listed to provide thought-starters for your own consideration of the problem. There is no easy, "cookbook" answer. Some point of balance must be sought, taking into account everything a car is supposed to do and be.

A specific example is associated with the trend toward smaller vehicles. Independent of whether this trend is related to the population explosion, resource and environmental pressures, or simply a change in taste, we know that, all other factors held constant, when a small car impacts a larger, heavier car the small car and its occupants usually will not fare as well. But this doesn't mean we should have no small cars. It only means that continued crashworthiness research must take place in our entire vehicle-road-driver system to provide a good state of balance among all factors.

But there are also other, equally important, considerations that are less discussed and in some circles overlooked completely. For example,

DESIGN TOOL	AFFECTED VARIABLE
OCCUPANT RESTRAINT SYSTEMS	[illegible] VELOCITY, AREA
ENERGY ABSORBING COMPONENTS	[illegible] VELOCITY
BROAD IMPACT SURFACES	[illegible]
OCCUPANT IMPACT LOCATION	[illegible]
VEHICLE & COMPONENT SIZE	[illegible]
VEHICLE SPEED CONTROL	[illegible]

FIGURE 11. *Design tool and affected variable*

FIGURE 12. *Constraints and tradeoffs*

at some point, efforts to eliminate occupant ejections may conflict with the need for easy extrication of injured occupants. Still another type of trade-off is involved when we are forced to make a decision between a few, potentially serious injuries and a larger number of injuries of a less serious nature. In general, only rarely can all variables of a system be optimized. Again, the usual state of affairs is one of balance in which the critical variables are brought within acceptable limits.

It is not good enough to merely respond that we must do everything, and right now, to improve safety. There are economic and social costs associated with safety improvements and we must seriously weigh the costs and benefits of each particular change. Some we will find socially desirable and others we will find lacking in overall benefit. Even the socially desirable changes cannot all be implemented at the same time. Some will be more effective than others and we must therefore determine priorities for our effort.

Diminishing Returns

Most of you have probably experienced the practical effects of the "law of diminishing returns" at some time during your lives. As you know, it simply tells us that, for many of our endeavors, we will reach a point at which the next additional increment of input will cost more than the value of the additional increment of output it produces. Thus, the farmer knows that as he continues to increase his input of nitrogen fertilizer, the incremental improvements in his wheat production will eventually start to decrease. The college student knows that studying for an exam beyond a certain point will bring little additional benefit. And the safety researcher knows that at some point, additional increments of safety performance will get harder and harder to achieve at an acceptable cost. This, of course, does not mean that we should not and will not continue to improve vehicle crashworthiness. But it does mean that society should be made aware of the cost/benefit effect of proposed changes.

In particular, as we set our crashworthiness goals higher and higher, the difficulties involved in reaching those goals will be increasing exponentially. One cause of this, as I'm sure you are aware, is the squared relationship between velocity and kinetic energy, or $E = \frac{1}{2} MV^2$. Crashworthiness research can really be viewed as an exercise in energy management. And, of course, the more energy there is in the system, the more difficult it becomes to manage in a non-injurious fashion.

However, we cannot let ourselves be stymied by this inexorable law. The course of the past two centuries has been determined by technological and sociological innovations which have allowed us to do today what we could not do yesterday. The history of automotive safety from the introduction of speed limits, to laminated glass, to energy absorbing steering columns, to lap and shoulder belts has been the history of social and technical innovations allowing us to achieve higher and higher goals at costs which have been acceptable to society. One of the goals of crashworthiness research, then, is the development of successful innovations at acceptable social costs.

Benefit Analyses

The questions I have been discussing are difficult to quantify, riddled with uncertainties, even annoying and disquieting to discuss. But if, as a society, we want to make rational decisions, then we must discuss these issues and decide on our answers regarding the overall balance of our safety effort. One of the factors for reaching this balance would be that of cost/benefit analysis. For whether it is conscious or unconscious, when trade-offs are considered and decisions are finally reached, we have gone through a process in which we compare the expected negative factors with the expected positive factors. And while not everyone agrees on how to weigh the various factors or even on which factors are positive and negative, we all go through much the same thinking process. Thus, another major objective of crashworthiness research is to improve the quality and usefulness of cost/benefit analyses. The major tool in this area is field accident research. For if occupant safety programs are to be of most benefit, they must relate to and be based on field accident data. We must know what areas of the vehicle are producing injuries and fatalities; what is the relative frequency of these events; what is the mechanism of the trauma; how are existing safety devices working; and, most importantly, how are new devices likely to affect present patterns.

Let me review with you a few facts given us by our GM field accident data file. First is this distribution (Figure 13) of occupants in terms

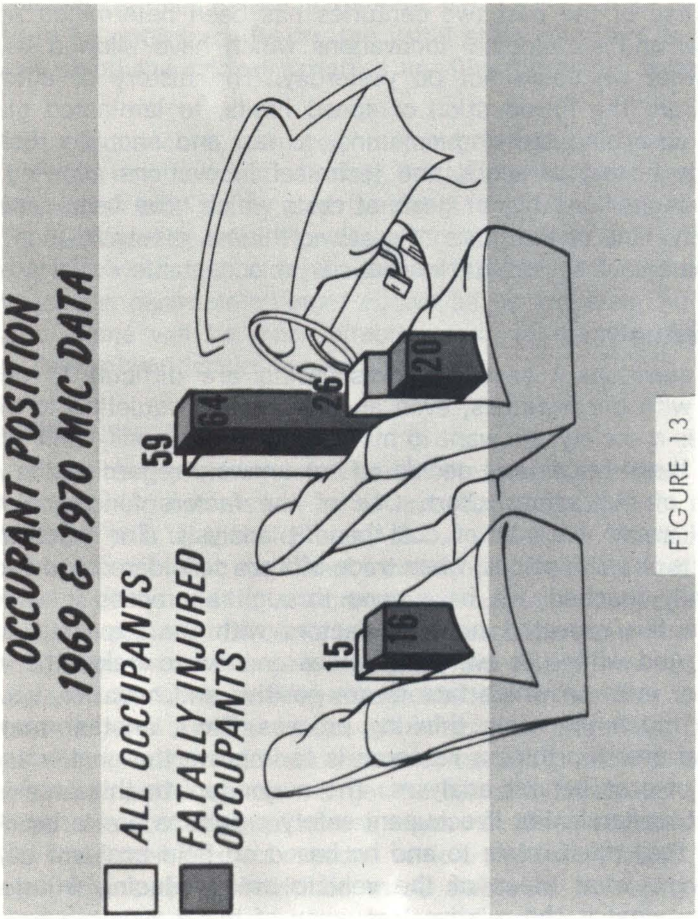


FIGURE 13. *Occupant position 1969 and 1970 MIC data*

of seated position and frequency of fatal injury. Looking at the seated position of all injured occupants, we are not surprised to find that drivers represent a 59 percent majority and that drivers plus front seat passengers represent 85 percent of the total occupants. Looking at fatalities we find that front seat occupants make up 84 percent of the total. The relative symmetry between the 'all occupant' and 'fatal occupant' distributions indicates that the risk of fatality associated with the front and rear seats is approximately equal. Within the front seat itself, it would appear that the risk of fatality for passengers is slightly lower than the risk for drivers. However, one must be cautious with such comparisons since the number of fatalities in this sample is relatively small and speed distributions for single- and multiple-occupant vehicles may not be the same.

What is perhaps more important than relative comparisons, such as the driver/passenger situation, is the absolute level of vehicle performance. Some will judge it acceptable and some not acceptable. The determination of acceptability is, of course, a moving target. As we have seen, throughout the life of the automobile industry and especially during the past decade, what was acceptable yesterday may no longer be acceptable today. What if the level of crashworthiness today is unacceptable, or if acceptable today will be unacceptable tomorrow? How should we go about improving things?

A Case in Point

To think about this question let's assume that we could design a restraint system which would save 100 percent of the occupants to whom it was available. Furthermore, let us assume that protecting the driver, front passengers and rear passengers each will increase the cost of the vehicle by the same increment. Given these circumstances and looking at the seating position data, it is obvious that for the first increment we could protect the drivers and thereby decrease total fatalities by 64 percent. A second increment could protect the front passengers and reduce fatalities an additional 20 percent. And a third increment, applied to the rear seat, could protect an additional 16 percent. Notice that the payoff associated with each increment is decreasing—maybe a case of diminishing returns.

This example serves to point up a serious dilemma, associated with the increasing cost of safety devices, which should be faced by the motoring public, federal regulatory agencies, and the automotive industry. Assuming that only a finite amount of money will be invested by the motoring public on vehicle safety, then how should that money be used? Should the emphasis be on areas of highest payoff or should there, instead, be an attempt to spread the funds throughout the vehicle, giving each occupant the same level of protection? Of course, some compromise between these extremes could also be achieved. But whatever the case, that decision will affect the cost of vehicles and therefore, as with the other decisions we have discussed, it ought to be a conscious decision.

Accident Configuration Trade-off

Field accident data provide us with other illustrations of these kinds of trade-offs between maximum absolute payoff and equal protection. As a second example, consider the distribution of accident configuration (Figure 14). This is an extremely important example since a safety device that works for one type of accident configuration will not necessarily provide equal protection in all accident configurations. In other words, head restraints are designed to function in rear impacts and energy absorbing steering columns are designed to function in frontal impacts. Similarly, air bag restraint systems are primarily frontal impact restraints which may provide little or no added protection in rear, side, and rollover impacts.

The distribution data show us several revealing facts. First, frontal impacts represent the majority of all accidents and all fatalities. And second, when we compare fatal accidents with all accidents, we find that rear impact fatalities are significantly underrepresented and rollover fatalities are significantly overrepresented. If you consider for a moment our earlier discussion of controllable and uncontrollable factors, the reason for this latter difference will be clear. In rear impacts the uncontrollable factors are at a minimum, whereas in a rollover—with randomly moving occupants and ejections—the uncontrollable factors are at a maximum. Now for the dilemma—do we use our safety dollars to improve protection in frontal impacts where the largest number of fatalities occur, or do we work on rollovers in view of their overrepresentation in the fatality distribution?

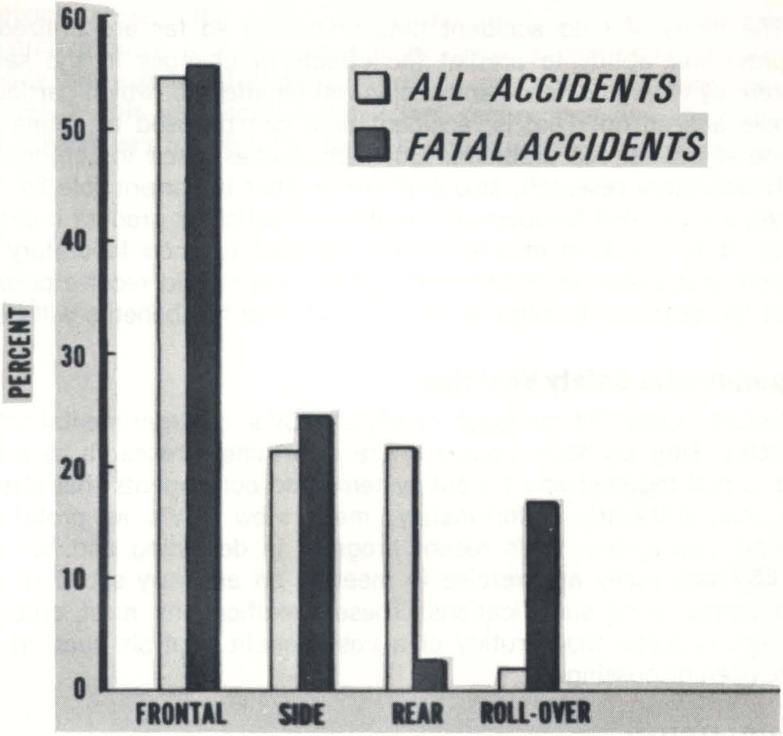


FIGURE 14. *Accident conguration based on damage 1969-1971 MIC data*

Other Feedback

The kinds of field accident data discussed so far are utilized to improve our ability to predict the effects of changes in the safety system by telling us how many people will be affected, which particular people and so on. That is, accident data can be used to define the scope of the various problems. But field studies, used in conjunction with laboratory research, also perform another important role by providing the detailed feedback information essential for product improvement. It is this kind of information, coupled to good laboratory research, that allows us to determine what areas should receive priority, what the best design alternatives are, and what the benefits will be.

Experimental Safety Vehicles

Before I close, let me touch briefly on ESV's, or experimental safety vehicles. They do have a place in crashworthiness research as a test bed to pull together and try out systems and components that stretch the state-of-the-art. Unfortunately, many view ESV's as prototypes of next year's cars. GM's recent program in designing and building an ESV was really an exercise in meeting an arbitrary set of design and performance specifications. These specifications most probably did not undergo the scrutiny of a cost/benefit analysis such as we have been discussing.

CONCLUSION

I have covered a great deal of ground during the past few minutes and perhaps the best way of tying up the loose ends would be to return to the beginning—to the nine-box matrix we saw earlier. In trying to put "Crashworthiness—In Perspective," I have shared with you some of my thoughts on the role of crashworthiness research in relation to a number of the matrix elements. In doing so I have suggested how crashworthiness research has a role in overcoming at least some implications of the law of diminishing returns. And finally, I have tried to put crashworthiness in perspective by emphasizing the need for cost/benefit analyses. Implicit in all of this has been my desire to express the importance of a balanced, systems approach to the highway safety problem. It is an approach which will require conscious consideration of the costs and benefits associated with changes in each of the nine matrix elements. It is, therefore, an approach which will require increasing amounts of communication and feedback between the public, our government, university and private research groups, and the automotive industry. We have, of course, already made great strides in improving our communication, as evidenced by this very conference. I feel secure that we will continue and I thank you for allowing me this opportunity to contribute to the process.

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