The Deployable Crash Pad

Final Report

GM/ASEE University Design Competition
on
Passive Restraints in Automobiles
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GM/ASEE UNIVERSITY DESIGN COMPETITION

ON

PASSIVE RESTRAINTS IN AUTOMOBILES

Abstract

A new (to the authors) concept in occupant crash protection, the deployable crash pad, is proposed. The crash forces are used to deploy the crash pad, integral with the dash, rearward and upward to intercept the front seat occupants' forward motion in a frontal collision. Hydraulic shock absorbers, supporting the front bumper, pump fluid to the crash pad deployment mechanism, eliminating the inadvertent deployment problem associated with air bags. Hydraulic force limiters provide a controlled ride down with very efficient use of the available space. A pressure switch is provided to disconnect the battery in severe accidents to reduce the fire hazard. Occupant contact with the crash pad occurs approximately halfway through the crash pulse with a relative velocity approximately one-half of the impact velocity. After contact, the occupant decelerations are the same as the vehicle chassis. Performance predictions using the Calspan Crash Victim Simulator model indicate that significant protection is provided in thirty mile-per-hour barrier crashes.

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1. Statement of the Problem

1.1 Background

The development of passive restraint systems (e.g., passive seat belts and air bag systems) by automobile manufacturers was spurred by a National Highway Traffic Safety Administration (NHTSA) ruling (1,2) requiring passive systems for all occupants in vehicles manufactured after August 15, 1975. A passive system was defined by NHTSA as a restraint system which required "no action [on the part of the occupants] other than would be required if the protective system were not present in the vehicle (3)." The major impetus for passive restraint systems was the resistance of the public to buckle up. Although this ruling was subsequently changed and postponed, development of passive restraint systems continues.

One approach that some automobile manufacturers have taken in the development of passive systems is passive seat belt systems. These systems are similar to conventional, active seat belt systems, except that they require no action on the part of the occupant. Upon ingress, the belts are automatically draped over the occupant and tightened; upon egress, the belts are automatically stowed out of the way. Some passive systems incorporate moving (i.e., sliding) belt anchor points. Typically, the two outboard anchor points slide around the frame or edge of the door. The inboard anchor point, if it moves at all, picks the lap belt off the seat and is usually the location of the emergency exit disconnect (4). Once in place, passive seat belt systems perform similarly to active systems; they provide protection to vehicle occupants in many crash situations (5).

A key problem with passive seat belt systems is user acceptance; many consumers view these seat belt systems as a tangle of webbing (4,6). Other problems with both active and passive seat belt systems include occupant discomfort, belt-induced injuries, and the possibility of entrapment after an accident.

One of the main contributors to occupant discomfort and belt-induced injuries is the fact that the occupant is restrained by relatively narrow belts across the torso and pelvis (7). Air bag restraint systems were developed to address these problems; they are protective systems that remain completely out of the way of vehicle occupants until they are needed in a crash.

Typical air bag restraint systems consist of separate systems for the driver and front seat passengers. The driver's system may consist of an air bag in the steering wheel, which is mounted on a collapsible steering column, and a padded knee bolster (8). The air bag, steering column and its mounts are the principal energy absorbers in the driver's system. The passengers' system is designed to protect the middle and outboard seating positions in the front seat. This system, usually stored in the lower part of the dashboard, consists of a large bag, to restrain the torso, and a smaller knee bolster or bag (8). Another important component of an air bag restraint system is the crash sensor/inflation mechanism. Multiple sensors may be linked to a variable inflation system to provide different levels of deployment for different levels of crash severity. Air bag inflation is usually inhibited for low-level crashes to allow drivers to maintain vehicle control (8,9).

A concern with air bag restraint systems is the inadvertent deployment hazard. The problems of reliability, storage, and deterioration of these complex systems may lead to inadvertent detonation, which could compromise the driver's control of the car (9). Another possible hazard is that out-of-position occupants can restrict proper air bag deployment (10). Also, the chemical gas generators in the inflation systems may produce toxic gaseous products and the noise level and exposure time and related pressure rise generated in the passenger compartment by air bag inflation may exceed the tolerance levels of the vehicle occupants (9). An injury potential may therefore exist for out-of-position occupants, small children, and the elderly (9,12).

There are other concerns with current air bag restraint systems besides deployment hazards. Small-scale production runs and laboratory sled tests indicate that these systems protect occupants primarily in frontal, symmetric, or near-symmetric collisions (8,9,11); they offer little protection in side-collision and rollover accidents. Ejection remains a problem in long duration or multiple-impact crashes. Air bags effectively restrain forward occupant motion but some systems provide little reduction in the rebound velocity (9). Although dual sensors and variable-inflation systems have broadened the scope of collisions which activate the restraints, current systems are less effective in non-barrier collisions (9). Prior to the addition of supplemental knee restraints, the lack of lap belts in completely passive systems increased the likelihood of submarining (9,12,13).

Despite the many ideas that have emerged from within the industry, none, as of yet, have gained the consumer acceptance or have satisfied the performance requirements to compete with existing seat belt systems. The purpose of the GM/ASEE competition was to develop alternative passive restraint systems that are acceptable and functional and to expose university students and faculty to the automotive design process. Twenty-seven American universities submitted proposals. Four universities, Texas Tech, Tennessee Tech, Purdue University, and Duke University, were selected by GM/ASEE to participate in the competition.

1.2 Summary

A deployable crash pad system for automobiles was designed by a multidisciplinary group of faculty and students of the Biomedical Engineering, Mechanical Engineering, and Orthopaedic Surgery Departments of Duke University. A principal design requirement was that the level of occupant protection provided by this passive system will be the same or higher than that provided by currently available active seat belt systems and friendly interiors. Other design requirements were high reliability, engineering and manufacturing feasibility, cost, and user acceptance. A corollary objective was to develop criteria that will allow an evaluation of competing designs and a rational optimization of design trade-offs. The results of preliminary analyses of the Duke deployable crash pad suggest that the design goals were adequately achieved.

The first phase of the program involved a careful review of the literature and an investigation of related technologies in order to phrase the problem in quantitative terms and develop a criteria for evaluating the performance of competing designs. This criteria is in the form of a statistically-based, weighted effectiveness equation relating Accident Injury Severity (AIS) values, direction and velocity of impact, injury potential, engineering and manufacturing feasibility, reliability, cost, and user acceptance.

The second phase of the program involved a search for sensible alternative solutions following brainstorming and formal synectics methods.

The third phase of the program involved an evaluation of the solutions generated in the second phase based upon the criteria developed in the first phase. Then, several alternative designs were selected and developed. This work was performed by small teams of students with limited faculty involvement.

The fourth phase of the program involved the selection of the optimum design solution based on the criteria developed in the first phase. This design was studied and further improved by the whole design team for presentation to the GM/ASEE committee.

2. Design Team Organization

2.1 Faculty and Staff

James H. McElhaney, Ph.D., was the project manager. He is professor and chairman of the Biomedical Engineering Department and professor of Experimental Orthopaedics of the Department of Surgery. He has had a long-term interest in automotive restraint system design (14,15,16). During his tenure as head of the Biomechanics Department at the Highway Safety Research Institute (University of Michigan), he performed a variety of studies of human tolerance, occupant kinematic modeling, and integrated restraint system development. He has particular expertise in the biomechanics of head and neck injuries and has an extensive library of books and papers dealing with these subjects.

George Pearsall, D.Sc., professor of Mechanical Engineering, provided expertise in mechanical design processes. He has significant experience in generalized design methods, fault tree analysis, and safety. He teaches the "cap stone," senior design course in mechanical engineering.

Frank Clippinger, M.D., is professor of Orthopaedics in the Department of Surgery. He acted as the medical consultant on the project to ensure that the final design represented good medical practice in reducing overall injury potential. He has extensive experience in the treatment of automotive-related trauma. He also has a strong interest in and understanding of biomechanics.

Jacqueline Paver, Ph.D., is a research assistant professor in the Biomedical Engineering Department. She provided expertise in vehicle occupant kinematic modeling. The final design development required use of the Calspan crash victim simulator model (also known as the AAMRL Articulated Total Body model) in parametric studies to predict and compare potential of various concepts. She made extensive use of this model in her dissertation and in subsequent research on dummy head-neck systems at Wright-Patterson Air Force Base. She is very familiar with the literature on trauma, injury criteria, and automotive restraint systems. During the past five years, she has developed an extensive library of journal papers in this area for the Industrial Safety Equipment Association. This library has been an excellent resource for this project.

Claude Walker is the instrument designer and master machinist in the Biomedical Engineering Department. He developed prototypes and test fixtures for the various designs and experiments as required.

2.2 Students

During fall 1986, the proposal team consisted of one graduate student and three undergraduate students (listed in Appendix A.1). These students performed the patent survey and the original literature search for academic credit through Duke's independent study option. These students substituted formal independent study under Dr. McElhaney's supervision for a course in the engineering curriculum. The patent survey was conducted at the U.S. Patent Office in Crystal City, Virginia. A literature search was conducted at Duke University libraries and at the North Carolina Highway Safety Research Center with the assistance of Dr. Donald Reinfurt, Associate Director for Analysis Studies.

During spring 1987, a special design course, centered around this project, was offered by the Biomedical Engineering Department. The course was supervised by Drs. McElhaney and Paver. Thirty students were enrolled in Biomedical Engineering 230 (see class list in Appendix A.1). During the semester, the class was divided a number of times into small teams. Most students participated in more than one team activity during the semester. Two teams remained intact throughout the semester, working in parallel with other class activities. The Computer Modeling team consisted of 3 students (listed in Appendix A.2). This team exercised a computer crash victim simulator model which was used as an aid in the final design process. The computer model was obtained originally from NHTSA and later from the Armstrong Aerospace Medical Research Laboratory (AAMRL) at Wright-Patterson Air Force Base. Louise Obergefell, at AAMRL, provided assistance in the use of the model. A second team, the Statistics/Criteria group, consisted of 6 students (listed in Appendix A.2). The goal of this team was to develop and tune the Criteria equation. Automobile accident data was accessed via modem from the University of Michigan Transportation Research Institute (UMTRI) using ADASS, the Automated Data Access and Analysis System. Charles Compton, at UMTRI, provided assistance in the use of this data bank. During phase I, the 14 -member design team (listed in Appendix A.3) reviewed the existing designs and literature and patent search results and initiated the search for design alternatives. Also, at this time, three students accessed AAMRL databases 56 and 57 and one student reviewed online literature searches with the Transportation Research Information Service (TRIS) and the National Technical Information Service (NTIS). During phase II, the entire class participated in the brainstorming sessions and individual assignments. During phase III, the class split up into five groups (listed in Table 7.1). These groups developed the design alternatives and performed feasibility studies. After selecting the final design, the class was reorganized, as shown in Appendix A.4. Ten members were given individual task assignments aimed at optimization of the final design. Four members were assigned to film a movie illustrating the operation of the final design. Four members were assigned to study consumer acceptance and cost issues, conduct a survey to collect relevant data for the criteria equation, and estimate scores. Dr. George, Assistant Professor of Sociology, reviewed the survey for biases and usefulness. Three students studied the relationship between injury severity and crash severity for frontal, side, and rear collisions. Finally, two members made up the report team, organizing and editing the class reports into the final report.

In addition, seven senior mechanical and electrical engineering formed an ME/EE Design Team (see Appendix A.1). The activities of this design team were coordinated by Dr. George Pearsall, but the students themselves developed the alternatives, assessed the feasibility of each, selected the most promising and innovative alternative, and made a first pass at optimizing that design. Five of the seven members received academic credit for independent studies in Restraint System Design. The other two members of the design team, who did not have room in their schedules for another course, applied for, and were granted, undergraduate research assistantships to be part of the Design Team. Two members of the ME/EE Design Team simultaneously were enrolled in ME 160, Mechanical System Design, taught by Dr. Pearsall. After selection of the team's optimal design solution, Dr. James Wilson, professor of Civil and Environmental Engineering, became an important source of information, based on his research in pneumatically-controlled robots.

3. Mode of Operation

The design process is a procedure that begins with a formulated problem and ends with an optimal solution. Although different groups use different labels for the steps of their design processes, the overall shape of the process is the same. The following steps were suggested by Buhl (17):

1. Recognition of the problem
2. Definition of the problem
3. Preparation
4. Analysis
5. Synthesis
6. Evaluation
7. Presentation.

First, the problem was recognized and defined. Then, as much information as possible was gathered about the problem. Divergent concept generation was performed in order to formulate possible problem solutions. These solutions were evaluated; several designs were selected and developed. Convergent concept generation was performed in order to produce an optimal solution.

The program was divided into six phases. These were:

1. Literature search, problem definition, and criteria development (three weeks)
2. Divergent concept generation and search for alternative solutions (four weeks)
3. Development of competing designs (six weeks)
4. Selection and development of final design (five weeks)
5. Final Report Writing (one week)
6. Final Presentation Preparation (two weeks).

3.1 Phase I – Literature Search, Problem Definition, and Criteria Development

Phase I of the project involved the Recognition, Definition, Preparation, and Analysis steps of the design process. In this competition, the general or "primitive" problem was already recognized and defined (i.e., passive restraint system design).

The Preparation step included a careful review of the literature and an investigation of related technologies to establish:

1. Crashworthy requirements dictated by the automotive environment
2. Human tolerance to the types of forces and decelerations encountered in automotive accidents
3. Performance of previous designs.

A patent search and preliminary literature searches were performed during fall 1986 by three undergraduate students and one graduate student, who did independent studies on Passive Restraint Systems. At the beginning of the spring semester, information from AAMRL databases 56 and 57, NTIS, and TRIS was accessed and reviewed.

During the Analysis step, the information generated in the Preparation step was used to provide a basis for a more specific problem definition (18). Obvious advantages or disadvantages of previous solutions to the specific problem and key design control parameters were identified (19). Questions such as the importance of protection from direct frontal, off-angle frontal, oblique, lateral, rear, and rollover accidents were addressed. Also, a passive restraint system design criteria was developed. This is an equation with statistically-based weighting factors relating injury protective potential, AIS values, direction and velocity of impact, engineering and manufacturing feasibility, reliability, cost, and user acceptance. The aim was to develop a rational basis for the evaluation of divergent concepts and competing designs. It was recognized that due to the limitations of time, talent, and resources, this first step was relatively unsophisticated. However, it was a most important one because, without a generalized evaluation procedure, decisions regarding design improvements would be based on intuition and opinion.

3.2 Phase II – Divergent Concept Generation and Search for Alternative Solutions

Phase II of the project involved the generation of as many alternative and divergent passive restraint system concepts as possible within the time allotted – the Synthesis step of the design process. During this concept generation period, the aim was to stimulate the innate creativity of the individual participants. Hill (19) defines creativity as "successful steps across the borderline of knowledge." This phase was as unstructured as possible. No attempt was made to compare or evaluate particular ideas. Brainstorming sessions conducted during class produced a wide variety of designs to be considered. One particular brainstorming list of ideas is given in Appendix B.1, taken from class on January 27, 1987. The entire class participated in the brainstorming sessions. Formal synectics methods were also utilized. Individual assignments with short reports illustrated and detailed the design possibilities.

3.3 Phase III – Development of Competing Designs

Phase III of the project involved design concept convergence towards the best solution for the problem – the Evaluation step of the design process. During this phase, the list of design possibilities proposed in the Synthesis step were carefully evaluated using the criteria developed in phase I. Six of the most promising concepts were selected for further study. Multidisciplinary groups were formed to further develop these alternatives in a competitive mode. They proceeded, with laboratory testing and computer analysis, to produce performance specifications and concept drawings for each of the design alternatives. Local junk yards were used as sources for existing U. S. and foreign seat-belt assemblies. A wood frame was constructed for studying the geometries of various safety-belt configurations and anchor points for these assemblies (see Figure 3.1). Pneumatically-powered and controlled prototypes of the design developed by the ME/EE team were constructed from bicycle tire tubing and reinforcing tape. Presentations were given and reports submitted by these groups to the entire design team.

Figure 3.1

3.4 Phase IV – Selection and Development of Final Design

Phase IV of the project involved the selection and development of the final design concept – the Evaluation and Presentation steps of the design process. During the Evaluation step, the design alternatives were evaluated; a final design was selected on March 3, 1987.

The class then evaluated each of the designs separately on a technical basis. The criteria were innovation, customer acceptance, engineering feasibility, functionability, ease of use, cost, and manufacturability. Each design was given a score between 1 (very good) and 5 (poor) on each of these criteria except cost. Cost would be used as a tiebreaker if necessary since the cost of an innovatively new restraint system would be very difficult to determine. The radar sensor was determined to be an add-on feature and was not evaluated by itself. The two air bag systems were combined back into one group, taking the best features of each. The passive belts system and overhead air bag/joystick system were hindered by a poor innovation score. The moving seat design was hampered by poor scores in functionability and engineering feasibility. The air bag design and the deployable crash pad design were left. The deployable crash pad was given higher scores in innovation and engineering feasibility (due to the crush activation concept), while the air bag system had a higher customer acceptance score. The rest of the criteria were determined to be relatively even. Thus, the class selected the deployable crash pad as the optimum design concept.

The design underwent systematic development by the various disciplines represented in the design team. This included detailed structural and stress analysis, system analysis, performance prediction, reliability analysis, and cost estimation. Laboratory tests and prototypes were developed as required. The computer model was used to improve the design and compare performance predictions with those of current seat belt systems. Ten members were given individual task assignments concerning the specifics of the final design. Four members were assigned to a group which would make a movie demonstration of the final design. Four members were assigned to a consumer acceptance and cost group. Their assignment was to review available literature and then make up a survey, testing the customer acceptance of our design versus the present restraint systems. Three students were asked to investigate the literature for information on Accident Injury Severity (AIS) versus impact speed. Two students were selected to make illustrations using CADKEY software.

3.5 Phases V and VI – Final Report Writing and Presentation Preparation

Phases V and VI involved the presentation of the final design concept. During the Presentation step of the design process, a report was prepared to present and sell the optimum plan generated in the Evaluation step for consideration in the final prototype phase of the program. Specifications, performance predictions, and design criteria are summarized.

4. Description of Facilities

The data banks and literature sources utilized were Dr. McElhaney's personal library, the Duke University Engineering, Medical, and Law Libraries, the North Carolina Safety Research Center Library (HSRC), the Office of Patents and Trademarks (PTO), the AAMRL Databases 56 and 57, the Transportation Research Information Service (TRIS), and the National Technical Information Service (NTIS), and the automobile accident data bank at the University of Michigan Transportation Research Center (UMTRI). The GEBOD computer program was exercised to generate 5th, 50th, and 95th percentile anthropometric data. The Calspan Crash Victim Simulator computer program (also called the WPAFB/AAMRL Articulated Total Body Model) was exercised to compare the performance of the Duke design with the performance of existing restraint systems. The CADKEY software package was utilized to visualize and modify the size and shape of the Duke design.

The Duke libraries contain all of the Stapp Car Crash Proceedings, the American Association of Automotive Medicine Conference Proceedings, the IRCOBI Conference Proceedings on the Biomechanics of Impacts, the SAE Journals, and the Federal Register documents associated with MVSS 208. Dr. McElhaney's personal library contains an extensive collection of papers on human tolerance and head and neck injury and protection.

The library at HSRC has thousands of articles about highway safety catalogued by subject. Over 300 pages of material on passive restraint systems were photocopied for use by the design team. An annotated bibliography was generated. The articles were catalogued by article number, title, and a description of contents in light of their applicability to the proposed design process.

An extensive patent search was conducted at the PTO in December, 1986. Listed in Appendix B.2 are the useful headings, along with their respective classes and subclasses. A "comment" column was added to generalize the type of material found. This is followed by a list of patents, catalogued by number, and a brief description of each.

Database 56 is the bibliographic file of the Biodynamics Data Bank at AAMRL. It consists of approximately 42,000 references compiled since 1948 from the National Library of Medicine, the Transportation Research Board, and Medical and Technical Laboratories at American Air Force Bases. The majority of the entries are technical reports and journal articles. Searches are performed by specifying certain words which occur within a set of text (i.e., title, abstract) and by the use of "and" or the use of "or". The key words were as follows: passive and restraint, deployable, air bag, deployable and cushion, deployable and restraint, cushion and restraint, crush or crushable, seat, sensor, and radar. Searches under such topics as doppler and radar, and pivot and seat were conducted, but nothing was found. A compilation of abstracts of relevant articles was produced. An annotated bibliography of the relevant articles was compiled.

Database 57 is a file consisting of data summarizing biomechanical protection tests conducted at AAMRL. The most important responsibilities of this laboratory are to determine human tolerance levels and establish design criteria and new biotechnology techniques for future aerospace systems. The goal is to protect and sustain personnel in all possible aerospace situations. In particular, the mission of the Biodynamics and Bioengineering Division, Protection Subdivision (BBP), is to develop crew protection technology for future Air Force systems development programs. The Branch research spans a wide range of basic science issues, exploratory development efforts, and support for aeronautical systems engineering programs. Specific research programs include: establishment of design criteria for crew protection equipment, exploration of new principles and techniques of impact and windblast protection, development of acceleration exposure-limit standards, experimental validation of mathematical models of human impact response, and test and evaluation of advanced as well as operational protection systems. Experimental impact studies are conducted using three major facilities: a 50-foot vertical deceleration tower, and unique 250-foot horizontal decelerator track, and 17-foot impact tower. Other impact test facilities include a 6-inch diameter vertical accelerator, a hydraulically actuated body retraction and restraint device, and a helmet test device. Data are being collected using electronic and photogrammetric systems. The impact studies are performed with animals, anthropometric dummies, and human volunteers. In addition to research in support of the USA Air Force, the Biomechanical Protection Branch has been active in research in support of the Department of Transportation, the Army, and the Navy. These efforts have included, among other things, the evaluation of automotive impact protection systems. Nineteen of the tests on file in database 57 were studied further (see Appendix B.3). Most of these tests dealt with harness systems and belt-related occupant injury patterns.

The NTIS database consists of government-sponsored research, development, and engineering plus analyses prepared by federal agencies, their contractors or grantees. It is the means by which unclassified, publicly available, unlimited distribution reports are made available for sale from such agencies as NASA, DDC, DOE, HUD, DOT, Department of Commerce and other government agencies. NTIS includes material on technical applications, business procedures and regulatory matters.

The TRIS database provides transportation research information in air, highway, rail, and maritime transport, mass transit, and other transportation modes. Subjects included are regulations and legislation, energy, environmental, and safety concerns, materials, design, construction and maintenance technology, and operations, traffic control, and communications. The database records can be either abstracts of documents and data holdings or resumes of research projects. Among the transportation research information services contributing to TRIS are the Highway Research Information Service (HRIS), the Maritime Research Information Service (MRIS), the Railroad Information Service (RRIS), the Air Transportation Service (ATRIS), and the Urban Mass Transportation Research Information Service (UMTRIS).

The accident data bank at the University of Michigan Transportation Research Institute was accessed using ADASS, the Automated Data Access and Analysis System. Approximately 100 data sets are available online. Two types of data sets were accessed for this project: (a) NASS, the National Accident Sampling System; and (b) ACRS, the Air Cushion Restraint Studies. These data sets were generated by the UMTRI from data collected by the National Center for Statistics and analysis (NCSA) and the National Highway Traffic Safety Administration (NHTSA). The data in NASS is a probability sample of the motor vehicle accidents that occurred in the USA during the year 1985. The study incorporates a sample of 15,000 accidents to represent the 2 million accidents which typically occur each year. The sample includes belted and unbelted occupants. The data in the ACRS is compiled from a small sample of accidents involving air bags.

The Calspan three-dimensional Crash Victim Simulator (CVS) Model is a digital computer program developed at Cornell Aeronautical Laboratory (20) for the DOT for the study of human and dummy dynamics during automobile crashes. Originally, its validity was determined from comparisons of predicted responses with those measured in sled tests and full-scale automobile crash tests using anthropometric dummies (21,22). The formulation, however, was of sufficient generality to allow application of this model to problems involving other impact environments. The Articulated Total Body (ATB) Model is a modified version of the CVS which accommodates specific Air Force applications such as encumbrance effects on crewman performance, vibration loading, and ejection from disabled aircraft (e.g., retraction, head-canopy impacts, windblast, parachute-opening shock).

The primary component of this program is the body dynamics model. The body dynamics model contains and solves the equation of motion and constraint. These equations are formulated from Euler's rigid body equations of motion with Lagrange-type constraints. This model differs from most other three-dimensional occupant models, which are formulated from Lagrange's equations of motion. Variation of the number of segments and joints is permitted within the formulation. In most applications, the crash victim is represented by fifteen rigid body segments connected by fourteen joints. If all of the joints are ball-and-socket types (three degrees-of-freedom) except the elbows and knees, which are pinned (one degree-of-freedom), the dynamic system has forty degrees-of-freedom. The resulting simultaneous first-order ordinary differential equations are solved using a Vector Exponential Integrator. The three-dimensional rotational equations are integrated using quaternions (also known as Euler Parameters).

GEBOD, an interactive computer program, was utilized by the occupant space/anthropometry and dash shape design groups. It produces the percentile-based body description data about adults and children in a format suitable for the CVS/ATB model input deck (23) and in a format similar to that of SAE Recommended Standard J963 (24). The mass, center of gravity location, contact surface dimensions, joint locations, principal moments of inertia and their associated directions are determined for each of fifteen body segments.

CADKEY, a microcomputer-based three-dimensional Computer-Aided Design and drafting system, is implemented at Duke University on IBM PC-XTs and Zenith PC-AT clones, to which students in ME 160 have 24-hour a day access. The CADKEY database stores data as lines and other primitives in three-dimensional coordinates. Designs created with CADKEY can be called up in six orthographic views, as well as a symmetric isometric view and an inverted axonometric view. Additional views can be generated by the specification of coordinate rotations about a specified axis. Geometric calculations such as area/centroid, moment of inertia, and perimeter can be made on selected regions. CADKEY was used to visualize and modify the shape and location of the deployable crash pad. Wire-mesh drawings of the deployable crash pad were generated from police-sketch-artist type descriptions. The shape of the pad was then modified to meet the specifications of the Phase IV shape/contour team. The computer simulations also provided design information.

5. Proposed Passive Restraint System

5.1 Concept - Deployable Crash Pad

A new concept for occupant protection in automobile frontal collisons is proposed. This concept involves a contoured crash pad that is deployed upward and outward to meet the occupant's head, torso and knees as he (she) slides forward during the impact. The deployed configuration of the crash pad would be similiar to crash pads used to restrain small children in modern child auto seats. The undeployed configuration of the crash pad corresponds to the shape of a well-padded dash and underdash. During deployment, the upper section hinges open to come between the occupant's head and windshield. The deployment mechanism is energized by the frontal crush of the vehicle either with a hydraulic system similiar to the bumper shock absorber system used on some G.M. automobiles or the ProconTen cable pulley system that Audi is developing for crash activation of a conventional seat belt tensioning system and retraction of the steering wheel. The crash pad deployment mechanism incorporates force limiters to provide a controlled ridedown of the front-seat occupants. The crash pad is contoured to provide significant protection in off-center frontal crashes over the range of $\pm 45°$, or from 10:30 to 1:30, with 12:00 being exactly head on. The steering wheel is detached and retracted into the deploying crash pad (dash) which is contoured to accept it. On the driver's side, the head pad pivots to cover the instruments and surround the retracted steering wheel.

5.2 Functional Characteristics

The proper function of the deployable crash pad requires a mechanism that provides the following sequence of events:

1. Frontal impact ($\pm 45°$) occurs at time $t = 0$.
2. Initial six inches of crush is used to deploy crash pad and retract steering wheel. Maximum deployment of crash pad is twelve to fifteen inches, depending on vehicle characterisitics. For an impact velocity of thirty miles per hour, this takes place in approximately 20 milliseconds.

3. During the deployment period, the occupants move forward approximately eleven inches.
4. The properly positioned occupant contacts the crash pad approximately thirty milliseconds after impact with a relative velocity of twenty to twenty-five feet per second.
5. This initial occupant impact is absorbed by the foam padding on the crash pad and by the force-limiting energy-managing support mechanism. The ability to design and control the force-limiting and energy-managing characteristics of the crash pad is a major feature of this design.
6. After the occupant's kinetic energy, due to the relative velocity with the crash pad, is absorbed, the remaining vehicle crush is rode down by the occupant with the crash pad providing good distribution of pressure and decelerations approximately equal to those of the occupant compartment.

The following figures (5.1, 5.2, and 5.3) show the basic configuration in the undeployed and deployed mode.

5.2.1 Preliminary Analysis and System Specification

A preliminary analysis is presented below to provide rough system specifications and to provide initial parameters to be input into the crash victim simulator for optimization and final performance predictions.

This simplified analysis assumes a frontal barrier crash at forty-four feet per second (30 mph), 1.5 feet of frontal crush, and an average vehicle deceleration of 20 g's. The governing equations for acceleration (a), velocity (V), and displacement (x) time histories are

$$a = 20\,\mathrm{g's}$$

$$V(t) = V_o - a\,t$$

$$x(t) = V_o\,t_c - \frac{a\,t^2}{2}$$

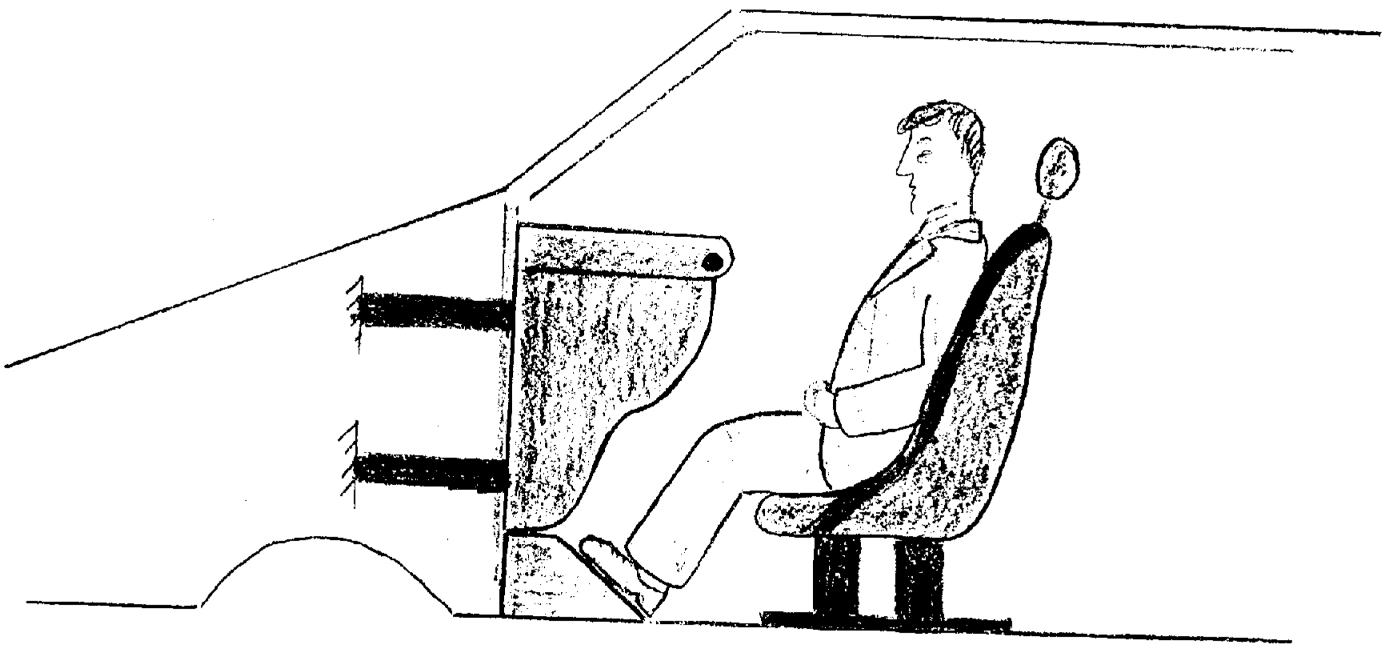


Figure 5.1

Undeployed Crash Pad

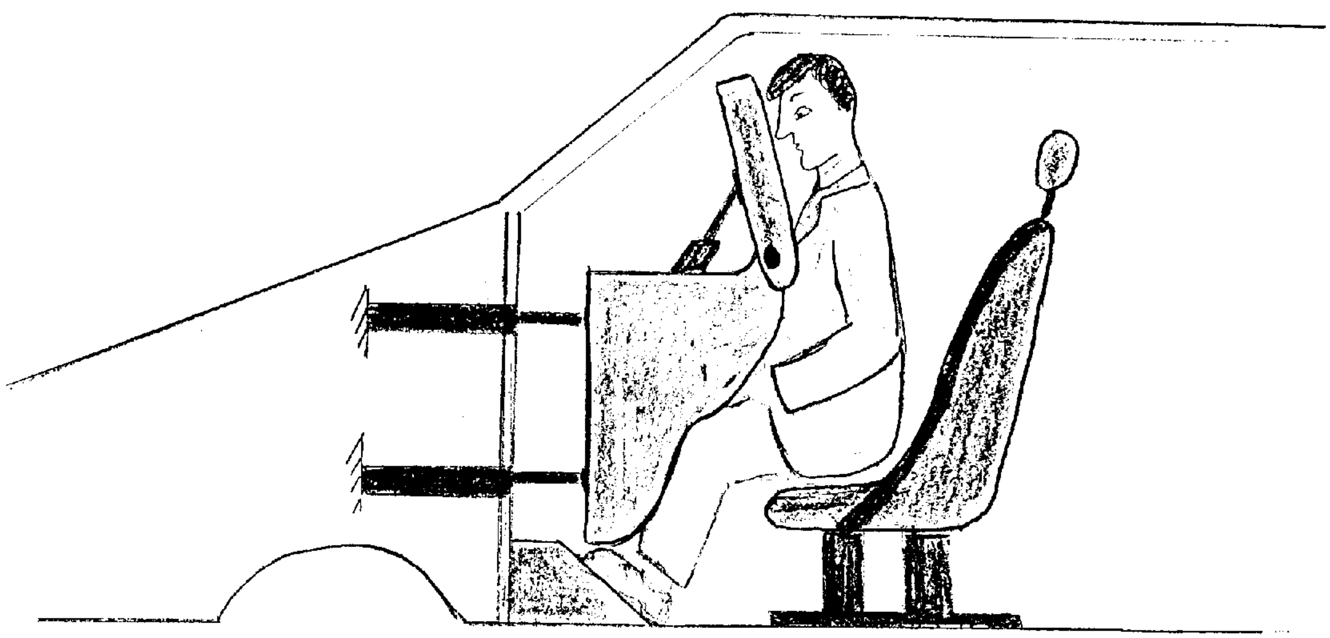


Figure 5.2

Crash Pad Deployed

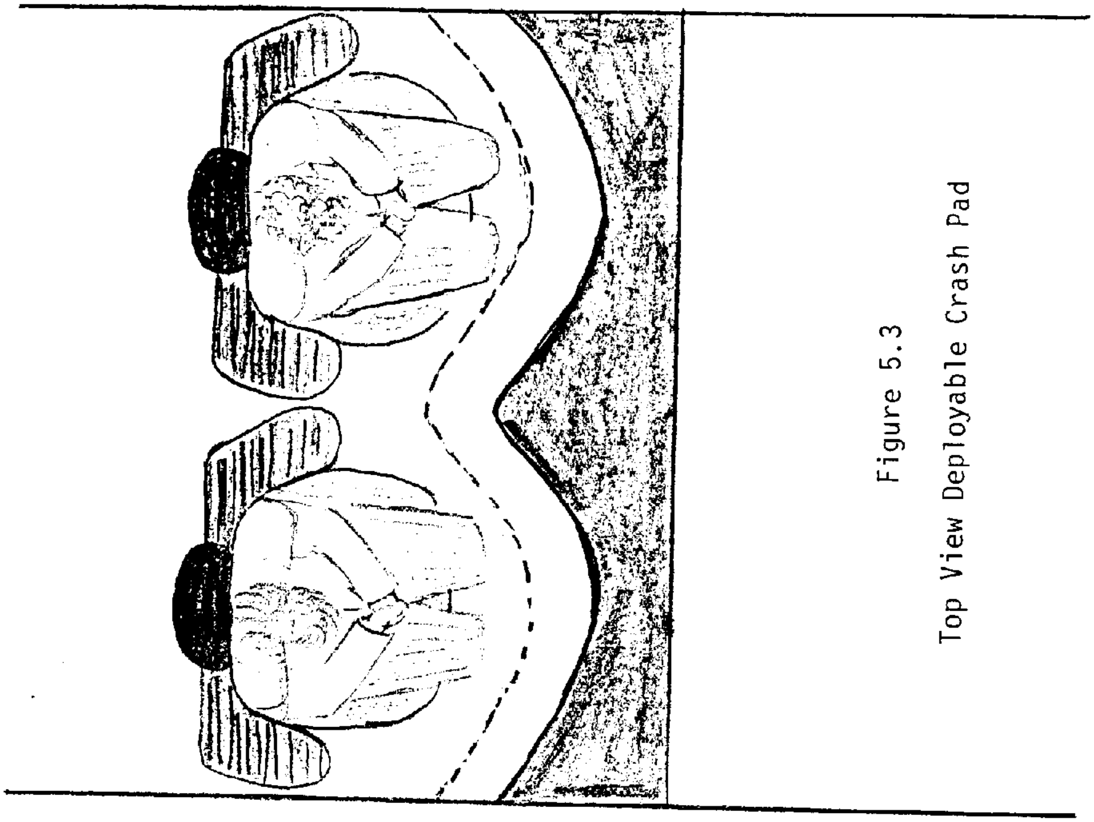


Figure 5.3
Top View Deployable Crash Pad

where the contact time

$$t_c = \frac{44\,ft/sec}{20 \times 32.2\,ft/sec^2} = 0.0683\,seconds$$

The occupants will continue at forty-four feet per second until contact with the deployed dash occurs. An estimate of the crash pad timing requirements follows for five configurations with the windshield initially two feet from the occupant.

A. Pad even with windshield before deployed

1. $x_d = 1\,ft$ (deployment distance)

   a. $t_d = 23\,msec$ assumed

   $x = 1\,ft = at^2 - \frac{1}{2}\,at^2$

   $a = 2(1\,ft)/(0.023\,sec)^2 = 3780\,ft/sec^2 = 117.4\,g$

   b. $t_d = 34\,msec$

   $x = 1\,ft = \frac{1}{2}at^2$

   $a = 2(1\,ft)/(0.034\,sec)^2 = 1730\,ft/sec^2 = 53.7\,g$

2. $x_d = 1.5\,ft$

   a. $t_d = 23\,msec$ assumed

   $x = 1.5\,ft = at^2 - \frac{1}{2}\,at^2$

   $a = 2(1.5\,ft)/(0.023\,sec)^2 = 5671\,ft/sec^2 = 176.1\,g$

   b. $t_d = 34\,msec$

   $x = 1.5\,ft = \frac{1}{2}at^2$

   $a = 2(1.5\,ft)/(0.034\,sec)^2 = 2595\,ft/sec^2 = 80.6\,g$

B. Pad 3 in closer to passenger

1. $x_d = 1.5\,ft$

   a. $t_d = 23\,msec$ assumed

   $x = 1.5\,ft = at^2 - \frac{1}{2}\,at^2$

   $a = 2(1.5\,ft)/(0.023\,sec)^2 = 5671\,ft/sec^2 = 176.1\,g$

Figures 5.4 and 5.5 show the displacement and velocity time histories for these five configurations.

The three arrows on Figure 5.4 indicate occupant contact with the deployed crash pad. By deploying the crash pad, occupant contact occurs early in the crash sequence with a relative velocity that is considerably lower than the vehicle velocity. The impact forces of this initial contact are reduced by the crash pad cushioning and the hydraulic force limiter. The occupant then rides the remaining vehicle crush down to zero velocity with the chassis decelerations predominating.

The relative velocity between the occupant and the crash pad at contact can be estimated by taking the initial contact time from Figure 5.4 and establishing the difference in velocity between the occupant and the vehicle in that time line in Figure 5.5. Figure 5.5 shows idealized velocity – time profiles for the occupant, vehicle, and crash pad for the crash pad configurations described above.

5.2.2 Crash Pad Design

The force-deflection profile is a major factor in the performance of the crash pad during the initial occupant contact phase. The ability to control this profile is a feature of this passive restraint concept. The required crush distance can be estimated by equating the kinetic energy of that part of the occupant with the strain energy of the pad or the area under the force-deflection profile. Thus:

$$\int_0^D F d\delta = \frac{MV^2}{2}$$

The integral can be approximated by

$$\int_0^D F d\delta \approx k F_M D\,, \quad 0 < k \leq 1$$

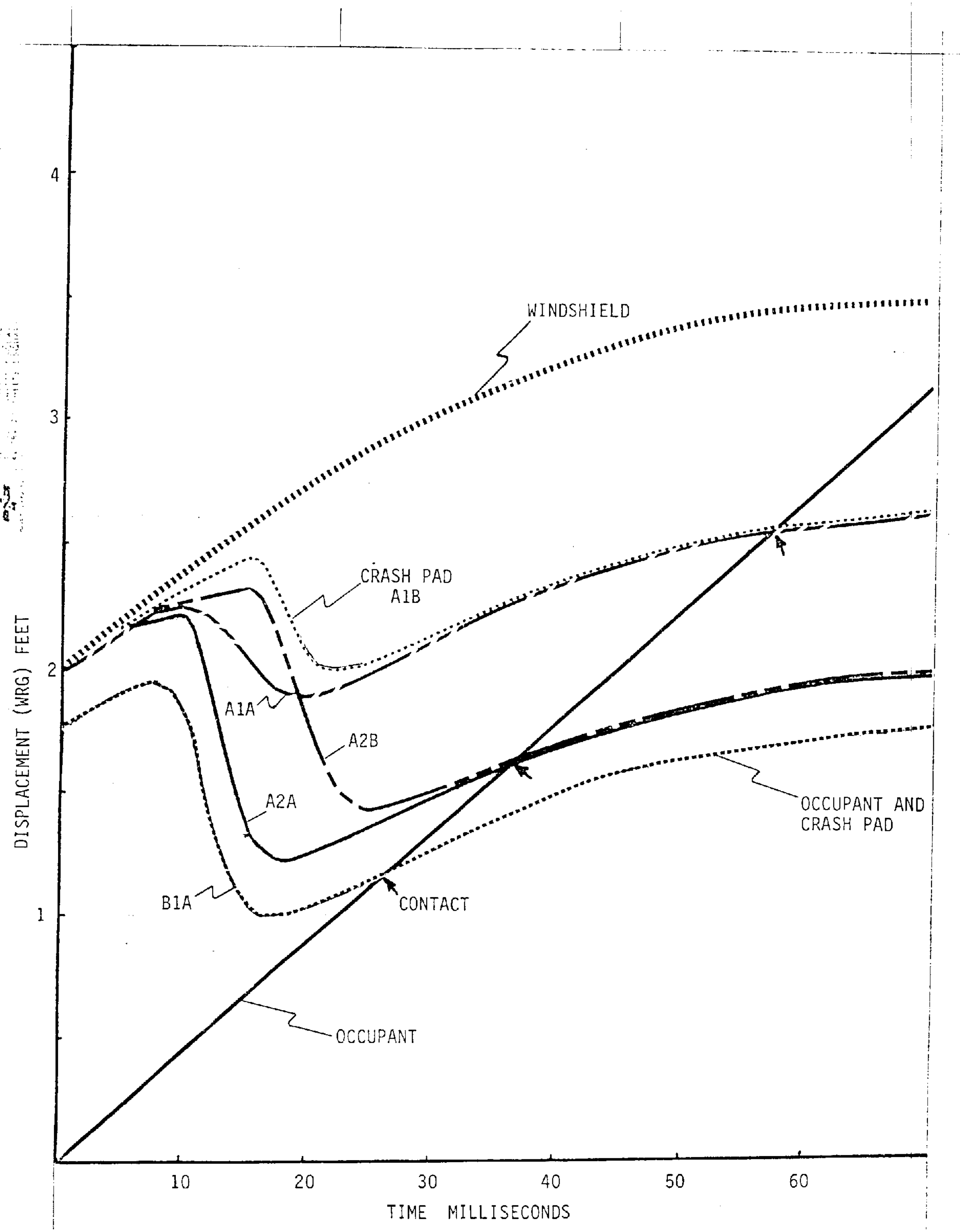


Figure 5.4 Displacement - Time Profiles
Deployable Crash Pad

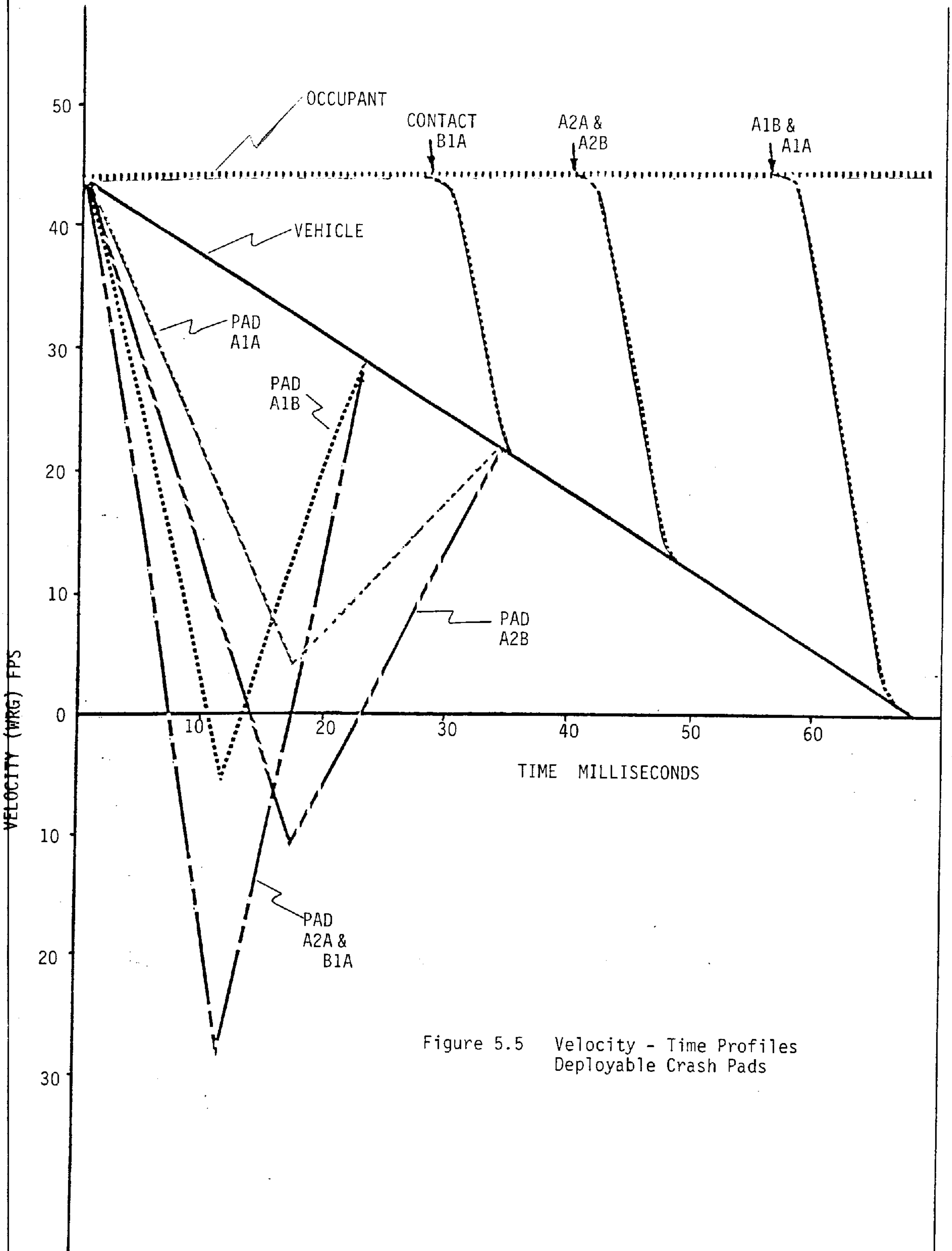


Figure 5.5 Velocity - Time Profiles
Deployable Crash Pads

where k is a performance factor and equals one for a flat top or fully plastic profile. This pad description has been incorporated into the vehicle occupant simulator model for performance prediction.

An alternate calculation that can be used to predict the required stopping distance is based on tolerable values of occupant deceleration. The minimum stopping distance is based on average deceleration. In practice, the stopping distances required to limit the peak decelerations to the values shown is more than doubled because of the stiffening force-deflection profile of most structures. In the deployable crash pad design, our analysis indicates that we can effectively utilize approximately 60% of the available crush space compared to 40% for air bags. Figure 5.6 shows the minimum stopping distances required for the perfectly plastic energy-absorbing structure.

5.3 Crash Pad

The crash pad will incorporate two to three inches of closed cell foam pad (Ensolite or Ethafoam) over a sheet steel supporting framework. The deployed contour is shown in Figure 5.7. The main function of the foam pad is to distribute body contact forces and reduce the deceleration of the initial impact. Additional stopping distance is provided by the deformation of the energy-absorbing support columns in the mechanically deployed system or the shock absorber supports in the hydraulic system.

The slight forward tilt of the head pad minimizes neck shear force while keeping neck tensile loading under control. The foam stiffness and sheet metal support in the head and neck strike areas is specified to be 250 lbs./inch, with total normal force limitation of 750 pounds. The interaction between the pad and the arms and legs is specified to be 500 lbs./inch, with a total normal force limitation of 1000 pounds. The torso strike area has been specified to be 1000 lbs./inch with a normal force limitation of 2000 pounds. These values were selected from parametric analysis using the vehicle occupant crash simulation model.

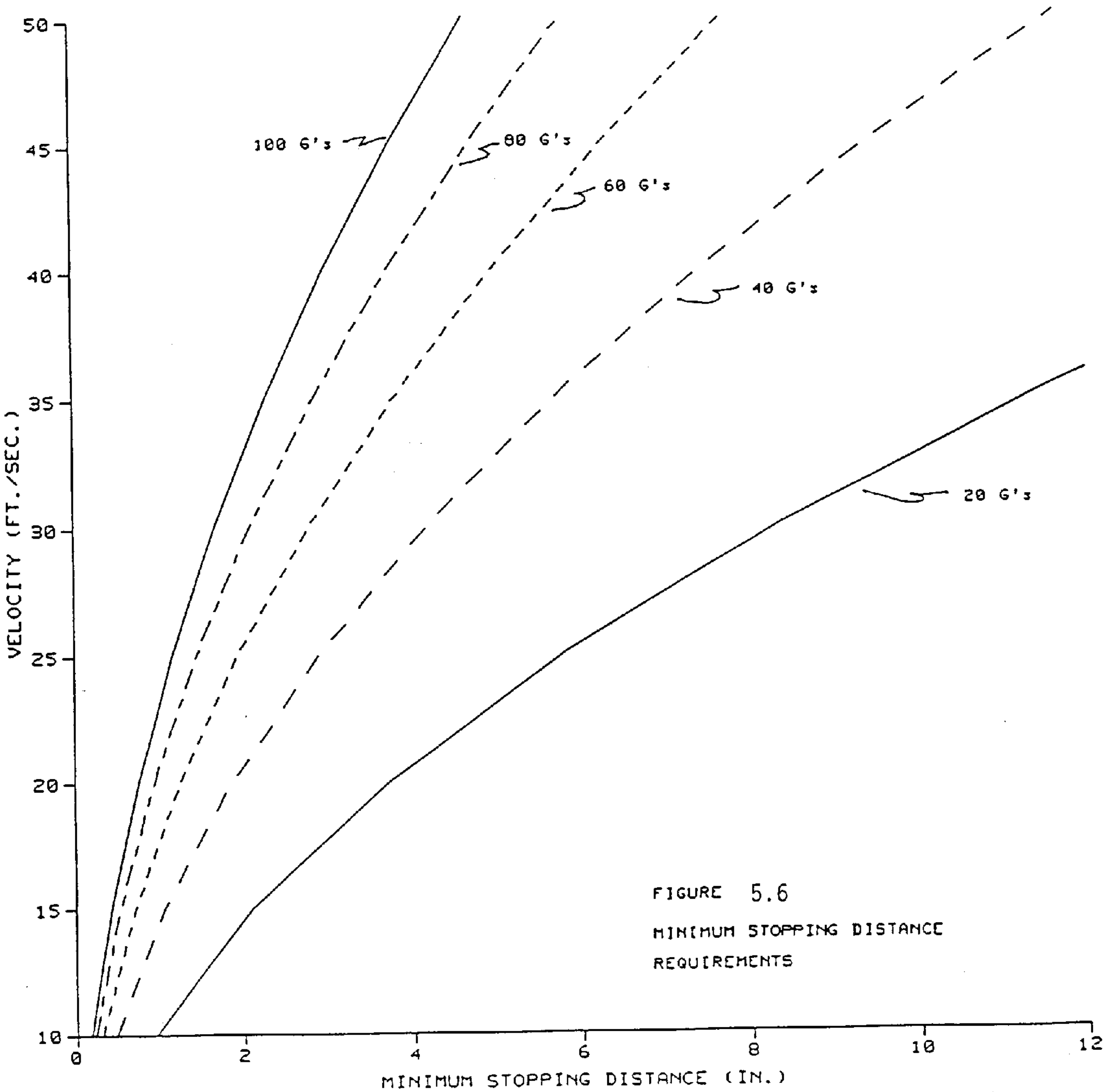
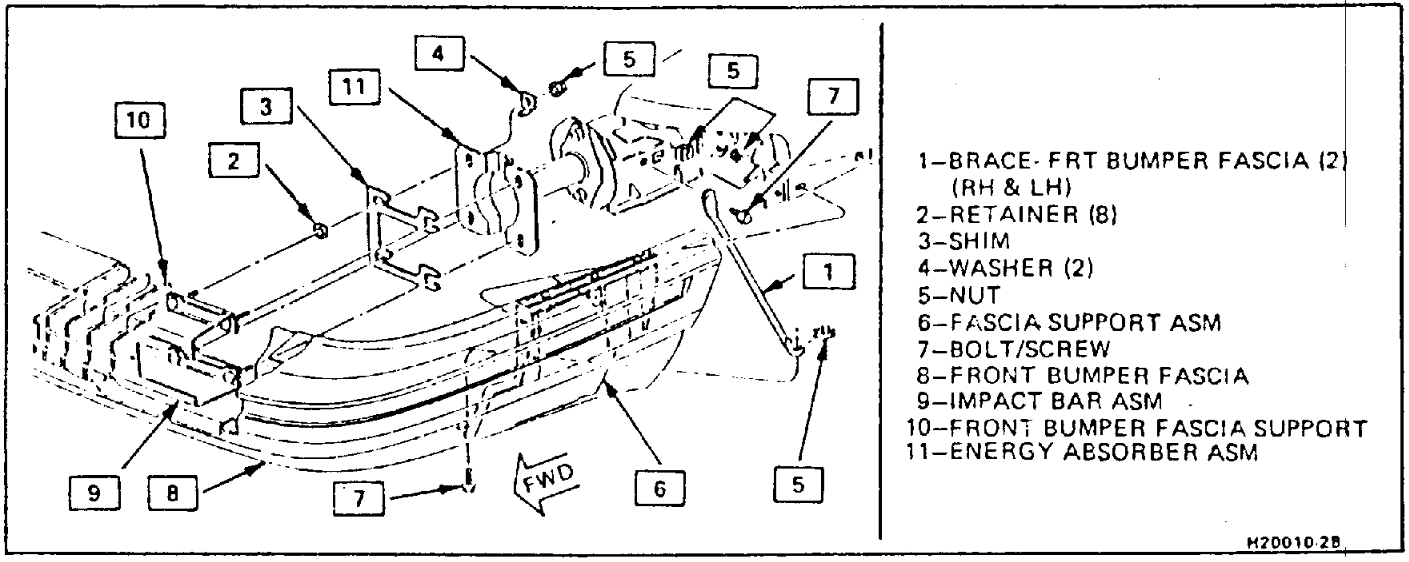
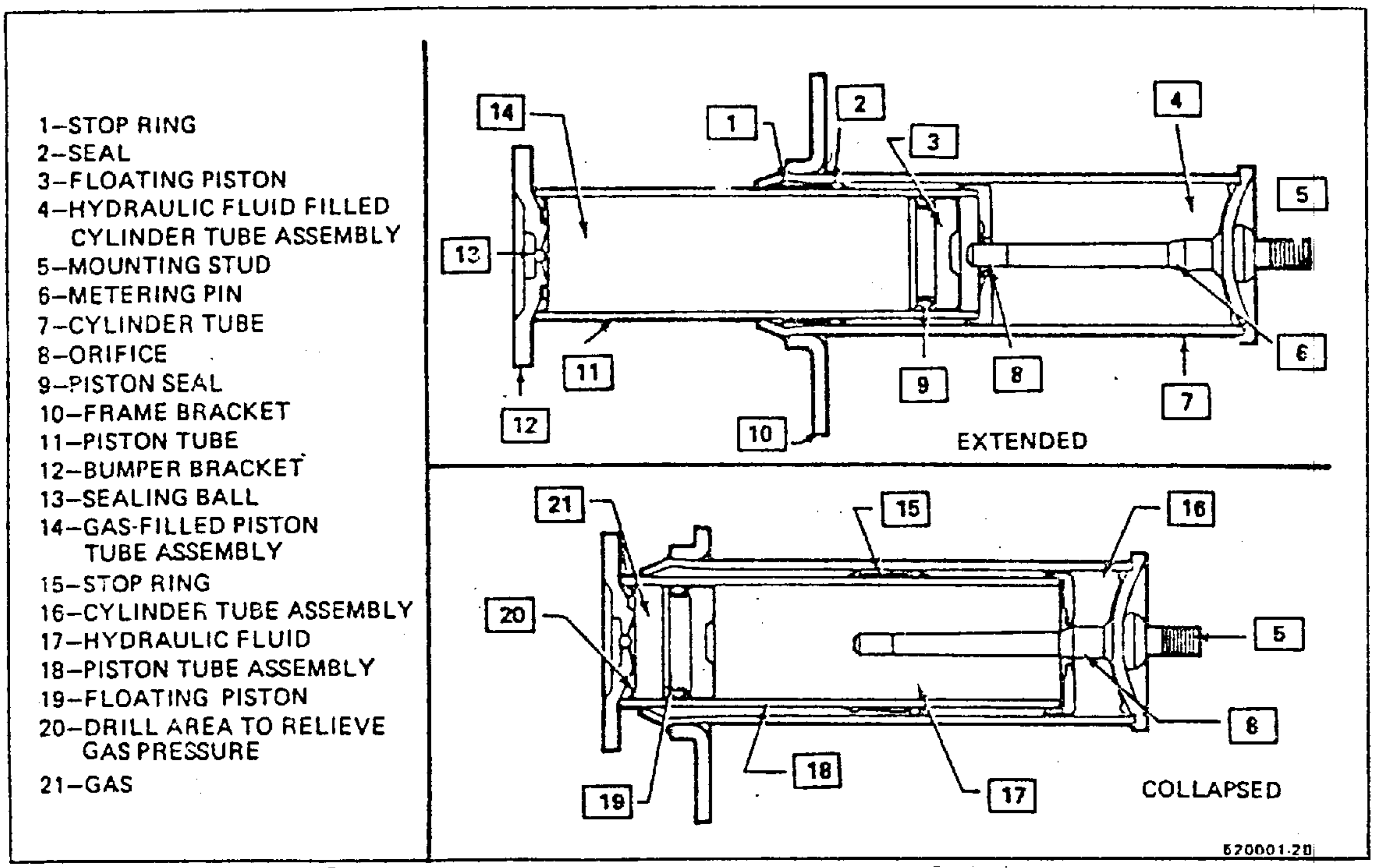


FIGURE 5.6

MINIMUM STOPPING DISTANCE REQUIREMENTS





Energy Absorber Extended and Collapsed (Typical)

Figure 5.7

The energy absorber currently used could be modified to contain fluid in the gas-filled piston tube assembly (14) and the sealing ball (13) could be replaced whith an aperture made continuous with a fluid filled hose. The strength of the piston should be modified, if needed, to accomodate the incresed pressure in the cylinder. Also, the length of the piston may have to be increased to accomodate the distance of deployment.

The pad is contoured in the underdash area so that the knees will pocket and reduce submarining while the seat sides and dash contour are extended to provide a measure of protection in off-axis impacts.

5.4 Crash Pad Deployment Mechanism

5.4.1 Specifications and Characteristics

Optimum performance of the crash pad requires that the pad be fully deployed before the occupant reaches it. In the event of an out-of-position occupant, the padding and force-limiting device will reduce injury potential but, as with the air bag, maximum protection will not be achieved. Unlike the air bag, however, which deploys in a fixed period of time (nominally 15 milliseconds), the crash pad deployment mechanisms proposed here deploy in times proportional to the initial impact velocity. Thus, the basic deployment requirement of this mechanism is to deploy the crash pad as the initial crush of the vehicle occurs. The vehicle occupant model analysis indicates that a twelve-to-fifteen-inch deployment of the dash during the first one-third of the vehicle crush is close to optimum. In the analyses that follow, total vehicle crush of eighteen inches at 30 mph barrier impact velocity was used for modeling purposes with full crash pad deployment of fifteen inches occurring after six inches of vehicle crush. An additional requirement is that the force limiters resist collapse with the levels described above.

Two systems with the potential to meet these requirements are proposed. The first is hydraulic with the energy derived from hydraulic shock absorbers supporting the front bumper. The second is a mechanical cable system also driven by the controlled collapse of the front bumper support system.

5.4.2 Hydraulic Deployment System

A hydraulic deployment system as shown schematically in Figure 5.8 is proposed. The system utilizes available and reliable components to rapidly deploy and contour the crash pad. To illustrate this point, consider the bumper system of a 1986 Bonneville shown schematically in figure 5.7.

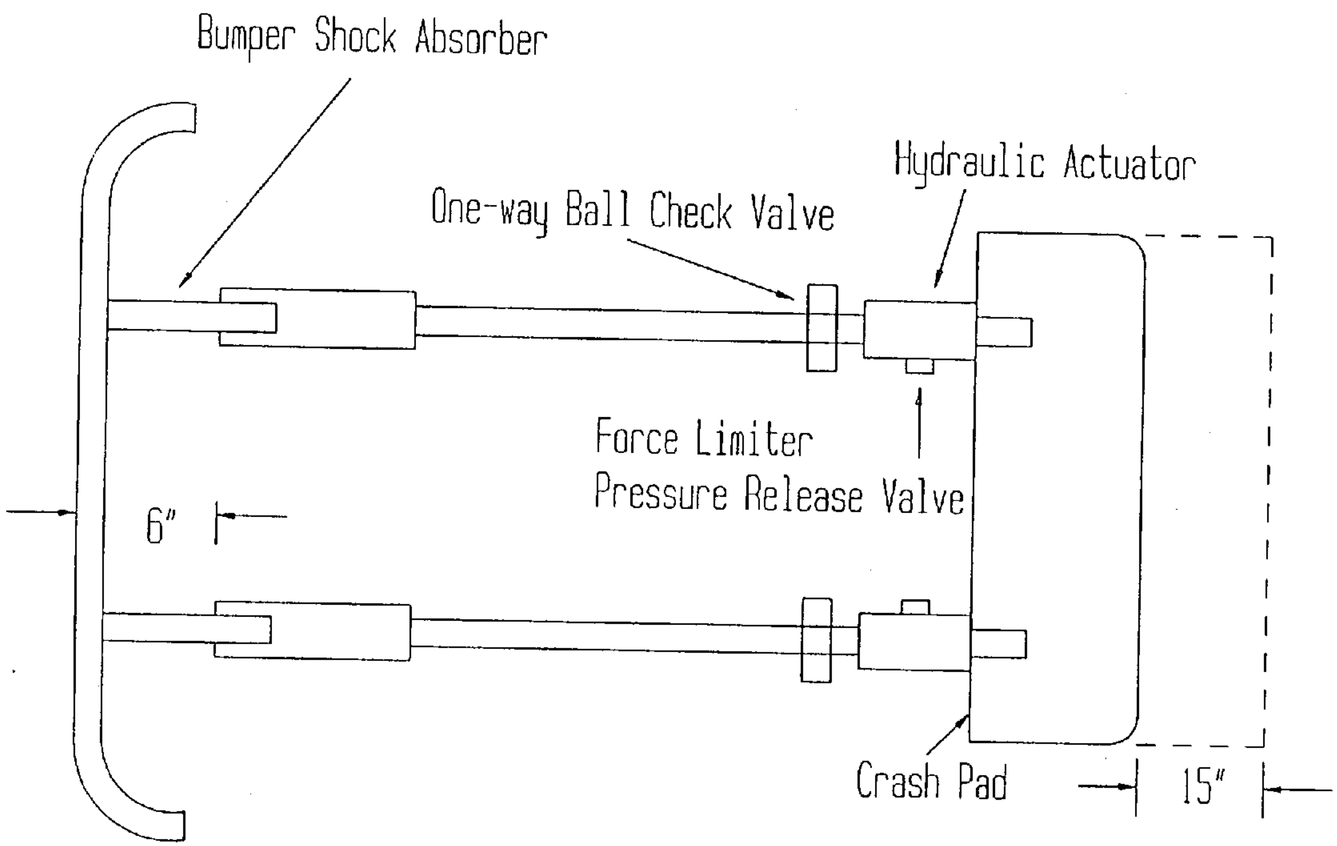


Figure 5.8 Hydraulic Actuated Deployable Crash Pad

The hydraulic fluid would be pumped from the energy absorbers supporting the front bumper to the cylinders that deploy the dash. The cylinders would be sized so that the initial six inches of crush would deploy the dash the full amount (i.e., twelve to fifteen inches, depending on the car interior dimensions). The cylinders and other hydraulic components would be required to handle pressures such that the maximum deployment force accelerates the crash pad at approximately 120 g's. For a dual crash pad assembly weighing sixty pounds, this corresponds to 7200 pounds force. For two deployment cylinders of one-inch diameter, this requires a working pressure of approximately 1100 psi and an average flow of 20 ft^3/sec. If a pressure drop of 4000 psi is allowed, a tubing diameter of 3/4 inch would be required for a tube length of five feet. Each line would have a ball check valve to provide one-way flow and each crash pad deployment cylinder would have a check valve to limit deployment forces and provide a controlled ride down.

A smaller pair of hydraulic actuators would be used to open the upper section of the dash between the occupants' head and the windshield. An additional hydraulic actuator would be used to retract the steering wheel and column. The upper section on the driver's side would be pivoted so that, in addition to opening upward, it would open downward to cover the upper section of the steering wheel and the instruments. The lower section of the steering wheel would be retracted into a moulded cavity in the foam of the crash pad.

The force-limiting check valve will be designed to restrict deployment of the crash pad to only those accidents that are severe enough to require it. Below ten miles-per-hour barrier equivalent, no deployment would occur. Partial deployment would occur in the range 10-15 miles per hour with full deployment occurring above 15 miles per hour. These speeds are approximate and full-scale sled testing is required to optimize them. The steering wheel and upper flap on the driver's side would not be deployed until the accident was severe enough to require this additional protection. Thus, driver control and vision would not be compromised until the crash deceleration becomes overwhelming. This feature reduces the injury potential associated with multiple impacts.

5.4.3 Battery Disconnect Switch

A pressure-activated switch will be provided in the service line that disconnects the battery from the electrical system at pressure levels associated with 15 mph and higher crash speeds. This will reduce the fire hazard by removing electrical power from the entire electrical service system at the battery.

5.4.4 Alternate Cable Deployment System

Audi Automotive Corporation has introduced a crash-activated cable and pulley system that tightens the seat belts and retracts the steering column. The rearward motion of the engine in a frontal crash is used to provide the required force. A similar system is proposed to deploy the crash pad. Given the large forces associated with an impact, this appears to be both feasible and practical. Final design configurations will be developed in phase II when the optimum crash pad configuration and timing are established with full scale sled testing.

5.5 Anthropometric Considerations

There has been extensive research and development in designing the occupant compartment of an automobile. The major considerations that apply to the deployable crash pad are that the crash pad in the deployed configuration does not contact the occupant (95th% male through 5th% female) and that the crash pad in the undeployed configuration conforms to an acceptable dash shape. All of the primary measurement data necessary for occupant space design is available from the literature (24-28). The anthropometric data is also available from the computer program GEBOD previously described (23).

Figures 5-9 and 5-10 were drawn to scale using CADKEY. The preliminary deployed crash pad configuration has been established using the crash victim simulator model. The optimum configuration will be established in Phase II from full-scale sled testing. The CADKEY program will then be used to design the undeployed configuration consistent with the anthropometric requirements.

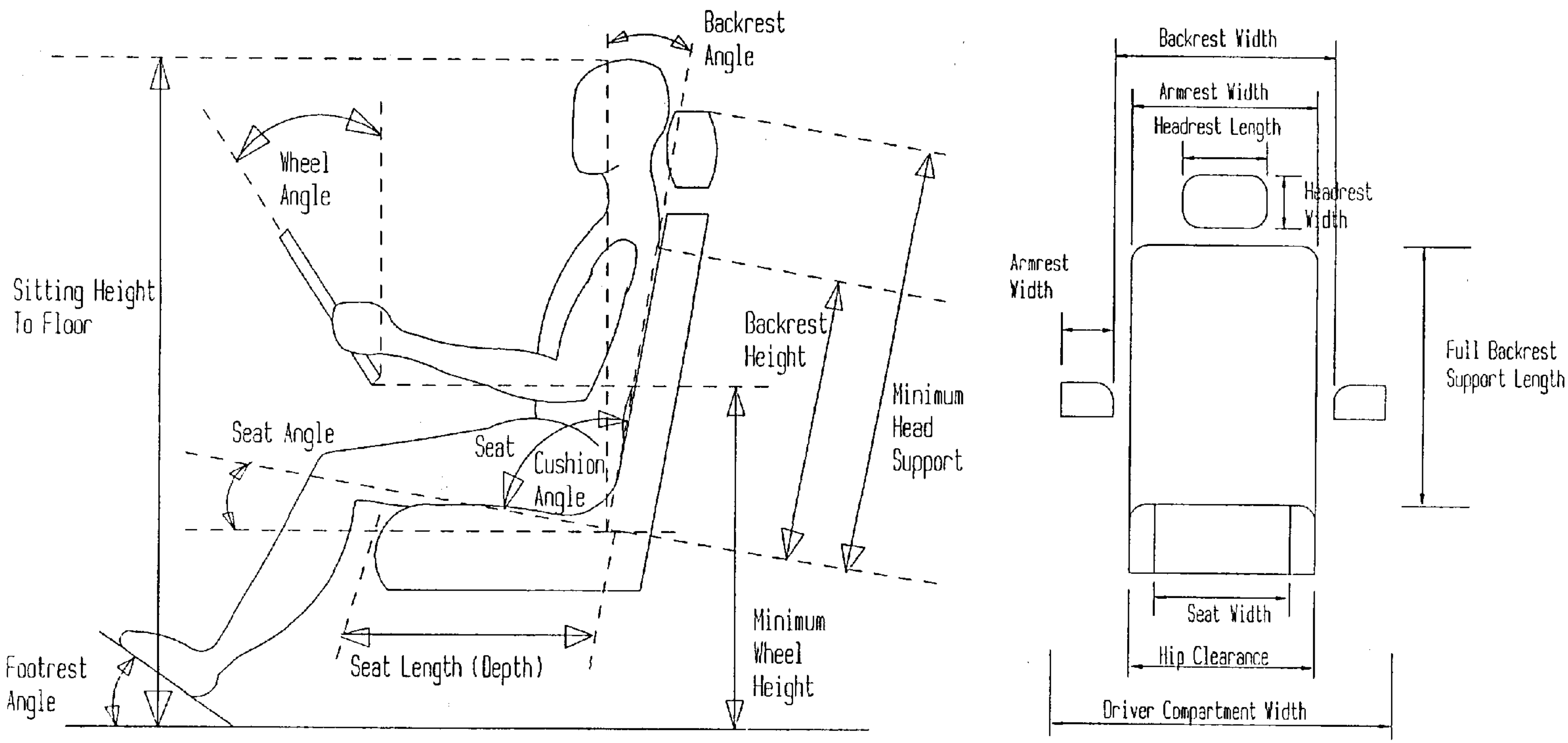


Figure 5.9 Important Occupant Compartment Dimensions

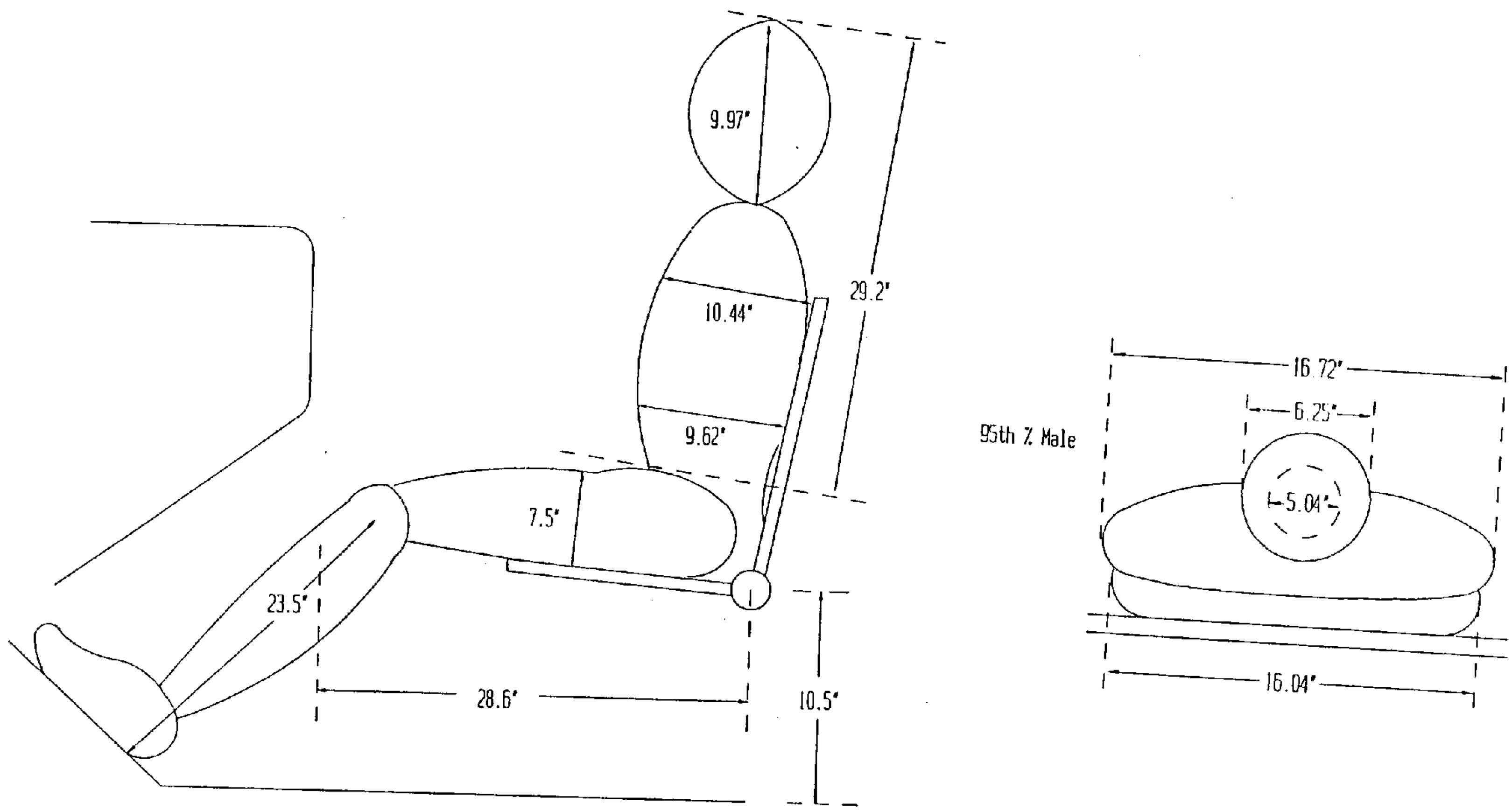


Figure 5.10 95th % Male Overall Dimensions

6. Evaluation of the Deployable Crash Pad

6.1 Design Features

6.1.1 Three-Point Belts

Current automotive seat belts offer significant protection in frontal collisions by reducing the severity of head, torso, and knee contacts with relatively stiff components such as the windshield header, the A posts, the steering wheel, and the dash. They greatly increase the occupant stopping distance by allowing the occupant to ride down much of the vehicle crush. They are very effective in preventing occupant ejection in severe accidents where the doors and/or windows are compromised. They do require that the occupants latch them. In some accidents, they can enhance injuries (e.g., side impacts with significant intrusion or where submarining due to a loose belt or small size causes the lap belt to ride over the pelvis).

6.1.2 Passive Belts

Passive belts share all of the virtues and shortcomings of active belts. In addition, they have special problems associated with anchor locations which are not optimal for minimizing belt-induced injuries. Customer acceptance is low; many users opt for active belts if given the choice.

6.1.3 Air Bags

Air bags offer an interesting alternative. The large occupant decelerating forces required of a restraint system are better distributed. Stopping distance is increased and performance in pure frontal crashes is good. Performance does fall off rapidly as the impact direction moves off center. But air bags present a new type of problem. Inadvertent actuation, failure to function when needed, and a hazard to out-of-position occupants are major concerns. They offer no protection from ejection, they cost more, and, since they are more complex, their reliability will be lower than seat belts.

6.1.4 The Deployable Crash Pad – Features Compared

The design features of the proposed Deployable Crash Pad are:

1. Completely hidden and passive – Deploys in the crash and requires no action on the part of the occupant
2. No problem with inadvertent actuation – Since it uses the crash force to deploy, it cannot deploy except in an accident
3. Contour offers higher level of protection in off-center frontal impacts than air bags while analysis indicates similar on-center performance
4. Deploying knee pad reduces submarining while maintaining passenger comfort
5. Crash pad deployment velocity varies in proportion to impact velocity reducing out-of-position occupant problem
6. Force-limiting, energy-absorbing supports limit injury potential in crash even with out-of-position occupant
7. Fire hazards are reduced – Battery is disconnected in a crash
8. Cost is comparable to air bags
9. Reliability should be much better than air bags because construction is of simple mechanical components
10. Protection potential can be increased by increasing occupant to dash and crash pad deployment distance
11. Design is based on existing well-known technology and would utilize, with slight modification, hydraulic bumper systems
12. No toxic material or overpressure developed.

6.1.5 Design Trade-Offs

1. Protection from ejection is limited but comparable to air bags.
2. Cost is higher than seat belts but comparable to air bags.
3. Protection from side impact and rollover is limited but comparable to seat belts and air bags.

6.2 Computer Simulation Results

The crash victim simulator program was utilized for optimization and final performance prediction of the deployable crash pad. A frontal barrier crash was simulated. An initial vehicle velocity of 44 feet per second (30 mph) and a constant vehicle deceleration of 20 g's for 68 msec was assumed. The occupant, an unrestrained 50th percentile Part 572 dummy, was located in the front seat of a 4-door 1981 Dodge Aries. The inertial and geometric properties of the 15 body segments and the joint locations and resistive characteristics of the 14 joints were abstracted from an operational AAMRL data set. The knee was defined as a pin joint; the hip, shoulder, elbow, and ankle were defined as Euler joints. Measurements of the car interior were used to define planes representing potential contact surfaces in the vehicle. Each contact between a body segment and a vehicle surface was identified and a force-deflection function describing that interaction was defined.

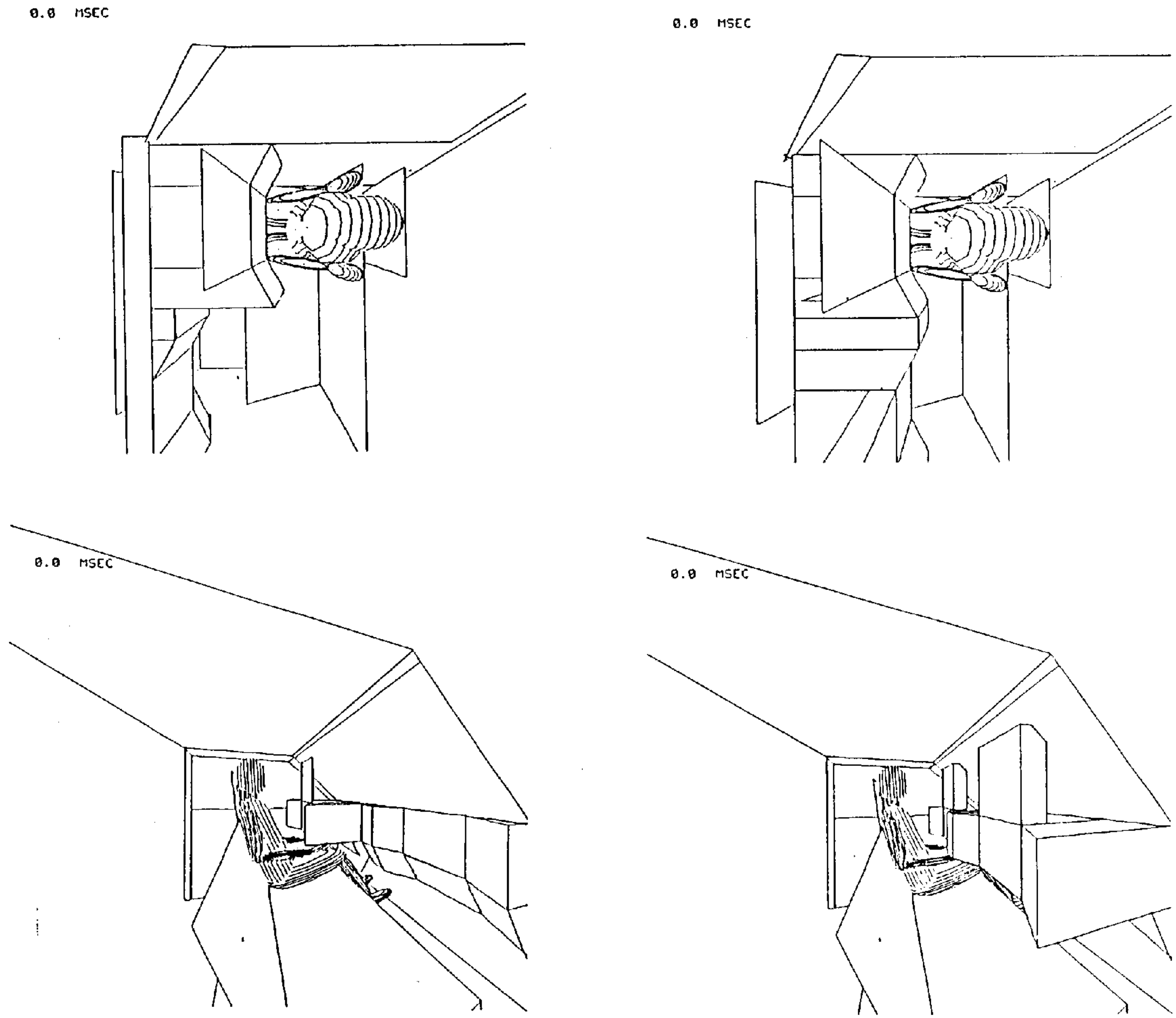
For the initial runs, the crash pad/dash was placed two feet from the occupant even with the windshield. The wings projected outward at a 30 degree angle relative to the crash pad. The crash pad bottom sloped away from the occupant at a 30 degree angle. A deployment distance of 1.5 feet was specified. The crash pad top was deployed upward 60 degrees relative to the undeployed position.

Results of the crash pad shape/contour studies suggested that the initial data set for the vehicle geometry should be modified so that the undeployed dash was four inches in front of the windshield. This change was made.

Preliminary parametric studies indicated that the crash pad performance was highly dependent on the specified force-deflection characteristics. The optimum profile was 250 pounds per inch with a normal force-limiting plateau of 750 pounds (and a friction coefficient of 0.2) for the interaction between the dash and the head and neck, 1000 pounds per inch with a normal force-limiting plateau of 2000 pounds (and a friction coefficient of 0.5) for the torso/dash contact, and 500 pounds per inch with a force-limiting plateau of 1000 pounds (and a friction coefficient of 0.5) for the interaction between the dash and the arms and legs. The crash pad shape and deployment distance was modified again in order to better tune the predicted performance. For the final design, the dash top was vertical, the initial distance from the pad to the occupant was nominally 20 inches, and the deployment distance was 16 inches.

Time history data for the motion of all segments, joint orientations and torques, and internal and external forces were predicted from the model. These results indicate that no windshield/head contact occurs. Peak head accelerations are within human tolerances. Peak torso accelerations nearly comply with the NHTSA specifications of less than 60 g's for time durations greater than 3 msec. The Head Injury Criterion (HIC) was 1421 for a time duration of 58.5 msec to 72.5 msec. The average head acceleration for the time duration was 101 g's. The Chest Severity Index (CSI), calculated for the lower torso, was 504. Body position graphical plots were obtained using the VIEW graphic display program, which shows the vehicle contact planes and occupant (see Figures 6.1 and 6.2). Each body segment is depicted as a three-dimensional ellipsoid.

Figures 6.3 through 6.11 show the force, velocity, and acceleration versus time predictions of the crash victim simulator model for the deployable crash pad. A clear observation of this analysis is that the performance of the system can be significantly improved by increasing the deployment distance and reducing the force limitation in the energy-managing supports. Further tuning of the dash shape, deployment timing, and mechanical properties is required. We believe that the model predictions are somewhat higher than experiments will show because of our inability to describe the initial contact with the pad. Overall, the model results demonstrate the feasibility of the deployable crash pad system.



One Side Deployed

Both Sides Deployed

Figure 6.1 Crash Victim Simulator Graphic Display

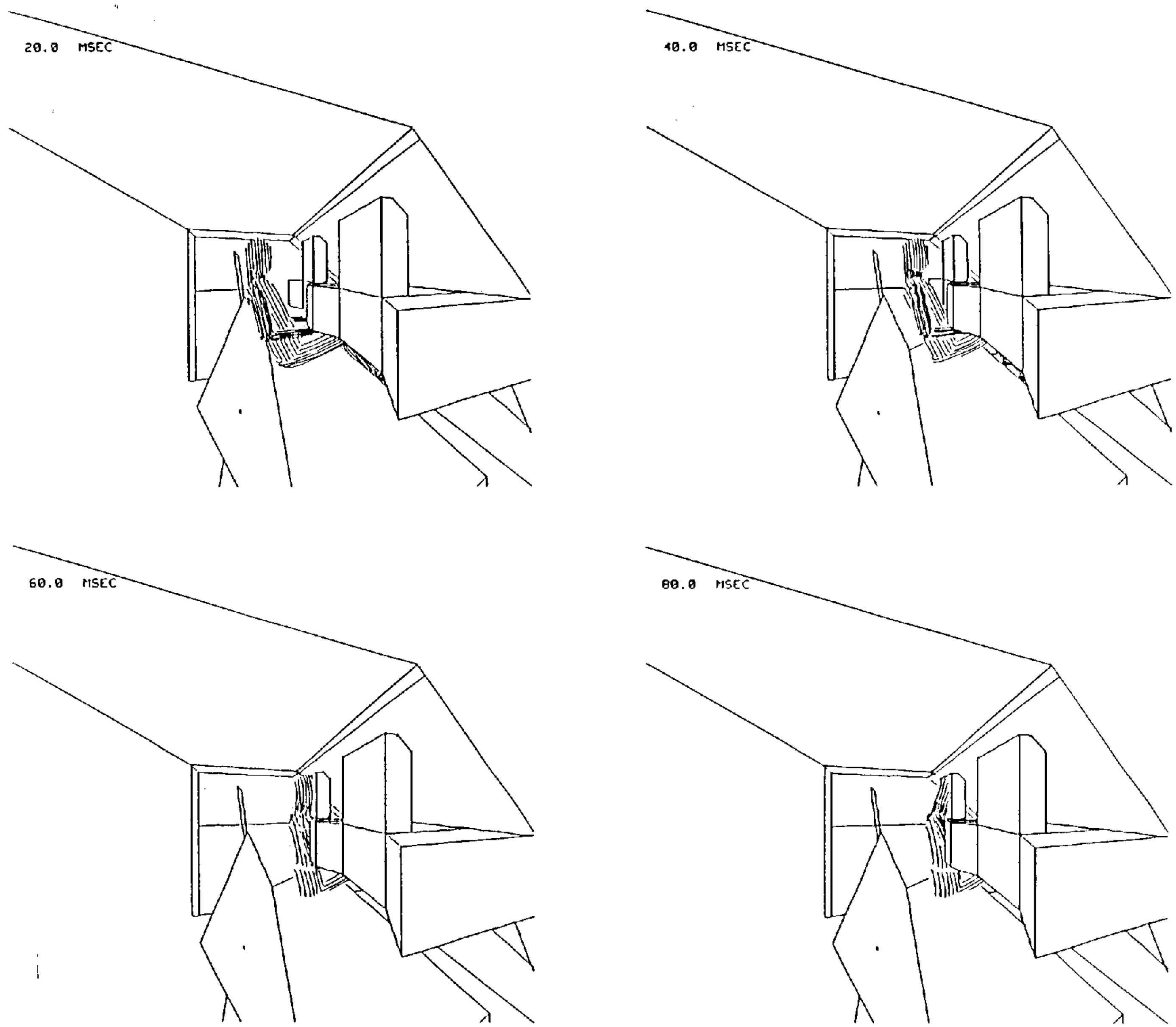


Figure 6.2 Crash Victim Simulator Graphic Display

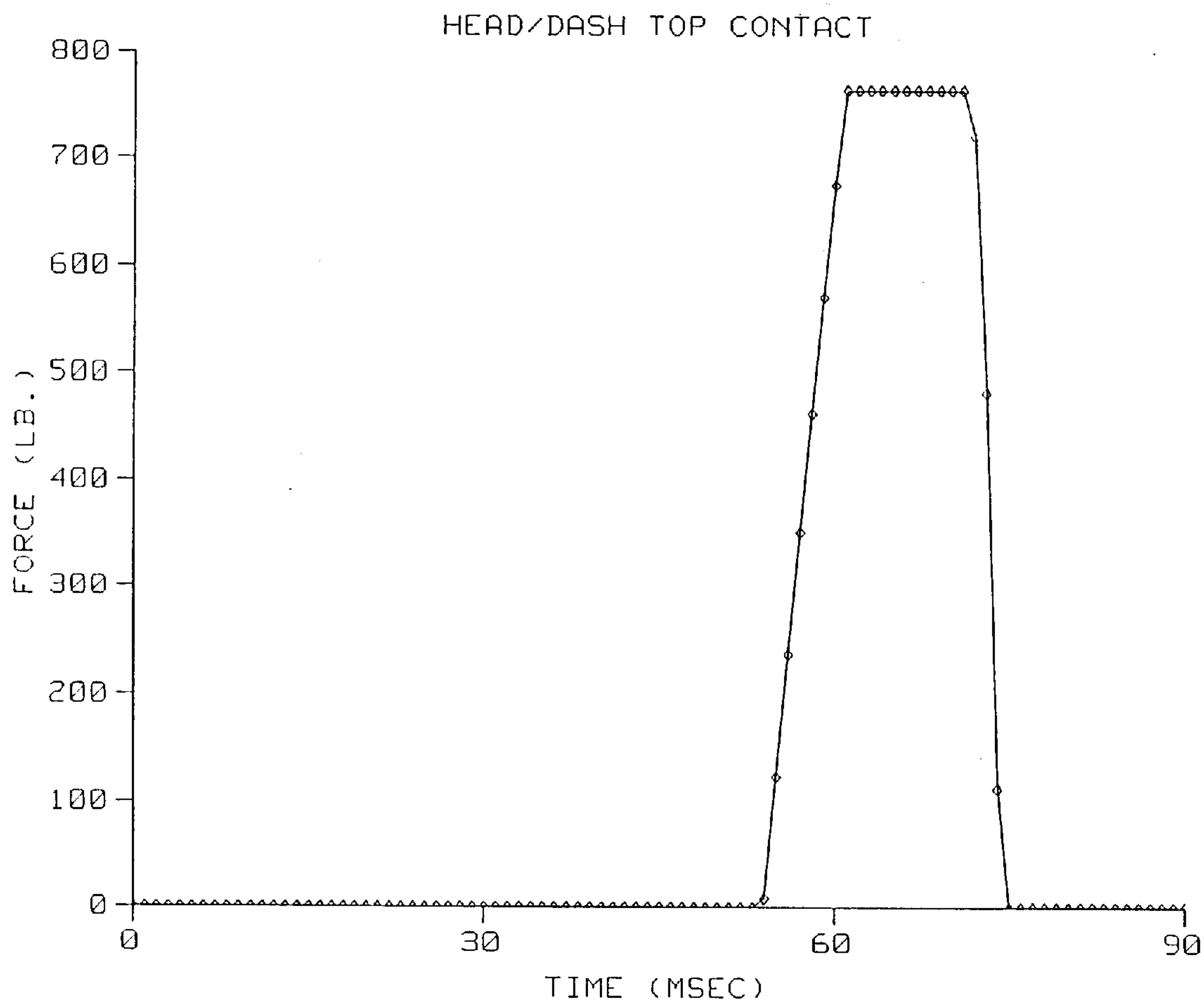
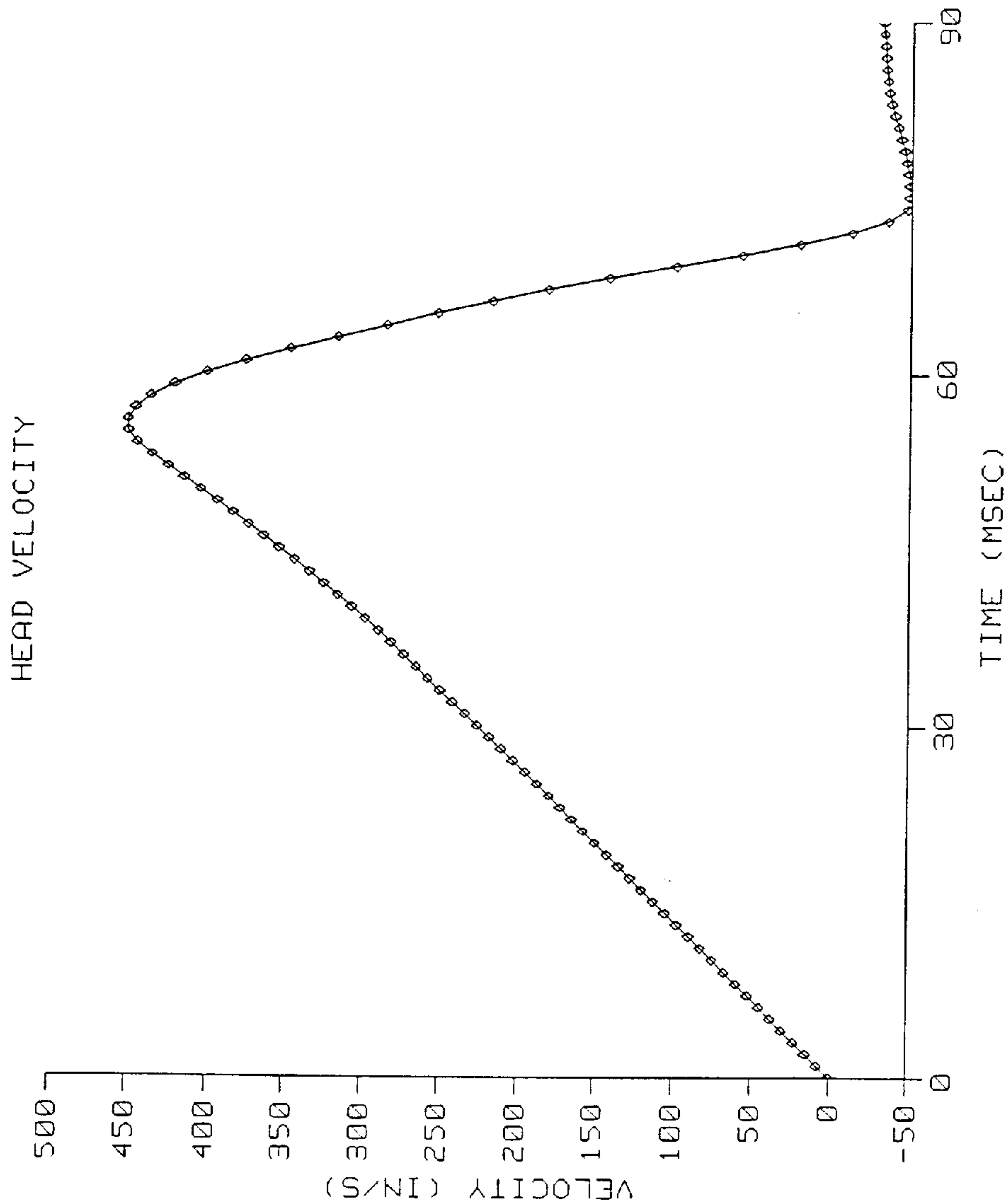

HEAD/DASH TOP CONTACT
FORCE (LB.)
800
700
600
500
400
300
200
100
0
0
30
60
90
TIME (MSEC)

Figure 6.3



HEAD VELOCITY
VELOCITY (IN/S)
500
450
400
350
300
250
200
150
100
50
0
-50
0
30
60
90
TIME (MSEC)

Figure 6.4

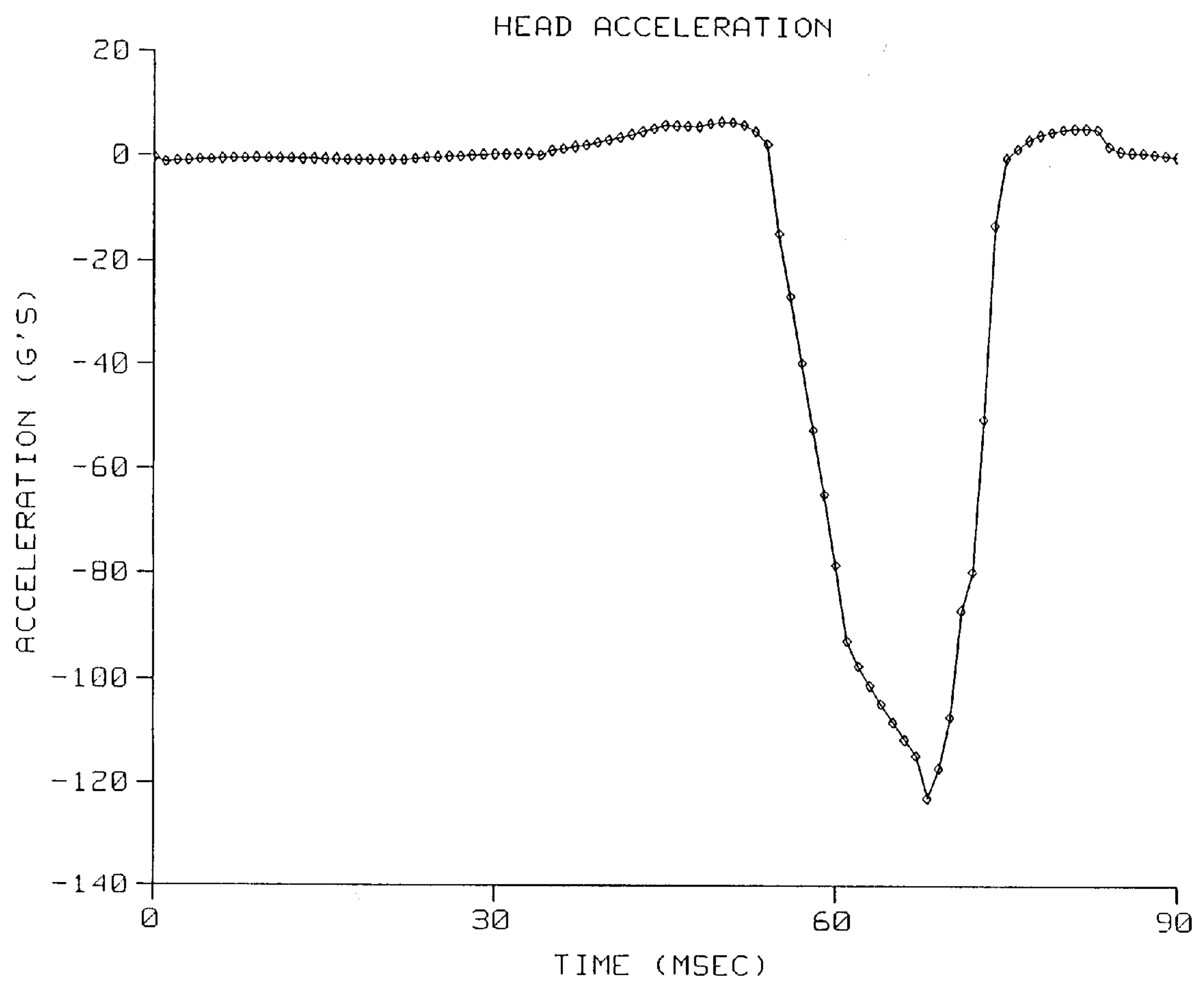

HEAD ACCELERATION
ACCELERATION (G'S)
20
0
-20
-40
-60
-80
-100
-120
-140
0
30
60
90
TIME (MSEC)

Figure 6.5

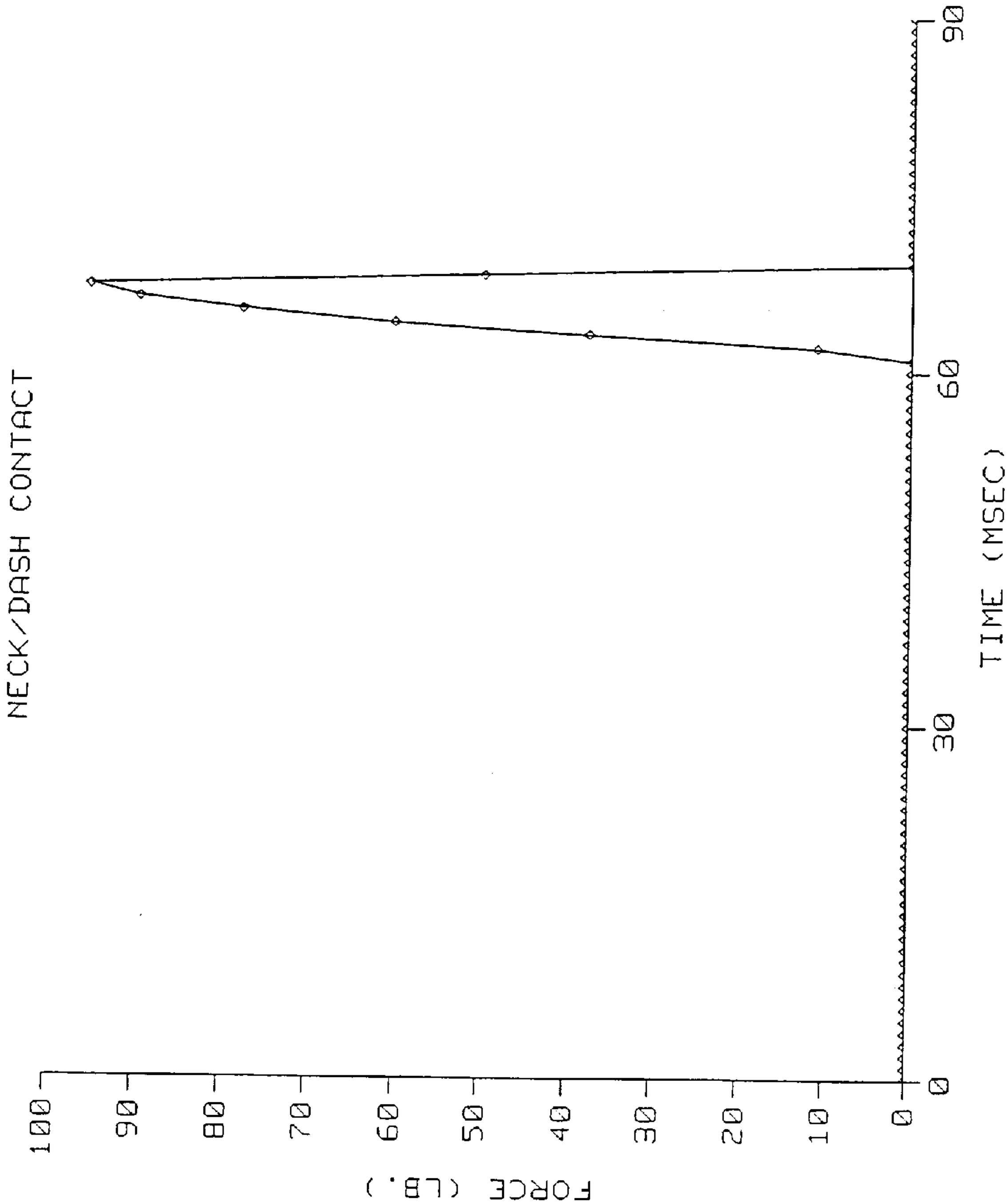

NECK/DASH CONTACT
FORCE (LB.)
100
90
80
70
60
50
40
30
20
10
0
0
30
60
90
TIME (MSEC)

Figure 6.6

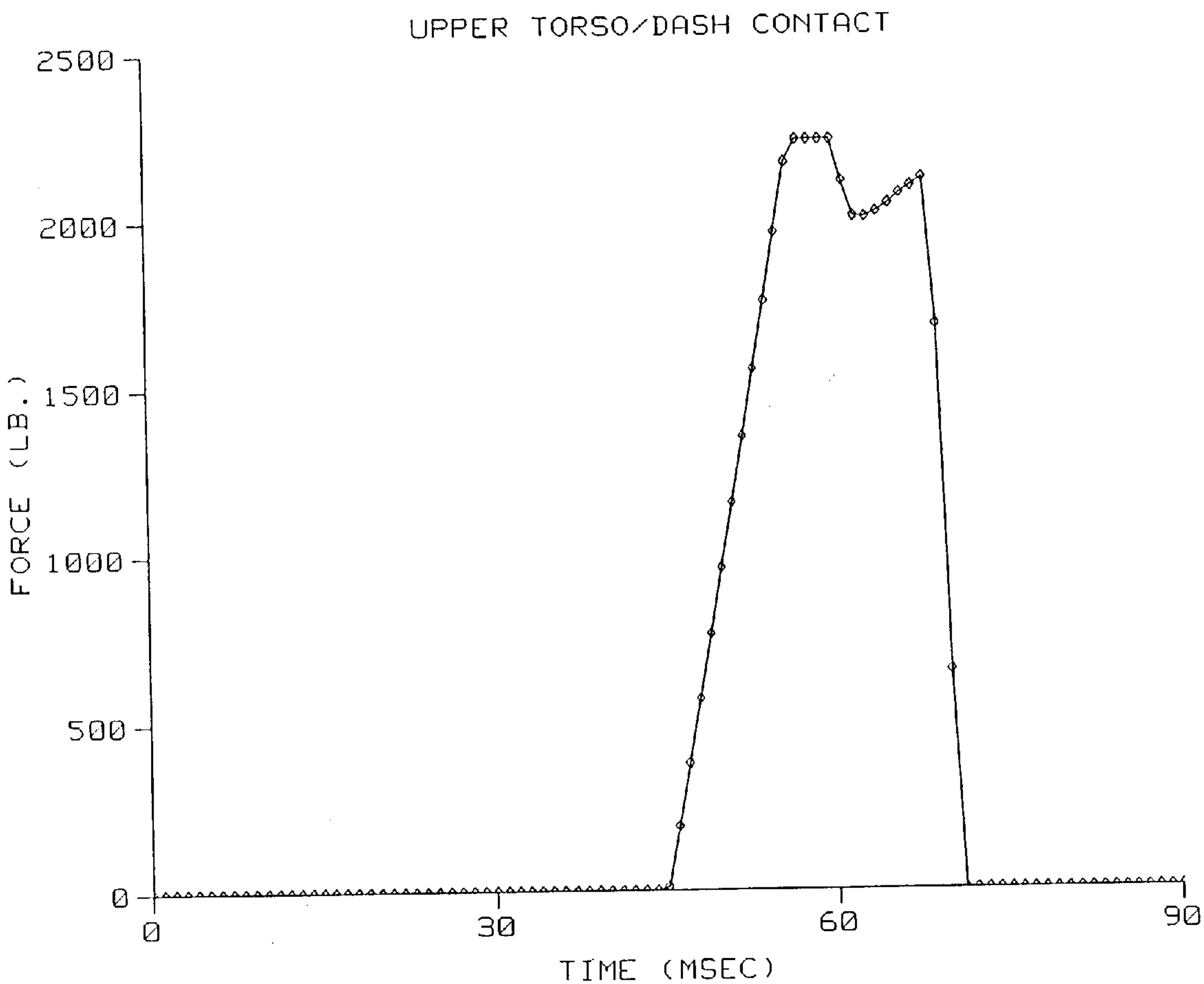
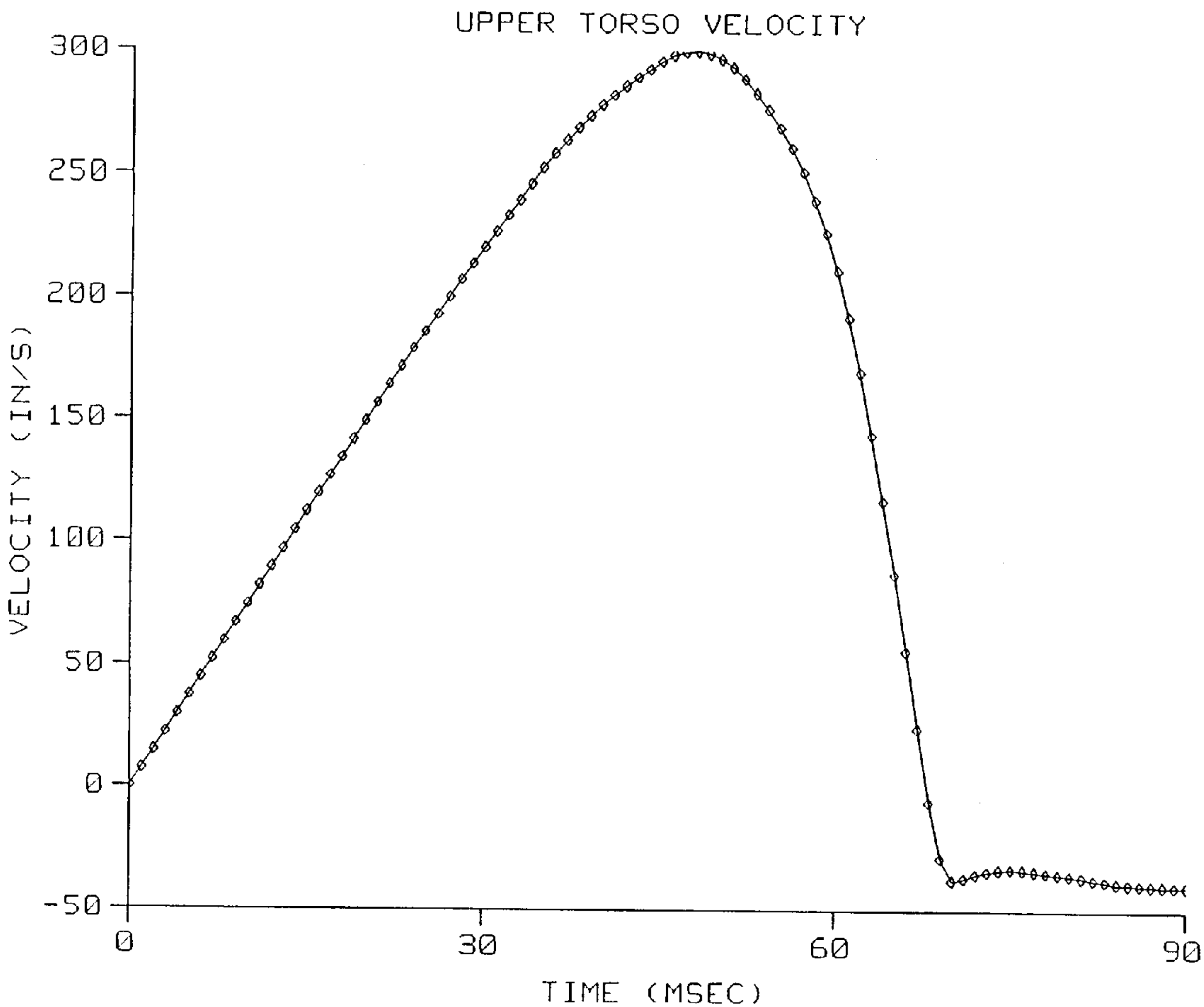

UPPER TORSO/DASH CONTACT
2500
2000
1500
1000
500
0
FORCE (LB.)
0
30
60
90
TIME (MSEC)

Figure 6.7



UPPER TORSO VELOCITY
300
250
200
150
100
50
0
-50
VELOCITY (IN/S)
0
30
60
90
TIME (MSEC)

Figure 6.8

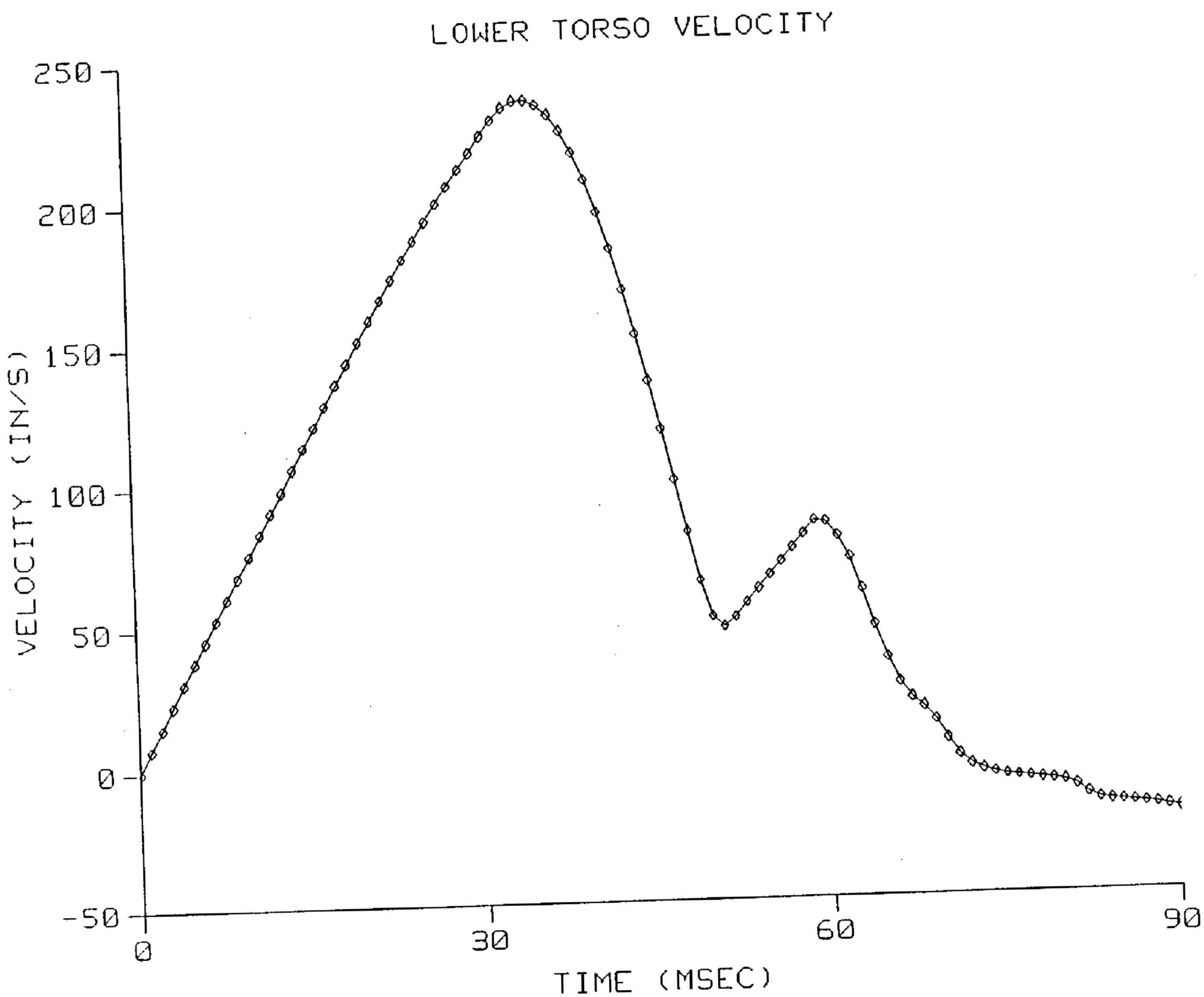

LOWER TORSO VELOCITY
250
200
150
100
50
0
-50
VELOCITY (IN/S)
0
30
60
90
TIME (MSEC)

Figure 6.9

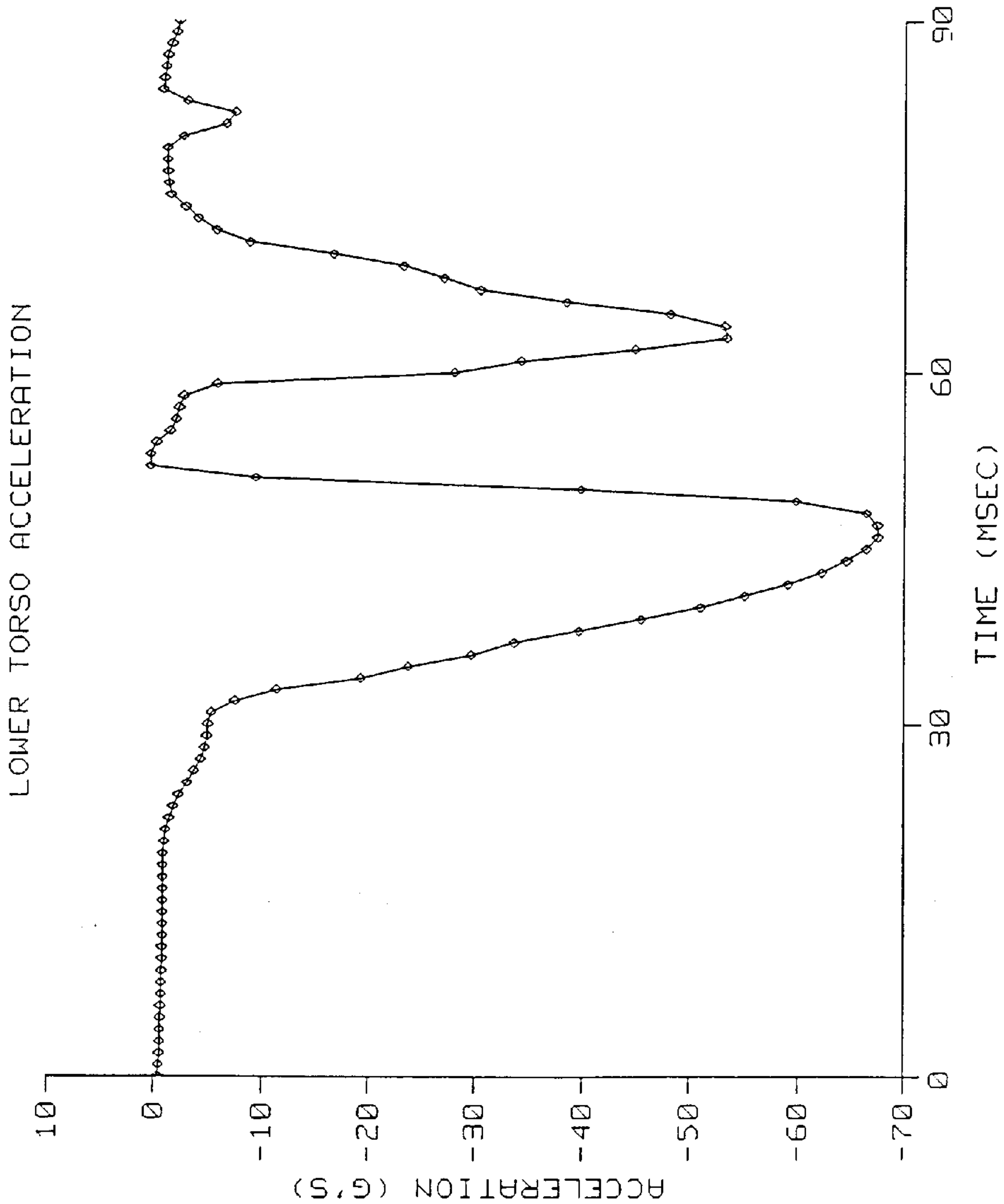
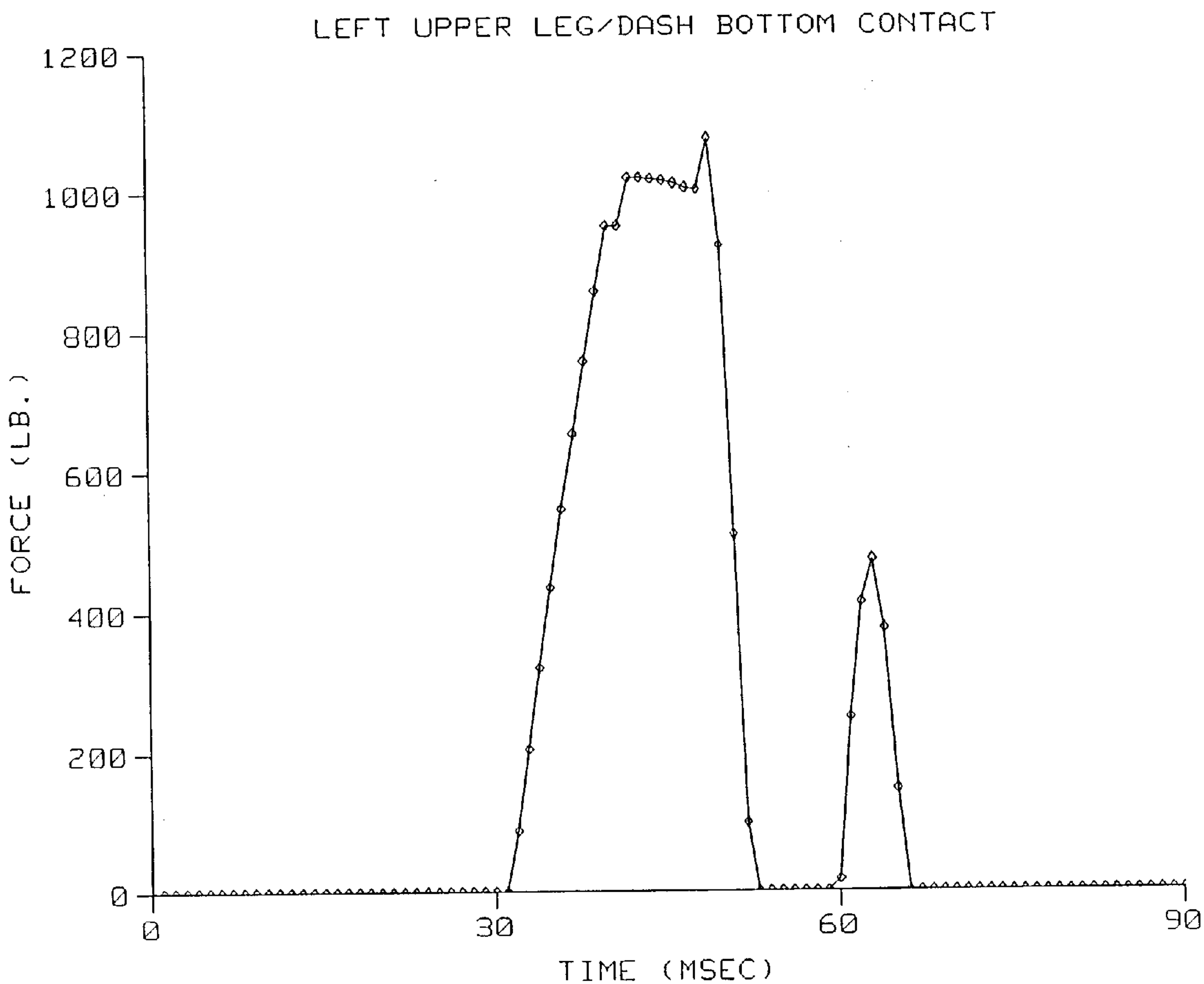

LOWER TORSO ACCELERATION
ACCELERATION (G'S)
10
0
-10
-20
-30
-40
-50
-60
-70
0
30
60
90
TIME (MSEC)

Figure 6.10



LEFT UPPER LEG/DASH BOTTOM CONTACT
1200
1000
800
600
400
200
0
FORCE (LB.)
0
30
60
90
TIME (MSEC)

Figure 6.11

6.3 Criteria Equation

An important part of the proposed program was the development of an algorithm to evaluate competing passive restraint designs. The resulting algorithm takes the form of a statistically-based, weighted effectiveness equation or performance index. By summing all of the pertinent factors of restraint system effectiveness multiplied by appropriate weighting factors, a rational optimization of design trade-offs is possible. Without quantitative criteria, decisions regarding design improvements would be based on intuition and opinion. Accident Injury Severity (AIS) values, direction and velocity of impact, injury potential, engineering and manufacturing feasibility, reliability, innovation, cost, user acceptance, economy of reuse, and other factors have been considered as potential criteria for design evaluation. The following linear algebraic equation was developed:

$$\mathrm{SCORE} = (\mathrm{REL1} * \mathrm{W1}) + (\mathrm{REL2} * \mathrm{W2}) + (\mathrm{COST} * \mathrm{W3}) + (\mathrm{CA} * \mathrm{W4}) + (\mathrm{P} * \mathrm{W5})$$

where W1, W2, W3, W4, W5 are the weightings and

$$\mathrm{W1}+\mathrm{W2}+\mathrm{W3}+\mathrm{W4}+\mathrm{W5}=1.$$

The REL1 score accounts for the injury potential and repair cost in case of inadvertent deployment. The REL2 score assesses the likelihood of nonideal behavior (airbag fails to deploy, belt's don't work, etc.). The COST score evaluates the installation cost and maintenance cost for five years. The CA (Consumer Acceptance) score assesses the consumers' opinions of the design. The P (Performance) score assesses the effectiveness of an ideal (reliable) restraint system.

The range of final scores is from 1-5, where 5 is a perfect score. The weightings are given below:

W1=0.15
W2=0.15
W3=0.60
W4=0.05
W5=0.05

Performance was weighted as the most important criteria. COST was weighted low because the cost of a mass-produced system will decrease. CA was weighted low because consumers can be educated as to the benefits of a certain system. REL1 and REL2 were weighted moderately.

Scores for REL1, REL2, and COST have been estimated from the results of the literature searches. The CA score was estimated from the results of the literature searches and the survey conducted by the Cost/Consumer Acceptance team. The restraint system performance P, which was calculated by the Statistics/Criteria Equation team on the basis of the results of the UMTRI accident data bank searches (see Table 6.1 and Appendix C.1), was defined by the following equation:

$$P = X_r * \text{REAR} + X_s * \text{SIDE} + X_f * \text{FRONT}$$

where

REAR = (% accidents with rear impact)/100

SIDE = (% accidents with side impact)/100

FRONT = (% accidents with front impact)/100

X_r = X in rear impact accident

X_s = X in side impact accident

X_f = X in front impact accident

and

$$X = D_d * E_d + D_p * E_p$$

D_d = % occupants drivers

D_p = % occupants passengers

E_d = injury severity to driver

E_p = injury severity to passenger

The accident injury severity was defined in terms of the percentage of minor, severe, and critical injuries using the following equation:

$$E = (1)(\%\text{ minor injury}) + (33)(\%\text{ severe injury}) + (66)(\%\text{ critical injury})$$

The criteria equation presented above resulted in the following scores:

System	Score
No Belt	2.4
3pt Belt	3.9
Air Bag	2.53
Deployable Crash Pad	4.1

REL1 Score:0-5

Inadvertent deployment Injury Potential (%)	Score
0	2.5
1	2.0
2	1.5
3	1.0
4	0.5
5	0.0

Repair Cost ($)	Score
0 -24	2.5
25 - 49	2.0
50 - 74	1.5
75 - 99	1.0
100-124	0.5
125+	0.0

REL2 Score:0-5

Likelihood of Nonideal Behavior (%)	Score
0	5
0.1-1	4
1.1-2	3
2.1-3	2
3.1-4	1
4+	0

CA Score:0-5

Consumer Acceptance (%)	Score
80 - 100	5
60 - 79	4
40 - 59	3
20 - 39	2
0 - 19	1

COST Score:0-5

Installation Cost ($)	Score
0	5
1-100	4
101-200	3
201-300	2
301-400	1
400+	0

P Score:0-5

Performance	Score
0 - .9	5
1.0 - 1.9	4
2.0 - 2.9	3
3.0 - 3.9	2
4+	1

Table 6.1 : Relevant Data for the Calculation of the Performance P

SITE	TOTAL CASES	RELEVANT CASES NUMBER	RELEVANT CASES % TOTAL
Rear	6924	2756	39.8
Side	6924	1867	27.0
Front	6924	2301	33.2

OCCUPANT ROLE	TOTAL CASES	RELEVANT CASES NUMBER	RELEVANT CASES % TOTAL
D_d (Driver)	6924	5291	76.4
D_p (Passenger)	6924	1633	23.6

SPEED (MPH)	VARIABLE	RESTRAINT	SITE	# OF TOTAL CASES	MINOR INJURY # CASES	MINOR INJURY % TOTAL	SEVERE INJURY # CASES	SEVERE INJURY % TOTAL	CRITICAL INJURY # CASES	CRITICAL INJURY % TOTAL	X
28-32	E_d	No Belt	Rear	76	71	93	4	5.5	1	1.5	3.735
28-32	E_d	No Belt	Side	18	18	100	0	0	0	0	1.0
28-32	E_d	No Belt	Front	33	26	78.8	7	21.2	0	0	7.784
28-32	E_d	3pt Belt	Rear	21	21	100	0	0	0	0	1.0
28-32	E_d	3pt Belt	Side	3	3	100	0	0	0	0	1.0
28-32	E_d	3pt Belt	Front	4	4	100	0	0	0	0	1.0
28-32	E_d	Air Bag	Rear	0	0	0	0	0	0	0	0
28-32	E_d	Air Bag	Side	12	12	100	0	0	0	0	1.0
28-32	E_d	Air Bag	Front	4	3	75	1	25	0	0	9.0

RESTRAINT	P	SCORE
No Belt	4.34	1
3pt Belt	1.0	4
Air Bag	3.25	2

DATA

Variable	No Belt	3pt Belt	Air Bag	Crash Pad
COST	$0 (5)	$88 (1)	$380 (1)	$380 (3)
REL1	0% (5) $0 (5)	0% (5) $0 (5)	.01% (3) $75 (1)	0% (3) $0 (3)
REL2	0% (5)	1.8% (2)	.5% (1)	.001% (3)
CA	4% (4)	100% (4)	50% (4)	42% (4)
P	4.34 (2)	1 (2)	3.25 (2)	1.9 (3)

SCORE

Variable	No Belt	3pt Belt	Air Bag	Crash Pad
COST	5	4	1	1
REL1	5	5	3.5	5
REL2	5	2	4	5
CA	1	5	3	3
P	1	4	2	4

(1) Warner, "Bags, Buckles and Belts," Journal of Health, Politics, Policy and Law. Volume 8, 1983/84.

(2) HSRI studies

(3) Dr McElhaney's estimations

(4) CA survey

(5) our estimation

The current three-point belts and the deployable crash pad scored highest. The three-point belts provide somewhat better overall performance and cost less but are not passive.

7. Alternate Designs

After the divergent brainstorming phase of the program and before the selection of the final design, the class split into five separate design groups (see Table 7.1). Each design group's basic concepts and ideas are presented below.

The first group worked on the idea of a deployable padded and contoured dash which extends up and out to meet the occupant at the knees and torso. The head is cushioned by the dash top and prevented from windshield contact. Dash deployment is activated by the crush of the car. This concept has several virtues. First, it is more appealing to the consumer than a conventional deployable system because it could not be inadvertently activated. Second, the steering system could either recede or be built into the system using its own energy-absorbing characteristics. Third, it provides cushioning in collisions other than direct, head-on crashes. Fourth, it is a relatively simple concept that can realistically fit in with current aesthetic and mechanical design concepts. Supplemental concepts that may work with this system are side deployable cushions from the front or back or deployable cushions that react and rotate according to the direction of the crash.

The second group worked on the idea of a contoured, stiffer air bag. Using strings inside the bag, similar to the design used in emergency escape chutes in airplanes, the bag would be shaped to completely envelope the passenger over the head and around the sides. A second smaller air bag would be deployed from under the dashboard that would fill the leg space and prevent submarining. For additional protection in side impacts, a rectangular bag, four to five inches thick, would deploy from the door to provide a few more inches of stopping distance. On the driver's side, the steering column would be collapsible to provide additional cushioning. This system would provide protection in all directions while present air bag systems only protect for head-on collisions and occupants are susceptible to submarining. Also, this passive restraint system would increase stopping distance, provide uniform deceleration, and be easy to implement.

The third group developed two concepts, which could be used together. The first concept was a deployable air bag cushion that expands away from the occupant. This clear

7.1 Phase III Groups

Crushable Vehicle/Cushioning of Interior

Jon Maxwell
Diane Crean
Michael Selgelid

Passive Belts/Bars

David Edmiston
Brent Fonner
Maureen Shaffer
Tom Dellinger
Cameron Fowler

Deployable Cushions

John Bartels
Chris Buckley
Barry Fishburne
Ralph de la Torre
Phil Saunders

Pivoting Seat or Passenger Compartment

Peggy Jones
Jeff Feinstein
Roger Nightingale
Sue Dunham
Lisa Johnson
Bruce Winkelstein

Miscellaneous

Rob Nagle
Jeff Rott
Karen Basile
Jonas Goldstein
Ruby Grewal
Bobby Donovan
Jackie Chan
Ingo Kempfe

deployable cushion would come out of the roof about one foot away from the occupant and expand toward the windshield. The second concept was to replace the steering wheel with a joystick steering device. This system has three main advantages. First, the driver has better control of the car in the case of inadvertent deployment. Second, there is more distance in front of the driver for energy-absorbing devices. Third, the common problem of the air bag slapping the passenger in the face on deployment is eliminated.

The fourth group considered a motorized lap belt to be put in place upon closing the door and/or starting the car. This group also considered employing a radar sensor to anticipate a collision and tighten the lap belt and/or shoulder belts. The tightening could be dependent on several factors such as the severity and certainty of the impending collision. The radar sensor could be used with any of the ideas of the other design groups to increase the reactivity of the passive restraint system.

The fifth group came up with the concept of moving the seat away from the impact. The main advantage of the moving seat is an increase in the stopping distance of the occupant resulting in an increase in the allowable crush of the vehicle. The seat on the impact side of the car is moved toward the opposite side of the car by a cable and pulley system. This system will need additional support and cushioning to protect the occupants. Some ideas are:

1) Deploy "cushions" between seats and side windows to prevent head injury and ejection
2) Deploy "cushion" between occupants to prevent occupant-occupant interaction
3) Keep occupant in seat with padded bars or air bags.

The primary advantage of this system is that it can withstand collisions from any angle. However, preliminary analysis indicates that the dynamics of the system could be dangerous to the occupants.

These five groups came up with a total of seven designs. The air bag group developed two separate designs; one was a single contoured air bag and the other was a dual air bag system. The fourth group also developed two separate designs; the first was a passive belt system and the second was a radar sensor which could be used in conjunction with any of the designs. Detailed descriptions and drawings of these designs and the passive belt concept developed by the ME/EE team are presented in Appendix D.

8. Phase II

Phase I involved the development of an innovative and, hopefully, useful concept in passive restraints to improve automotive crashworthiness. The analysis and simulations indicate that the "Deployable Crash Pad," as proposed here, has the potential to offer a higher level of occupant protection with better reliability than air bags.

8.1 Design Refinements

8.1.1 Crash Pad Contour

The analysis and simulation of the Phase I study demonstrates that the required deployed crash pad shape can be accommodated in a conventional dash configuration. The crash victim simulator model predicts good performance for the highly idealized deployed contours used in the analysis. A major effort of the Phase II study would involve full-scale sled testing using the various available sizes of anthropomorphic crash test devices to establish the deformation characteristics, contours, and deployment timing required to optimize occupant protection. The initial sled tests would be performed with fixed crash pads in the deployed configuration. Once the proper deployed configuration is established, the design requirements of the deployment mechanism would be specified and a complete system developed.

8.1.2 Deployment System

Due to the severe limitations of time and resources available for this project, many design refinements are required before the Deployable Crash Pad concept can become a reality. A careful comparison of the performance, cost, and reliability of the hydraulic vs. the cable system should be made. We believe the crash-activated deployment mechanism can be adequately designed using standard mechanical engineering technology. The new Audi Procon Ten system supports this contention. However, the details need to be developed. This effort would be one component of the Phase II activity.

8.2 Future Research and Development

To fully realize the protective potential of the Deployable Crash Pad requires the optimal use of the available crush space and stopping distance. Successful completion of Phase II would provide a fully functioning prototype. Additional research and development would be required to refine the force-limiting mechanisms, to simplify the deployment system, to optimize the crash pad contour and deployment timing, and to meet the various requirements of style and personalized interior.

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APPENDIX A

A.1 Student Involvement

A.1.1 BME 230.01 Students, Spring Semester 1987

Name	Class	Major
Bartels, John Brian	E4	BME/EE
Basile, Karen Elizabeth	E4	BME
Buckley, Christine Ann	E3	BME
Caldwell, Christopher Duncan	E3	BME/EE
Chan, Jackie	E4	BME/EE
Conner, Elizabeth Drummond (Lisa)	E3	BME
Crean, Diane Theresa	E4	BME
De La Torre, Ralph	E4	BME
Dellinger, Thomas William (Tom)	E4	EE
Donovan, Robert James, II.	E4	BME
Dunham, Susan Lynn	E4	BME
Edmiston, David Neil	E4	BME/EE
Feinstein, Jeffrey Allan	G	BME
Fishburne, Barron Crawford (Barry)	E4	BME/EE
Fowler, Cameron Harold	E4	ME
Goldstein, Jonas Henry	E4	BME/EE
Grewal, Ravinder K. (Ruby)	E4	BME/EE
Johnson, Lisa Diane	E4	ME
Jones, Margaret Ann (Peggy)	E3	EE
Kempfe, Robert Ingo (Ingo)	E3	BME
Maxwell, Jonathan Beckett (Jon)	E4	ME
Nagle, Robert Russell (Rob)	E4	BME/EE
Naughton, George Patrick	E4	BME
Nightingale, Roger William	E4	BME
Rott, Jeffrey Keith (Jeff)	E4	BME
Saunders, Phillip Lee (Phil)	E4	BME
Selgelid, Michael John	E3	BME
Shaffer, Maureen Ann	E4	BME
Winkelstein, Bruce Andrew	E4	BME/EE

A.1.2 BME Independent Study Students, Spring Semester 1987

Name	Class	Major
Mensh, Brett	E4	BME

A.1.3 ME/EE Passive Restraint Design Team, Spring Semester 1987

Name	Class	Major
Choby, Tara	E4	ME
Cullon, Steve	E4	ME
DeSantis, Doug	E4	EE
Jacobs, Tom	E4	ME
Lyn, Kevin	E4	ME
McCrea, Jeff	E4	EE
Schoder, Reuben	E4	EE

A.1.4 Independent Study Students, 1986

Name	Class	Major
Doherty, Brian	G	BME
Fonner, Brent	E4	ME
Jacobs, Tom	E4	ME
Mensh, Brett	E4	BME

A.2 Computer Modeling and Statistics/Criteria Equation Teams

Computer Modeling

Roger Nightingale
Barry Fishburne
Jeff Feinstein

Statistics/Criteria Equation

Bruce Winkelstein
Ruby Grewal
Christine Buckley
Brent Fonner
Karen Basile
Peggy Jones

A.3 Phase I Teams

Design Group

Michael Selgelid
Susan Dunham
Tom Dellinger
Jonas Goldstein
Rob Nagle
George Naughton
Christopher Caldwell
Jeff Rott
Cameron Fowler
Diane Crean
Lisa Conner
Jon Maxwell
Lisa Johnson
Jackie Chan

NTIS/TRIS Search

Bobby Donovan

AAMRL Data Base 56/57

Ralph de la Torre
David Edmiston
Maureen Shaffer

A.4 Phase IV Teams

Group	Personnel
User Acceptance & Cost..............	B. Fonner B. Winklestein B. Donovan J. Chan
Statistics & Criteria Equation........	R. Grewal K. Basile P. Jones C. Buckley
AIS vs. Speed........................	G. Naughton P. Jones C. Buckley
Computer............................	J. Feinstein B. Fishburne R. Nightingale J. Bartels
Movie...............................	C. Caldwell J. Field I. Kempfe T. Dellinger
CADKEY...........................	Tom Jacobs Tara Choby
Audi design	R. De la Torre
Deceleration pulses of vehicles	D. Crean
Crush characteristics of vehicles	L. Conner
Dash shape/contour	J. Maxwell
Dash deployment mechanism	C. Fowler
Dash force-limiting mechanism	M. Selgelid
Dash deployment timing	S. Dunham
Torso deceleration injury criteria	D. Edmiston
Head/neck injury criteria	M. Shaffer
Occupant space design/anthropometry	L. Johnson
Report..............................	J. Goldstein R. Nagle

APPENDIX B

B.1 Brainstorming Ideas

1. Cushions or padding (windshield)
2. Belts (passive lap belts, passive torso belts, wider belts)
3. Deployable bag (in different directions)
4. Energy-absorbing steering column
5. Using crush of vehicle to activate belts
6. Using crush of vehicle to activate cushion (from dash)
7. Using crush of vehicle to swing seat 90°
8. Using crush of vehicle or crash force to reposition occupant
9. Water bags or other to impose deceleration characteristics
10. Energy-absorbing belts
11. Deployable padded bars or harness
12. Joystick steering
13. Contoured seat with movable anchors
14. Relocate anchor point for intrusion
15. Deployable net or bag surrounding occupant
16. Movable passenger compartment
17. Padded roll cage
18. Ejection of passenger compartment
19. Magnetic or electrical repulsion
20. Mechanical control of vehicle to override driver with slow reactions
21. Smaller deployable cushions to fill compartment
22. Expandable doors and other parts cushion occupant (crash activated)
23. Softer cars, larger cars
24. Breakaway sections (drive train, back wheels rotate to allow vehicle to roll instead of slide)
25. Side bumpers, bumpers all around
26. Increase crush by diverting deformation
27. Safety compartment trap door
28. Grabbing robotic seat
29. Extending column
30. Clear cushion drops in front
31. Electromagnet belt tensioner

32. More crush in front (corrogated box all around)
33. Radar sensor to extend crush zone, tighten belt
34. Add energy absorption to top belt
35. Bumper car (360° wheels)
36. Side bags to partition occupants
37. Seat belt on tracks
38. Roof bag or cushion
39. Deploy anchor or parachute
40. Rotating seat (various axes)
41. Velcro seats (attachments)
42. Padded foots stirrups
43. Hinged in center to increase crush distance in side impact
44. Deploy cushion from sides
45. Deployable crush
46. Move seat backward (reduce ΔV)

B.2 Patent Search Results

B.2.1 Patent Survey

Car	Class	Sub-Class	Comment
Air Bag Passive Resistance	280	728	
Collision Avoidance	367	909	Highway Systems
Headrest	D6	501	Armrests, Chairs
Inflatable Passive Resistance	280	728	
Safety Belt or Harness	280	801	
Passive	280	802	
System Responsive	180	268	Seat Belts
With Seat Structure	297	468	
Safety Promoting Means	180	271	
Safety Guard	280	748	

Automobile			
Safety Belt or Harness	297	464	
Air Cushion	180	116	Hovercrafts
Cushion Design	D12	5	Hydrofoils

B.2.2 Patent List

Class 280/Subclass 728

2,781,203	A typical setup for an airbag system
3,853,334	A typical release mode for airbag systems
4,198,075	A bag that reduces impact via the knees
4,359,200	If we were working for NASA...
4,477,732	An interesting acceleration detector

Class 280/Subclass 802

3,713,694	An elaborate containing system – purely passive
3,743,046	Elaborate straps – remarkably, passive
3,764,159	Chest pad
3,781,061	A setup of a weight-activated strap system – passive
3,795,411	Elaborate passive hook-up system
3,907,059	One more strap system – passive
3,931,988	Energy-absorber, through knees

Class 180/Subclass 271

3,162,479	Cabin-detachment system
3,441,103	Pad that's "shot" to passenger
3,782,492	Chest pad
3,831,998	Another cabin-detachment system
3,879,073	Engine slide system
3,998,291	The seat rotates to absorb energy.

Class 280/Subclass 748

3,309,109	"Spheres" fall into cabin upon impact
3,081,127	Windshield on a hinge
2,943,866	Leg lifter redistributes forces
3,732,944	Vacuum retains passenger to seat
4,089,545	Seat rotates to "embrace" passenger between seat and dash
4,154,472	Seat adjusts to redistribute forces

B.3 Summaries of AAMRL Database 57 Tests

1. "Evaluation of a Proposed Modified F/FB-111 Crew Seat and Restraint System" shows that modifications to a restraint system (i.e., harness belt system) can be injurious if the seat design is not taken into account.

2. "Comparative Vertical Impact Testing of F/FB-111 Crew Restraint System and a Proposed Modification (Negative Shoulder Harness Angle Study)" finds that belt restraints are subject specific and that head accelerations increase with increased vertical adjustment of the seat.

3. "Vertical Impact Tests of a Modified F/FB-111 Crew Seat to Evaluate Headrest Position and Restraint Configuration Effects" evaluates the effects of changes in headrest position, upper body bracing, and restraint harness configuration on human response.

4. "Sublethal Injury Patterns in the Baboon Restrained with a Three-Point Harness (-Gx Impact)" tests a standard three-point belt system. Results show that most injuries occur because of belts and that the most severe and frequent injuries occur to the abdominal contents, shoulder, and extremities. Also, lap belt placement must be controllable and energy-absorbing harnesses produce lower peak loads than elastic ones.

5. "Human Dynamic Responses to Varying Rise-Time and Varying G Level During -Gx Acceleration" measures and analyzes dynamic response properties of human body and body segments.

6. "Evaluation of the Human Dynamic Response to Varying Rise-Time Regimen During -Gx Impact Acceleration" measures and analyzes human response to -Gx impact pulses with varying acceleration.

7. "Human Dynamic Response to Varying Rise-Time and Varying G Level During +Gx Acceleration" hypothesizes that the magnitude of human dynamic responses decreases when rise times are below 30 msec.

8. "Effects of a Negative G Strap on Restraint Dynamics and Human Impact Response" assesses the influence of a negative G strap on torso submarining and impact response. The findings are a decreased tendency towards submarining in -Gx impacts and improved +Gx impact protection.

9. "Lateral (-Gy) Impact Tests with Inflatable Restraint Systems for Air Force Crew Escape Module Applications" demonstrates the feasibility of using an inflatable restraint system.

10. "Child Restraint Systems Evaluation Using Baboons and Child-Sized Dummies" evaluates the relative performance characteristics in child restraint systems of two proposed child manikins as compared with those of juvenile baboons.

11. "Effect of Webbing Material on Aircraft Personnel Restraint Systems Impact Devices" determines the influence of the mechanical properties of restraint systems during impact and provides biodynamic data for restraint design and computer modelling.

12. "Effect of Tie-Down geometry and Strap Angle on Aircraft Personnel Restraint Systems Impact Devices" provides information on biodynamic data for restraint design and computer modelling.

13. "Evaluation of the Influence of Upper Extremity Bracing Techniques on Human Response During Vertical Impact" evaluates the effectiveness of various upper extremity bracing techniques.

14. "Impact Tests of Adjusters for the HBU-12 Lap Belt" demonstrates the adequacy of Koch Webbing Adjusters under high energy impact conditions and evaluates USAF use of automotive crash test manikins.

15. "Impact Tests of HBU-X Automatic Lap Belt Prototypes" evaluates three preproduction HBU-X automatic lap belts of different designs by testing at 32, 38, and 40 Gs in -Gx impact. Lap belt and/or adjuster (belt slippage) failures were also studied.

16. "Impact Tests of Automatic Lap Belt Configuration" evaluates the HBU-X lap belt prototypes with alternative adjusters and evaluates the influence of webbing materials on lap belt structural adequacy and adjuster performance.

APPENDIX C - DESIGN EVALUATION RESULTS

C.1 Computer Simulation Results

```
4/14/87        IRSIN=    0  IRSOUT=    0  RSTIME =  0.0000
                                                                                                        CARDS A
1981 DODGE ARIES NO BELT FRONTAL COLLISION--DUKE DEPLOYED DASH
20G'S CONSTANT DECELERATION; 30MPH

   UNITL =  IN.      UNITM =  LB.      UNITT = SEC.      GRAVITY VECTOR = (    0.0000,    0.0000, 386.0880)     G = 386.0880

   NDINT =    8      NSTEPS =   80     DT =0.001000      H0 =0.000250     HMAX =0.001000     HMIN =0.000008

 NPRT ARRAY
   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
   0  0  5  1  0  0  0  0  0  0  0  0  0  0  0  0  0  5  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1
 POSTPROCESSOR CONTROL PARAMETERS                                                                      PAGE     0

        HIC & HSI POINT       CSI POINT
  H.11         3                  1


 HEAD INJURY CRITERION

 HIC =  1421.02         TIME DURATION =     58.500   TO     72.500 MSEC
                  WITH HEAD RESULTANTS =     58.632 AND     65.576 G'S

          AVERAGE HEAD RESULTANT FOR TIME DURATION =   100.598 G'S


 CHEST SEVERITY INDEX

 CSI =   504.46

 MAX CHEST RESULTANT =    68.867 G'S AT    47.000 MSEC
```

AAMRL ARTICULATED TOTAL BODY (ATB) MODEL

DEVELOPED BY CALSPAN CORP., P.O. BOX 400, BUFFALO NY 14225
AND BY J&J TECHNOLOGIES INC., ORCHARD PARK NY 14127

FOR THE AIR FORCE ARMSTRONG AEROSPACE MEDICAL RESEARCH
LABORATORY, AFSC AERONAUTICAL SYSTEMS DIVISION, WPAFB
UNDER CONTRACTS F33615-75C-5002,-78C-0516 AND -80C-05117

AND FOR THE NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION,
U.S. DEPARTMENT OF TRANSPORTATION, UNDER CONTRACTS
FH-11-7592, HS-053-2-485, HS-6-01300 AND HS-6-01410.

PROGRAM DOCUMENTATION: NHTSA REPORT NOS. DOT-HS-801-507
THROUGH 510 (FORMERLY CALSPAN REPORT NO. ZQ-5180-L-1),
AVAILABLE FROM NTIS (ACCESSION NOS. PB-241692,3,4 AND 5),
APPENDIXES A-J TO THE ABOVE (AVAILABLE FROM CALSPAN),
AND REPORT NOS. AMRL-TR-75-14, AFAMRL-TR-80-14, AND
AFAMRL-TR-83-073.

PROGRAM ATBIV, EXECUTED ON THE AAMRL/BB PERKIN-
ELMER 3250 COMPUTER,WRIGHT-PATTERSON AFB, OHIO

```
  4/14/87       IRSIN=    0  IRSOUT=    0  RSTIME =  0.0000                                                CARDS A

1981 DODGE ARIES NO BELT FRONTAL 20G'S ACC--DEPLOYED DUKE DASH
MCELHANEY F(DELTA) W/ D4=0 - new dash size - new 35,36 contacts

   UNITL =  IN.     UNITM =  LB.     UNITT = SEC.     GRAVITY VECTOR = (    0.0000,    0.0000, 386.0880)     G = 386.0880

   NDINT =    8     NSTEPS =    90     DT =0.001000     H0 =0.000250     HMAX =0.001000     HMIN =0.000008

 NPRT ARRAY
   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
   0  0 20  0  0  0  0  0  0  0  0  0  0  0  0  0  0  5  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1
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CRASH VICTIM PART 572 DUMMY 16 SEGMENTS 15 JOINTS

CARD B.1
CARDS B.2

SEGMENT I	SYM	PLOT	WEIGHT (LB.)	PRINCIPAL MOMENTS OF INERTIA (LB.-SEC.**2- IN.) X	Y	Z	SEGMENT CONTACT ELLIPSOID SEMIAXES (IN.) X	Y	Z	CENTER (IN.) X	Y	Z	PRINCIPAL AXES (DEG) YAW	PITCH	ROLL
1	LTOR	5	29.040	1.9859	1.3852	1.4802	4.900	6.940	6.000	0.000	0.000	-0.270	0.00	23.85	0.00
2	MTOR	4	3.000	0.0213	0.0213	0.0087	4.100	5.250	4.400	2.150	0.000	0.300	0.00	0.00	0.00
3	UTOR	3	37.870	2.0799	1.5915	1.3362	4.660	6.780	9.000	0.800	0.000	2.200	0.00	0.00	0.00
4	NECK	2	1.820	0.0118	0.0118	0.0050	2.700	2.280	4.000	-0.100	0.000	1.650	0.00	0.00	0.00
5	HEAD	1	9.670	0.2197	0.2562	0.1638	4.000	3.100	5.000	0.500	0.000	0.400	0.00	42.21	0.00
6	RULG	6	20.990	0.7723	0.7721	0.1164	3.300	3.500	11.400	0.150	0.000	-2.200	0.00	0.00	0.00
7	RLLG	7	7.000	0.5948	0.5907	0.0322	2.360	2.230	9.450	0.000	0.000	0.000	0.00	-3.74	0.00
8	RFT	8	2.760	0.0383	0.0434	0.0132	1.520	1.600	5.220	0.000	0.000	0.950	0.00	0.00	0.00
9	LULG	9	20.990	0.7723	0.7721	0.1164	3.300	3.500	11.400	0.150	0.000	-2.200	0.00	0.00	0.00
10	LLLG	0	7.000	0.5948	0.5907	0.0322	2.360	2.230	9.450	0.000	0.000	0.000	0.00	-3.74	0.00
11	LFT	1	2.760	0.0383	0.0434	0.0132	1.520	1.600	5.220	0.000	0.000	0.950	0.00	0.00	0.00
12	RUAM	2	4.760	0.1378	0.1426	0.0125	2.070	1.640	6.880	0.000	0.000	0.000	0.00	0.00	-11.52
13	RLAM	3	4.610	0.2696	0.2614	0.0125	1.300	1.110	8.380	0.000	0.000	0.000	0.00	0.00	0.00
14	LUAM	4	4.760	0.1378	0.1426	0.0125	2.070	1.640	6.880	0.000	0.000	0.000	0.00	0.00	11.52
15	LLAM	5	4.610	0.2696	0.2614	0.0125	1.300	1.110	8.380	0.000	0.000	0.000	0.00	0.00	0.00
16	CAR	C	0.500	0.1000	0.1000	0.1000	0.500	0.500	0.500	0.000	0.000	0.000	0.00	0.00	0.00

CARDS B.3

JOINT J	SYM	PLOT	JNT	PIN	LOCATION(IN.) - SEG(JNT) X	Y	Z	LOCATION(IN.) - SEG(J+1) X	Y	Z	PRIN. AXIS(DEG) - SEG(JNT) YAW	PITCH	ROLL	PRIN. AXIS(DEG) - SEG(J+1) YAW	PITCH	ROLL
1	LTMT	P	1	-2	-1.790	0.000	-2.140	0.000	0.000	2.075	0.00	0.00	0.00	0.00	0.00	0.00
2	MTUT	O	2	-2	0.000	0.000	-2.325	-1.131	0.000	6.559	0.00	0.00	0.00	0.00	0.00	0.00
3	UTNK	N	3	-2	1.575	0.000	-6.576	0.000	0.000	2.185	0.00	-20.00	0.00	0.00	0.00	0.00
4	NKHD	M	4	-2	0.000	0.000	-2.185	-0.370	0.000	1.390	0.00	0.00	0.00	0.00	0.00	0.00
5	RHIP	Q	1	-4	-0.130	3.500	1.700	1.300	0.000	-9.000	90.00	90.00	0.00	0.00	4.76	0.00
6	RKNE	R	6	1	-0.043	-0.100	6.740	-0.097	0.000	-7.365	0.00	0.00	0.00	0.00	43.00	0.00
7	RANK	S	7	-4	-0.097	0.000	8.835	1.600	0.130	-2.030	90.00	0.00	-0.60	90.00	0.00	0.00
8	LHIP	T	1	-4	-0.130	-3.500	1.700	1.300	0.000	-9.000	-90.00	90.00	0.00	0.00	4.76	0.00
9	LKNE	U	9	1	-0.043	0.100	6.740	-0.097	0.000	-7.365	0.00	0.00	0.00	0.00	43.00	0.00
10	LANK	V	10	-4	-0.097	0.000	8.835	1.600	-0.130	-2.030	90.00	0.00	-0.60	90.00	0.00	0.00
11	RSLD	W	3	-4	-0.161	7.400	-3.580	0.047	-0.030	-4.690	0.00	0.00	-90.00	0.00	0.00	0.00
12	RELB	X	12	-4	0.047	-0.030	5.610	-0.120	0.025	-6.340	90.00	0.00	0.00	90.00	0.00	0.00
13	LSLD	Y	3	-4	-0.161	-7.400	-3.580	0.047	0.030	-4.690	0.00	0.00	90.00	0.00	0.00	0.00
14	LELB	Z	14	-4	0.047	0.030	5.610	-0.120	-0.025	-6.340	90.00	0.00	0.00	90.00	0.00	0.00
15	CAR	C	17	-1	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00

CARDS B.4

JOINT	FLEXURAL SPRING CHARACTERISTICS: SPRING COEF. (IN. LB./DEG**J) LINEAR (J=1)	QUADRATIC (J=2)	CUBIC (J=3)	ENERGY DISSIPATION COEF.	JOINT STOP (DEG)	TORSIONAL SPRING CHARACTERISTICS: SPRING COEF. (IN. LB./DEG**J) LINEAR (J=1)	QUADRATIC (J=2)	CUBIC (J=3)	ENERGY DISSIPATION COEF.	JOINT STOP (DEG)
1 LTMT	50.000	0.000	0.000	0.000	90.000	34.383	0.000	0.000	0.000	170.000
2 MTUT	50.000	0.000	0.000	0.000	90.000	34.383	0.000	0.000	0.000	170.000
3 UTNK	31.200	0.000	0.000	0.000	90.000	15.000	0.000	0.000	0.000	170.000
4 NKHD	31.200	0.000	0.000	0.000	90.000	15.000	0.000	0.000	0.000	170.000
5 RHIP	7.500	75.000	75.000	0.000	77.000	7.500	75.000	75.000	0.000	35.000
	16.000	160.000	160.000	0.000	60.000					
6 RKNE	0.000	10.000	0.000	0.000	53.000	0.000	0.000	0.000	0.000	0.000
7 RANK	1.000	10.000	10.000	0.000	26.000	1.000	10.000	10.000	0.000	42.000
	0.000	0.000	0.000	0.000	0.000					
8 LHIP	7.500	75.000	75.000	0.000	77.000	7.500	75.000	75.000	0.000	35.000
	16.000	160.000	160.000	0.000	60.000					
9 LKNE	0.000	10.000	0.000	0.000	53.000	0.000	0.000	0.000	0.000	0.000
10 LANK	1.000	10.000	10.000	0.000	26.000	1.000	10.000	10.000	0.000	42.000
	0.000	0.000	0.000	0.000	0.000					
11 RSLD	0.000	100.000	100.000	0.000	125.000	0.000	100.000	100.000	0.000	60.000
	0.000	0.000	0.000	0.000	0.000					
12 RELB	0.000	20.000	20.000	0.000	52.000	5.000	50.000	50.000	0.000	70.000
	0.000	0.000	0.000	0.000	0.000					
13 LSLD	0.000	100.000	100.000	0.000	125.000	0.000	100.000	100.000	0.000	60.000
	0.000	0.000	0.000	0.000	0.000					
14 LELB	0.000	20.000	20.000	0.000	52.000	5.000	50.000	50.000	0.000	70.000
	0.000	0.000	0.000	0.000	0.000					
15 CAR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

CARDS B.5

JOINT VISCOUS CHARACTERISTICS AND LOCK-UNLOCK CONDITIONS

JOINT	VISCOUS COEFFICIENT (IN. LB.SEC./DEG)	COULOMB FRICTION COEF. (IN. LB.)	FULL FRICTION ANGULAR VELOCITY (DEG/SEC.)	MAX TORQUE FOR A LOCKED JOINT (IN. LB.)	MIN TORQUE FOR UNLOCKED JOINT (IN. LB.)	MIN. ANG. VELOCITY FOR UNLOCKED JOINT (RAD/SEC.)	IMPULSE RESTITUTION COEFFICIENT
1 LTMT	1.200	122.40	30.00	500.00	0.00	0.00	0.000
2 MTUT	1.200	122.40	30.00	300.00	0.00	0.00	0.000
3 UTNK	0.150	100.00	30.00	15.00	0.00	0.00	0.000
4 NKHD	0.150	100.00	30.00	10.00	0.00	0.00	0.000
5 RHIP	1.000	100.00	30.00	150.00	0.00	0.00	0.000
	1.000	200.00	30.00	300.00	0.00	0.00	0.000
	1.000	100.00	30.00	150.00	0.00	0.00	0.000
6 RKNE	1.000	20.00	30.00	30.00	0.00	0.00	0.000
7 RANK	0.500	20.00	30.00	30.00	0.00	0.00	0.000
	0.500	20.00	30.00	30.00	0.00	0.00	0.000
	0.000	0.00	30.00	0.00	0.00	0.00	0.000
8 LHIP	1.000	100.00	30.00	150.00	0.00	0.00	0.000
	1.000	200.00	30.00	300.00	0.00	0.00	0.000
	1.000	100.00	30.00	150.00	0.00	0.00	0.000
9 LKNE	1.000	20.00	30.00	30.00	0.00	0.00	0.000
10 LANK	0.500	20.00	30.00	30.00	0.00	0.00	0.000
	0.500	20.00	30.00	30.00	0.00	0.00	0.000
	0.000	0.00	30.00	0.00	0.00	0.00	0.000
11 RSLD	0.100	50.00	30.00	100.00	0.00	0.00	0.000

	0.100	50.00	30.00	100.00	0.00	0.00	0.000
	0.000	0.00	30.00	0.00	0.00	0.00	0.000
12 RELB	0.100	20.00	30.00	30.00	0.00	0.00	0.000
	0.100	20.00	30.00	30.00	0.00	0.00	0.000
	0.000	0.00	30.00	0.00	0.00	0.00	0.000
13 LSLD	0.100	50.00	30.00	100.00	0.00	0.00	0.000
	0.100	50.00	30.00	100.00	0.00	0.00	0.000
	0.000	0.00	30.00	0.00	0.00	0.00	0.000
14 LELB	0.100	20.00	30.00	30.00	0.00	0.00	0.000
	0.100	20.00	30.00	30.00	0.00	0.00	0.000
	0.000	0.00	30.00	0.00	0.00	0.00	0.000
15 CAR	0.000	0.00	0.00	0.00	0.00	0.00	0.000

SEGMENT INTEGRATION CONVERGENCE TEST INPUT

SEGMENT	ANGULAR VELOCITIES (RAD/SEC.)			LINEAR VELOCITIES (IN./SEC.)			ANGULAR ACCELERATIONS (RAD/SEC.**2)			LINEAR ACCELERATIONS (IN./SEC.**2)		
NO. SYM	MAG. TEST	ABS. ERROR	REL. ERROR	MAG. TEST	ABS. ERROR	REL. ERROR	MAG. TEST	ABS. ERROR	REL. ERROR	MAG. TEST	ABS. ERROR	REL. ERROR
1 LTOR	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.001	0.001	0.0010
2 MTOR	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
3 UTOR	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
4 NECK	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
5 HEAD	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
6 RULG	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
7 RLLG	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
8 RFT	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
9 LULG	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
10 LLLG	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
11 LFT	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
12 RUAM	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
13 RLAM	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
14 LUAM	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
15 LLAM	0.000	0.000	0.0000	0.000	0.000	0.0000	0.010	0.010	0.0010	0.000	0.000	0.0000
16 CAR	0.000	0.000	0.0000	0.000	0.000	0.0000	0.000	0.000	0.0000	0.000	0.000	0.0000

VEHICLE DECELERATION INPUTS

20 G'S CONSTANT DECELERATION

YAW	PITCH	ROLL	VIPS	VTIME	X0(X)	X0(Y)	X0(Z)	NATAB	AT0	ADT	MSEG
0.000	0.000	0.000	528.000	0.000	0.000	0.000	0.000	60	0.000000	0.002000	0

UNIDIRECTIONAL VEHICLE POSITION TABLES

TIME (MSEC)	ACC (G)	VELOCITY (IN./SEC.)	POSITION (IN.)	TIME (MSEC)	ACC (G)	VELOCITY (IN./SEC.)	POSITION (IN.)
0.00000	20.00	528.0000	0.00000	100.00000	0.00	-2.2275	17.98001
2.00000	20.00	512.5565	1.04056	102.00000	0.00	-2.2275	17.97556
4.00000	20.00	497.1130	2.05023	104.00000	0.00	-2.2275	17.97110
6.00000	20.00	481.6694	3.02901	106.00000	0.00	-2.2275	17.96665
8.00000	20.00	466.2259	3.97690	108.00000	0.00	-2.2275	17.96219
10.00000	20.00	450.7824	4.89391	110.00000	0.00	-2.2275	17.95774
12.00000	20.00	435.3389	5.78003	112.00000	0.00	-2.2275	17.95328
14.00000	20.00	419.8954	6.63527	114.00000	0.00	-2.2275	17.94882
16.00000	20.00	404.4518	7.45961	116.00000	0.00	-2.2275	17.94437
18.00000	20.00	389.0083	8.25307	118.00000	0.00	-2.2275	17.93991
20.00000	20.00	373.5648	9.01565	120.00000	0.00	-2.2275	17.93546
22.00000	20.00	358.1213	9.74733				
24.00000	20.00	342.6778	10.44813				
26.00000	20.00	327.2342	11.11805				
28.00000	20.00	311.7907	11.75707				
30.00000	20.00	296.3472	12.36521				
32.00000	20.00	280.9037	12.94246				
34.00000	20.00	265.4602	13.48882				
36.00000	20.00	250.0166	14.00430				
38.00000	20.00	234.5731	14.48889				
40.00000	20.00	219.1296	14.94259				
42.00000	20.00	203.6861	15.36541				
44.00000	20.00	188.2426	15.75734				
46.00000	20.00	172.7990	16.11838				
48.00000	20.00	157.3555	16.44853				
50.00000	20.00	141.9120	16.74780				
52.00000	20.00	126.4685	17.01618				
54.00000	20.00	111.0250	17.25367				
56.00000	20.00	95.5814	17.46028				
58.00000	20.00	80.1379	17.63600				
60.00000	20.00	64.6944	17.78083				
62.00000	20.00	49.2509	17.89478				
64.00000	20.00	33.8074	17.97784				
66.00000	20.00	18.3638	18.03001				
68.00000	20.00	2.9203	18.05129				
70.00000	0.00	-3.5145	18.04941				
72.00000	0.00	-2.2275	18.04238				
74.00000	0.00	-2.2275	18.03793				
76.00000	0.00	-2.2275	18.03347				
78.00000	0.00	-2.2275	18.02902				
80.00000	0.00	-2.2275	18.02456				
82.00000	0.00	-2.2275	18.02011				
84.00000	0.00	-2.2275	18.01565				
86.00000	0.00	-2.2275	18.01120				
88.00000	0.00	-2.2275	18.00674				
90.00000	0.00	-2.2275	18.00229				
92.00000	0.00	-2.2275	17.99783				
94.00000	0.00	-2.2275	17.99338				

96.00000	0.00	-2.2275	17.98892						
98.00000	0.00	-2.2275	17.98447						
NPL	NBLT	NBAG	NELP	NQ	NSD	NHRNSS	NWINDF	NJNTF	NFORCE
24	0	0	3	0	0	0	0	0	0

CARD D.1

PLANE INPUTS

CARDS D.2

PLANE NO. 1 CUSHION

	X	Y	Z
POINT 1	-20.0000	27.0000	-1.9900
POINT 2	2.2200	27.0000	-9.3100
POINT 3	-20.0000	-27.6300	-1.9900

PLANE NO. 2 SEAT CUS[redacted]ION - 2

	X	Y	Z
POINT 1	-15.7800	27.0000	-3.3800
POINT 2	2.2200	27.0000	-9.3100
POINT 3	-15.7800	-27.6300	-3.3800

PLANE NO. 3 SEAT BACK

	X	Y	Z
POINT 1	-15.7800	-27.6300	-3.3800
POINT 2	-23.4100	-27.6300	-21.9400
POINT 3	-15.7800	27.0000	-3.3800

PLANE NO. 4 WINDSHIELD - LEFT

	X	Y	Z
POINT 1	-6.1800	-26.6300	-41.1300
POINT 2	13.7200	-26.6300	-23.6300
POINT 3	-6.1800	27.0000	-41.1300

PLANE NO. 5 FOOTBOARD

	X	Y	Z
POINT 1	31.3500	-27.6300	-11.5600
POINT 2	21.1000	-27.6300	3.5000
POINT 3	31.3500	27.0000	-11.5600

PLANE NO. 6 FLOOR

	X	Y	Z
POINT 1	21.1000	-27.6300	3.5000
POINT 2	-25.7800	-27.6300	3.5000
POINT 3	21.1000	27.0000	3.5000

PLANE NO. 7 SEAT FRONT

	X	Y	Z
POINT 1	2.2200	27.0000	-9.3100
POINT 2	1.2200	27.0000	3.5000
POINT 3	2.2200	-27.6300	-9.3100

PLANE INPUTS

PLANE NO. 8 HEAD REST - LEFT

	X	Y	Z
POINT 1	-23.4100	-8.3100	-21.9400
POINT 2	-23.4100	-20.0600	-21.9400
POINT 3	-24.9300	-8.3100	-34.2000

PLANE NO. 9 L DASH--DPL LS(19)

	X	Y	Z
POINT 1	-8.7400	-26.3200	-17.5600
POINT 2	-5.2800	-20.3200	-17.5600
POINT 3	-8.7400	-26.3200	-26.6300

PLANE NO. 10 L DASH--DPL CTR(20,

	X	Y	Z
POINT 1	-5.2800	-20.3200	-17.5600
POINT 2	-5.2800	-8.3200	-17.5600
POINT 3	-5.2800	-20.3200	-26.6300

PLANE NO. 11 L DASH--DPL RS(22)

	X	Y	Z
POINT 1	-5.2800	-8.3200	-17.5600
POINT 2	-8.7400	-2.3200	-17.5600
POINT 3	-5.2800	-8.3200	-26.6300

PLANE NO. 12 L DASH--BTM LS

	X	Y	Z
POINT 1	5.7200	-20.3200	-17.5600
POINT 2	2.2600	-26.3200	-17.5600
POINT 3	9.7200	-20.3200	-11.5600

PLANE NO. 13 L DASH--BTM CTR(23)

	X	Y	Z
POINT 1	9.7200	-20.3200	-11.5600
POINT 2	9.7200	-8.3200	-11.5600
POINT 3	5.7200	-20.3200	-17.5600

PLANE NO. 14 L DASH--BTM RS

	X	Y	Z
POINT 1	5.7200	-8.3200	-17.5600
POINT 2	9.7200	-8.3200	-11.5600
POINT 3	2.2600	-2.3200	-17.5600

PLANE INPUTS

PLANE NO. 15 L DASH--TOP CTR

	X	Y	Z
POINT 1	-5.2800	-20.3200	-26.6300
POINT 2	-5.2800	-8.3200	-26.6300
POINT 3	-5.2800	-20.3200	-41.6300

PLANE NO. 16 L DASH--DPL BTM LS

	X	Y	Z
POINT 1	-8.7400	-26.3200	-17.5600
POINT 2	6.2600	-26.3200	-17.5600
POINT 3	-5.2800	-20.3200	-17.5600

PLANE NO. 17 L DASH--DPL BTM CTR

	X	Y	Z
POINT 1	-5.2800	-20.3200	-17.5600
POINT 2	9.7200	-20.3200	-17.5600
POINT 3	-5.2800	-8.3200	-17.5600

PLANE NO. 18 L DASH--DPL BTM RS

	X	Y	Z
POINT 1	-5.2800	-8.3200	-17.5600
POINT 2	9.7200	-8.3200	-17.5600
POINT 3	-8.7400	-2.3200	-17.5600

PLANE NO. 19 L DASH--LS(9)

	X	Y	Z
POINT 1	-8.7400	-26.3200	-17.5600
POINT 2	-5.2800	-20.3200	-17.5600
POINT 3	-8.7400	-26.3200	-26.6300

PLANE NO. 20 L DASH--CTR(10,21)

	X	Y	Z
POINT 1	-5.2800	-20.3200	-17.5600
POINT 2	-5.2800	-8.3200	-17.5600
POINT 3	-5.2800	-20.3200	-26.6300

PLANE NO. 21 L DASH--CTR(10,20)

	X	Y	Z
POINT 1	-5.2800	-20.3200	-17.5600
POINT 2	-5.2800	-8.3200	-17.5600
POINT 3	-5.2800	-20.3200	-26.6300

PLANE INPUTS

PLANE NO. 22 L DASH--RS(11)

	X	Y	Z
POINT 1	-5.2800	-8.3200	-17.5600
POINT 2	-8.7400	-2.3200	-17.5600
POINT 3	-5.2800	-8.3200	-26.6300

PLANE NO. 23 L DASH--BTM CTR(13)

	X	Y	Z
POINT 1	9.7200	-20.3200	-11.5600
POINT 2	9.7200	-8.3200	-11.5600
POINT 3	5.7200	-20.3200	-17.5600

PLANE NO. 24 L DASH--DPL [redacted]TM CTR

	X	Y	Z
POINT 1	-5.2800	-20.3200	-17.5600
POINT 2	9.7200	-20.3200	-17.5600
POINT 3	-5.2800	-8.3200	-17.5600

ADDITIONAL ELLIPSOID INPUT

	SEMIAXES (IN.)			OFFSET (IN.)			ROTATION (DEG)		
NO.	X	Y	Z	X	Y	Z	YAW	PITCH	ROLL
17	4.500	3.000	3.000	0.000	-4.000	-3.500	0.000	0.000	0.000
18	3.200	6.000	8.000	0.000	0.000	-7.000	0.000	0.000	0.000
19	2.000	40.000	7.250	11.500	-25.000	-18.680	0.000	0.000	0.000

BODY SEGMENT SYMMETRY INPUT

CARD D.7

SEG NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
NSYM(J)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FUNCTION NO. 1 CONSTANT F=.20 NTI(1) = 1

D0	D1	D2	D3	D4
0.0000	0.0000	0.2000	0.0000	0.0000

FUNCTION IS CONSTANT 0.200000

FUNCTION NO. 3 SEAT CUSHION NTI(3) = 6 CARDS E

D0	D1	D2	D3	D4
0.0000	-10.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 12 TABULAR POINTS

D	F(D)
0.000000	0.0000
0.300000	25.0000
0.900000	50.0000
1.350000	75.0000
1.900000	100.0000
2.300000	125.0000
2.600000	150.0000
3.400000	200.0000
3.800000	250.0000
4.150000	300.0000
7.000000	900.0000
8.000000	1400.0000

FUNCTION NO. 4 CONSTANT F=0.4 NTI(4) = 36

D0	D1	D2	D3	D4
0.0000	0.0000	0.4000	0.0000	0.0000

FUNCTION IS CONSTANT 0.400000

FUNCTION NO. 5 WINDSHIELD NTI(5) = 41 CARDS E

D0	D1	D2	D3	D4
0.0000	-9.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 11 TABULAR POINTS

D	F(D)
0.000000	0.0000
0.500000	500.0000
1.000000	1000.0000
2.000000	1500.0000
3.000000	1000.0000
4.000000	500.0000
5.000000	200.0000
6.000000	100.0000
7.000000	50.0000
8.000000	20.0000
9.000000	0.0000

FUNCTION NO. 6 DASH NTI(6) = 69

D0	D1	D2	D3	D4
0.0000	-11.0000	0.0000	0.0000	0.0000

FIRST PART OF FUNCTION - 7 TABULAR POINTS

D	F(D)
0.000000	0.0000
5.500000	1175.0000
6.000000	850.0000
7.500000	1000.0000
9.750000	1200.0000
10.000000	1280.0000
11.000000	2080.0000

CARDS E

FUNCTION NO. 7 CUSHION VISCOUS NTI(7) = 89

D0	D1	D2	D3	D4
-2000.0000	-2000.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 5 TABULAR POINTS

D	F(D)
-2000.000000	0.0000
-200.000000	0.0000
0.000000	0.0000
200.000000	10.0000
2000.000000	200.0000

FUNCTION NO. 8 DASH VISCOUS NTI(8) = 105

D0	D1	D2	D3	D4
-2000.0000	-2000.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 5 TABULAR POINTS

D	F(D)
-2000.000000	0.0000
-200.000000	0.0000
0.000000	0.0000
400.000000	30.0000
2000.000000	500.0000

FUNCTION NO. 9 BODY STIFFNESS NTI(9) = 121

D0	D1	D2	D3	D4
0.0000	-3.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 10 TABULAR POINTS

D	F(D)
0.000000	0.0000
0.250000	1.0000
0.500000	6.0000
0.750000	20.0000
1.000000	40.0000
1.250000	125.0000
1.500000	250.0000
2.000000	500.0000
2.500000	1000.0000
3.000000	2000.0000

FUNCTION NO. 11 SEAT CUSHION 3 NTI(11) = 147

D0	D1	D2	D3	D4
0.0000	-7.1800	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 8 TABULAR POINTS

D	F(D)
0.000000	18.0000
1.180000	35.0000
2.180000	60.0000
3.180000	100.0000
4.180000	160.0000
5.180000	250.0000
6.180000	400.0000
7.180000	1500.0000

FUNCTION NO. 13 CUSHION ABSORPTION NTI(13) = 169

D0	D1	D2	D3	D4
-1000.0000	-1000.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 4 TABULAR POINTS

D	F(D)
-1000.000000	0.5000
-1.000000	0.5000
0.000000	1.0000
1000.000000	1.0000

FUNCTION NO. 14 DASH ABSORPTION NTI(14) = 183

D0	D1	D2	D3	D4
-1000.0000	-1000.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 4 TABULAR POINTS

D	F(D)
-1000.000000	0.4000
-1.000000	0.4000
0.000000	1.0000
1000.000000	1.0000

CARDS E

FUNCTION NO. 15 WINDS■IELD ABSORPTON NTI(15) = 197

D0	D1	D2	D3	D4
-1000.0000	-1000.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 4 TABULAR POINTS

D	F(D)
-1000.000000	0.3000
-1.000000	0.3000
0.000000	1.0000
1000.000000	1.0000

FUNCTION NO. 16 UNDER DASH ABSORPTON NTI(16) = 211

D0	D1	D2	D3	D4
-1000.0000	-1000.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 4 TABULAR POINTS

D	F(D)
-1000.000000	0.2500
-1.000000	0.2500
0.000000	1.0000
1000.000000	1.0000

FUNCTION NO. 17 ABDOMINAL ABSORPTION NTI(17) = 225

CARDS E

D0	D1	D2	D3	D4
-1000.0000	-1000.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 4 TABULAR POINTS

D	F(D)
-1000.000000	0.5000
-1.000000	0.5000
0.000000	1.0000
1000.000000	1.0000

FUNCTION NO. 18 ABDOMINAL VISCOUS NTI(18) = 239

D0	D1	D2	D3	D4
-2000.0000	-2000.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 5 TABULAR POINTS

D	F(D)
-2000.000000	0.0000
-200.000000	0.0000
0.000000	0.0000
200.000000	50.0000
2000.000000	1000.0000

FUNCTION NO. 19 ABDOMINAL STIFFNES 1 NTI(19) = 255

D0	D1	D2	D3	D4
0.0000	-10.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 9 TABULAR POINTS

D	F(D)
0.000000	0.0000
1.000000	5.0000
2.000000	14.0000
2.600000	22.0000
2.610000	22.0000
2.620000	11.0000
2.630000	0.0000
2.640000	0.0000
10.000000	0.0000

FUNCTION NO. 21 BODY ABSORPTION NTI(21) = 279

D0	D1	D2	D3	D4
-1000.0000	-1000.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 4 TABULAR POINTS

D	F(D)
-1000.000000	0.2000
-1.000000	0.2000
0.000000	1.0000
1000.000000	1.0000

FUNCTION NO. 22 CONSTANT = 0.0 NTI(22) = 293

D0	D1	D2	D3	D4
0.0000	0.0000	0.0000	0.0000	0.0000

FUNCTION IS CONSTANT 0.000000

FUNCTION NO. 23 CONSTANT = 0.0 NTI(23) = 298 CARDS E

D0	D1	D2	D3	D4
0.0000	0.0000	0.0000	0.0000	1.0000

FUNCTION IS CONSTANT 0.000000

FUNCTION NO. 25 HARD SURFACE NTI(25) = 303 CARDS E

D0	D1	D2	D3	D4
0.0000	-3.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 6 TABULAR POINTS

D	F(D)
0.000000	0.0000
0.250000	100.0000
0.500000	400.0000
1.000000	1500.0000
2.000000	4000.0000
3.000000	6000.0000

FUNCTION NO. 28 UP ARM - UTOR STIFF NTI(28) = 321

D0	D1	D2	D3	D4
0.0000	-4.5000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 10 TABULAR POINTS

D	F(D)
0.000000	0.0000
1.250000	0.0000
1.500000	2.0000
1.750000	12.0000
2.000000	40.0000
2.250000	75.0000
2.500000	140.0000
2.500000	250.0000
3.000000	450.0000
4.500000	1000.0000

FUNCTION NO. 31 HARNESS FDF NTI(31) = 347

D0	D1	D2	D3	D4
0.0000	-4.0000	0.0000	0.0000	0.0000

FIRST PART OF FUNCTION - 8 TABULAR POINTS

D	F(D)
0.000000	0.0000
0.010000	150.0000
0.020000	300.0000
0.030000	450.0000
0.050000	850.0000
0.100000	3500.0000
1.000000	35000.0000
4.000000	140000.0000

FUNCTION NO. 32 HARNESS FRICTION NTI(32) = 369

D0	D1	D2	D3	D4
0.0000	0.0000	0.2000	0.0000	0.2000

FUNCTION IS CONSTANT 0.200000

FUNCTION NO. 33 STIFF SEAT CUSHION NTI(33) = 374

D0	D1	D2	D3	D4
0.0000	-10.0000	0.0000	0.0000	1.0000

FIRST PART OF FUNCTION - 12 TABULAR POINTS

D	F(D)
0.000000	0.0000
0.300000	25.0000
0.900000	50.0000
1.350000	100.0000
1.900000	200.0000
2.300000	250.0000
2.600000	300.0000
3.400000	400.0000
3.800000	500.0000
4.150000	600.0000
7.000000	1800.0000
8.000000	2000.0000

FUNCTION NO. 35 DASH TOP/FRONT/am/1g

NTI(35) = 404

D0	D1	D2	D3	D4
0.0000	-12.0000	0.0000	0.0000	0.0000

FIRST PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
0.000000	0.0000
2.000000	1000.0000
12.000000	1000.0000

FUNCTION NO. 36 DASH FRNT/BOT/TOR

NTI(36) = 416

CARDS E

D0	D1	D2	D3	D4
0.0000	-12.0000	0.0000	0.0000	0.0000

FIRST PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
0.000000	0.0000
2.000000	2000.0000
12.000000	2000.0000

FUNCTION NO. 37 CONSTANT R = 0.02 NTI(37) = 428

D0	D1	D2	D3	D4
0.0000	0.0000	0.0200	0.0000	0.0000

FUNCTION IS CONSTANT 0.020000

CARDS E

FUNCTION NO. 38 CONSTANT G = 0.98 NTI(38) = 433

D0	D1	D2	D3	D4
0.0000	0.0000	0.9800	0.0000	0.0000

FUNCTION IS CONSTANT 0.980000

FUNCTION NO. 39 CONSTANT F = 0.5 NTI(39) = 438

D0	D1	D2	D3	D4
0.0000	0.0000	0.5000	0.0000	0.0000

FUNCTION IS CONSTANT 0.500000

FUNCTION NO. 40 CONSTANT F = 0.2 NTI(40) = 443

CARDS E

D0	D1	D2	D3	D4
0.0000	0.0000	0.2000	0.0000	0.0000

FUNCTION IS CONSTANT 0.200000

FUNCTION NO. 41 DASH TOP/FRONT/HD/NK NTI(41) = 448

D0	D1	D2	D3	D4
0.0000	-12.0000	0.0000	0.0000	0.0000

FIRST PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
0.000000	0.0000
3.000000	750.0000
12.000000	750.0000

ALLOWED CONTACTS AND ASSOCIATED FUNCTIONS

CARDS F.1

PLANE	SEGMENT	FORCE DEFLECTION	INERTIAL SPIKE	R FACTOR	G FACTOR	FRICTION COEF.	OPT
1- 16 CUSHION	1- 1 LTOR	22 CONSTANT = 0.0	-3 SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1
1- 16 CUSHION	2- 2 MTOR	22 CONSTANT = 0.0	-3 SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1
1- 16 CUSHION	6- 6 RULG	22 CONSTANT = 0.0	-3 SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1
1- 16 CUSHION	9- 9 LULG	22 CONSTANT = 0.0	-3 SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1
2- 16 SEAT CUSHION - 2	13- 13 RLAM	23 CONSTANT = 0.0	-3 SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1
2- 16 SEAT CUSHION - 2	15- 15 LLAM	23 CONSTANT = 0.0	-3 SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1
3- 16 SEAT BACK	1- 1 LTOR	22 CONSTANT = 0.0	-33 STIFF SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1
3- 16 SEAT BACK	2- 2 MTOR	22 CONSTANT = 0.0	-33 STIFF SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1
3- 16 SEAT BACK	3- 3 UTOR	22 CONSTANT = 0.0	-33 STIFF SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1
3- 16 SEAT BACK	12- 12 RUAM	22 CONSTANT = 0.0	-33 STIFF SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1
3- 16 SEAT BACK	14- 14 LUAM	22 CONSTANT = 0.0	-33 STIFF SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1
4- 16 WINDSHIELD - LEFT	5- 5 HEAD	23 CONSTANT = 0.0	-5 WINDSHIELD	-15 WINDSHIELD ABSORPTON	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	-1
5- 16 FOOTBOARD	8- 8 RFT	23 CONSTANT = 0.0	-25 HARD SURFACE	-15 WINDSHIELD ABSORPTON	-8 DASH VISCOUS	4 CONSTANT F=0.4	1
5- 16 FOOTBOARD	11- 11 LFT	23 CONSTANT = 0.0	-25 HARD SURFACE	-15 WINDSHIELD ABSORPTON	-8 DASH VISCOUS	4 CONSTANT F=0.4	1
6- 16 FLOOR	8- 8 RFT	23 CONSTANT = 0.0	-25 HARD SURFACE	-15 WINDSHIELD ABSORPTON	-8 DASH VISCOUS	4 CONSTANT F=0.4	1
6- 16 FLOOR	11- 11 LFT	23 CONSTANT = 0.0	-25 HARD SURFACE	-15 WINDSHIELD ABSORPTON	-8 DASH VISCOUS	4 CONSTANT F=0.4	1
8- 16 HEAD REST - LEFT	3- 3 UTOR	22 CONSTANT = 0.0	-33 STIFF SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1
8- 16 HEAD REST - LEFT	5- 5 HEAD	22 CONSTANT = 0.0	-33 STIFF SEAT CUSHION	-13 CUSHION ABSORPTION	-7 CUSHION VISCOUS	1 CONSTANT F=.20	1

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   9- 16             1-  1       36                   0        37                    38                    39               1
L DASH--DPL LS(19)   LTOR DASH FRNT/BOT/TOR                    CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

   9- 16             2-  2       36                   0        37                    38                    39               1
L DASH--DPL LS(19)   MTOR DASH FRNT/BOT/TOR                    CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

   9- 16             3-  3       36                   0        37                    38                    39               1
L DASH--DPL LS(19)   UTOR DASH FRNT/BOT/TOR                    CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  11- 16             1-  1       36                   0        37                    38                    39               1
L DASH--DPL RS(22)   LTOR DASH FRNT/BOT/TOR                    CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  11- 16             2-  2       36                   0        37                    38                    39               1
L DASH--DPL RS(22)   MTOR DASH FRNT/BOT/TOR                    CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  11- 16             3-  3       36                   0        37                    38                    39               1
L DASH--DPL RS(22)   UTOR DASH FRNT/BOT/TOR                    CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  12- 16             9-  9       35                   0        37                    38                    39               1
L DASH--BTM LS       LULG DASH TOP/FRONT/am/lg                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  12- 16            10- 10       35                   0        37                    38                    39               1
L DASH--BTM LS       LLLG DASH TOP/FRONT/am/lg                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  12- 16            15- 15       35                   0        37                    38                    39               1
L DASH--BTM LS       LLAM DASH TOP/FRONT/am/lg                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  13- 16             6-  6       35                   0        37                    38                    39               1
L DASH--BTM CTR(23)  RULG DASH TOP/FRONT/am/lg                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  13- 16             9-  9       35                   0        37                    38                    39               1
L DASH--BTM CTR(23)  LULG DASH TOP/FRONT/am/lg                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  13- 16             7-  7       35                   0        37                    38                    39               1
L DASH--BTM CTR(23)  RLLG DASH TOP/FRONT/am/lg                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  13- 16            10- 10       35                   0        37                    38                    39               1
L DASH--BTM CTR(23)  LLLG DASH TOP/FRONT/am/lg                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  14- 16             6-  6       35                   0        37                    38                    39               1
L DASH--BTM RS       RULG DASH TOP/FRONT/am/lg                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  14- 16             7-  7       35                   0        37                    38                    39               1
L DASH--BTM RS       RLLG DASH TOP/FRONT/am/lg                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  14- 16            13- 13       35                   0        37                    38                    39               1
L DASH--BTM RS       RLAM DASH TOP/FRONT/am/lg                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  15- 16             3-  3       36                   0        37                    38                    39               1
L DASH--TOP CTR      UTOR DASH FRNT/BOT/TOR                    CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5

  15- 16             4-  4       41                   0        37                    38                    40               1
L DASH--TOP CTR      NECK DASH TOP/FRONT/HD/NK                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.2

  15- 16             5-  5       41                   0        37                    38                    40               1
L DASH--TOP CTR      HEAD DASH TOP/FRONT/HD/NK                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.2

  15- 16            12- 12       35                   0        37                    38                    39               1
L DASH--TOP CTR      RUAM DASH TOP/FRONT/am/lg                 CONSTANT R = 0.02     CONSTANT G = 0.98     CONSTANT F = 0.5
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   15- 16           14- 14     35                                 37                    38                    39
L DASH--TOP CTR      LUAM DASH TOP/FRONT/am/lg        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   16- 16            9-  9     35                                 37                    38                    39
L DASH--DPL BTM LS   LULG DASH TOP/FRONT/am/lg        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   16- 16           10- 10     35                                 37                    38                    39
L DASH--DPL BTM LS   LLLG DASH TOP/FRONT/am/lg        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   16- 16           15- 15     35                                 37                    38                    39
L DASH--DPL BTM LS   LLAM DASH TOP/FRONT/am/lg        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   17- 16            6-  6     35                                 37                    38                    39
L DASH--DPL BTM CTR RULG DASH TOP/FRONT/am/lg         0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   17- 16            9-  9     35                                 37                    38                    39
L DASH--DPL BTM CTR LULG DASH TOP/FRONT/am/lg         0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   17- 16            7-  7     35                                 37                    38                    39
L DASH--DPL BTM CTR RLLG DASH TOP/FRONT/am/lg         0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   17- 16           10- 10     35                                 37                    38                    39
L DASH--DPL BTM CTR LLLG DASH TOP/FRONT/am/lg         0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   18- 16            6-  6     35                                 37                    38                    39
L DASH--DPL BTM RS   RULG DASH TOP/FRONT/am/lg        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   18- 16            7-  7     35                                 37                    38                    39
L DASH--DPL BTM RS   RLLG DASH TOP/FRONT/am/lg        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   18- 16           13- 13     35                                 37                    38                    39
L DASH--DPL BTM RS   RLAM DASH TOP/FRONT/am/lg        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   19- 16            4-  4     41                                 37                    38                    40
L DASH--LS(9)        NECK DASH TOP/FRONT/HD/NK        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.2     1
   19- 16           14- 14     35                                 37                    38                    39
L DASH--LS(9)        LUAM DASH TOP/FRONT/am/lg        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   19- 16           15- 15     35                                 37                    38                    39
L DASH--LS(9)        LLAM DASH TOP/FRONT/am/lg        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   20- 16            1-  1     36                                 37                    38                    39
L DASH--CTR(10,21)   LTOR DASH FRNT/BOT/TOR           0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   20- 16            2-  2     36                                 37                    38                    39
L DASH--CTR(10,21)   MTOR DASH FRNT/BOT/TOR           0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   20- 16            3-  3     36                                 37                    38                    39
L DASH--CTR(10,21)   UTOR DASH FRNT/BOT/TOR           0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   20- 16           13- 13     35                                 37                    38                    39
L DASH--CTR(10,21)   RLAM DASH TOP/FRONT/am/lg        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   20- 16           15- 15     35                                 37                    38                    39
L DASH--CTR(10,21)   LLAM DASH TOP/FRONT/am/lg        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.5     1
   21- 16            4-  4     41                                 37                    38                    40
L DASH--CTR(10,20)   NECK DASH TOP/FRONT/HD/NK        0     CONSTANT R = 0.02    CONSTANT G = 0.98    CONSTANT F = 0.2     1
```

21- 16 L DASH--CTR(10,20)	12- 12 RUAM DASH	35 TOP/FRONT/am/lg	0	37 CONSTANT R = 0.02	38 CONSTANT G = 0.98	39 CONSTANT F = 0.5	1
21- 16 L DASH--CTR(10,20)	14- 14 LUAM DASH	35 TOP/FRONT/am/lg	0	37 CONSTANT R = 0.02	38 CONSTANT G = 0.98	39 CONSTANT F = 0.5	1
22- 16 L DASH--RS(11)	12- 12 RUAM DASH	35 TOP/FRONT/am/lg	0	37 CONSTANT R = 0.02	38 CONSTANT G = 0.98	39 CONSTANT F = 0.5	1
22- 16 L DASH--RS(11)	13- 13 RLAM DASH	35 TOP/FRONT/am/lg	0	37 CONSTANT R = 0.02	38 CONSTANT G = 0.98	39 CONSTANT F = 0.5	1
22- 16 L DASH--RS(11)	4- 4 NECK DASH	41 TOP/FRONT/HD/NK	0	37 CONSTANT R = 0.02	38 CONSTANT G = 0.98	40 CONSTANT F = 0.2	1
23- 16 L DASH--BTM CTR(13)	13- 13 RLAM DASH	35 TOP/FRONT/am/lg	0	37 CONSTANT R = 0.02	38 CONSTANT G = 0.98	39 CONSTANT F = 0.5	1
23- 16 L DASH--BTM CTR(13)	15- 15 LLAM DASH	35 TOP/FRONT/am/lg	0	37 CONSTANT R = 0.02	38 CONSTANT G = 0.98	39 CONSTANT F = 0.5	1
24- 16 L DASH--DPL BTM CTR	13- 13 RLAM DASH	35 TOP/FRONT/am/lg	0	37 CONSTANT R = 0.02	38 CONSTANT G = 0.98	39 CONSTANT F = 0.5	1
24- 16 L DASH--DPL BTM CTR	15- 15 LLAM DASH	35 TOP/FRONT/am/lg	0	37 CONSTANT R = 0.02	38 CONSTANT G = 0.98	39 CONSTANT F = 0.5	1

CARDS F.3

SEGMENT	SEGMENT	FORCE DEFLECTION	INERTIAL SPIKE	R FACTOR	G FACTOR	FRICTION COEF.	OPT
1- 1 LTOR	13- 13 RLAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
1- 1 LTOR	15- 15 LLAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
2- 2 MTOR	12- 12 RUAM	23 CONSTANT = 0.0	-19 ABDOMINAL STIFFNES 1	-17 ABDOMINAL ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
2- 2 MTOR	13- 13 RLAM	23 CONSTANT = 0.0	-19 ABDOMINAL STIFFNES 1	-17 ABDOMINAL ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
2- 2 MTOR	14- 14 LUAM	23 CONSTANT = 0.0	-19 ABDOMINAL STIFFNES 1	-17 ABDOMINAL ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
2- 2 MTOR	15- 15 LLAM	23 CONSTANT = 0.0	-19 ABDOMINAL STIFFNES 1	-17 ABDOMINAL ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
3- 3 UTOR	6- 6 RULG	22 CONSTANT = 0.0	-28 UP ARM - UTOR STIFF	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
3- 3 UTOR	9- 9 LULG	22 CONSTANT = 0.0	-28 UP ARM - UTOR STIFF	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
3- 3 UTOR	12- 12 RUAM	22 CONSTANT = 0.0	-28 UP ARM - UTOR STIFF	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
3- 3 UTOR	14- 14 LUAM	22 CONSTANT = 0.0	-28 UP ARM - UTOR STIFF	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0

5- 5 HEAD	3- 3 UTOR	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
5- 5 HEAD	12- 12 RUAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
5- 5 HEAD	13- 13 RLAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
5- 5 HEAD	14- 14 LUAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
5- 5 HEAD	15- 15 LLAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
6- 6 RULG	9- 9 LULG	22 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
6- 6 RULG	10- 10 LLLG	22 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
6- 6 RULG	12- 12 RUAM	22 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
6- 6 RULG	13- 13 RLAM	22 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
6- 6 RULG	15- 15 LLAM	22 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
7- 7 RLLG	10- 10 LLLG	22 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
7- 7 RLLG	9- 9 LULG	22 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
7- 7 RLLG	11- 11 LFT	22 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
7- 7 RLLG	13- 13 RLAM	22 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
8- 8 RFT	11- 11 LFT	22 CONSTANT = 0.0	-25 HARD SURFACE	-15 WINDSHIELD ABSORPTON	-8 DASH VISCOUS	1 CONSTANT F=.20	0
9- 9 LULG	14- 14 LUAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
9- 9 LULG	13- 13 RLAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
9- 9 LULG	15- 15 LLAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
10- 10 LLLG	8- 8 RFT	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
10- 10 LLLG	15- 15 LLAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0

12- 12 RUAM	15- 15 LLAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
13- 13 RLAM	15- 15 LLAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0
13- 13 RLAM	14- 14 LUAM	23 CONSTANT = 0.0	-9 BODY STIFFNESS	-21 BODY ABSORPTION	-18 ABDOMINAL VISCOUS	1 CONSTANT F=.20	0

SUBROUTINE INITAL INPUT

CARD G.1

ZPLT(X)	ZPLT(Y)	ZPLT(Z)	I1	J1	I2	J2	I3	SPLT(1)	SPLT(2)	SPLT(3)
0.	0.	0.	0	0	0	0	0	10.00	6.00	1.00

INITIAL POSITIONS (INERTIAL REFERENCE) CARDS G.2

SEGMENT	LINEAR POSITION (IN.)			LINEAR VELOCITY (IN./SEC.)		
NO. SEG	X	Y	Z	X	Y	Z
1 LTOR	-13.10880	-14.19000	-9.80070	528.00000	0.00000	0.00000
2 MTOR	-16.61012	-14.19000	-12.71720	528.00000	0.00000	0.00000
3 UTOR	-19.53078	-14.19000	-21.18327	528.00000	0.00000	0.00000
4 NECK	-21.18358	-14.19000	-29.95637	528.00000	0.00000	0.00000
5 HEAD	-21.06386	-14.19000	-33.54847	528.00000	0.00000	0.00000
6 RULG	-3.50557	-9.79254	-9.73506	528.00000	0.00000	0.00000
7 RLLG	7.64353	-9.18230	-6.11498	528.00000	0.00000	0.00000
8 RFT	15.52997	-9.30905	1.83925	528.00000	0.00000	0.00000
9 LULG	-3.50557	-18.58746	-9.73506	528.00000	0.00000	0.00000
10 LLLG	7.64353	-19.19770	-6.11498	528.00000	0.00000	0.00000
11 LFT	15.52997	-19.07095	1.83925	528.00000	0.00000	0.00000
12 RUAM	-20.14693	-6.43642	-19.77926	528.00000	0.00000	0.00000
13 RLAM	-12.45864	-7.06192	-14.31342	528.00000	0.00000	0.00000
14 LUAM	-20.14693	-21.94358	-19.77926	528.00000	0.00000	0.00000
15 LLAM	-12.45864	-21.31808	-14.31342	528.00000	0.00000	0.00000
16 CAR	0.00000	0.00000	0.00000	528.00000	0.00000	0.00000

INITIAL ANGULAR ROTATION AND VELOCITY CARDS G.3

SEGMENT	ANGULAR ROTATION (DEG)			ANGULAR VELOCITY (DEG/SEC.)				IYPR		
NO. SEG	YAW	PITCH	ROLL	X	Y	Z				
1 LTOR	0.00000	27.84580	0.00000	0.00000	0.00000	0.00000	3	2	1	0
2 MTOR	0.00000	-1.55700	0.00000	0.00000	0.00000	0.00000	3	2	1	1
3 UTOR	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	3	2	1	2
4 NECK	0.00000	4.00000	0.00000	0.00000	0.00000	0.00000	3	2	1	0
5 HEAD	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	3	2	1	4
6 RULG	-8.03450	108.21640	-13.72900	0.00000	0.00000	0.00000	3	2	1	0
7 RLLG	8.48880	39.03710	5.48210	0.00000	0.00000	0.00000	3	2	1	0
8 RFT	2.06090	104.00770	1.50320	0.00000	0.00000	0.00000	3	2	1	0
9 LULG	8.03450	108.21640	13.72900	0.00000	0.00000	0.00000	3	2	1	0
10 LLLG	-8.48880	39.03710	-5.48210	0.00000	0.00000	0.00000	3	2	1	0
11 LFT	-2.06090	104.00770	-1.50320	0.00000	0.00000	0.00000	3	2	1	0
12 RUAM	-10.04570	13.41400	-6.27500	0.00000	0.00000	0.00000	3	2	1	0
13 RLAM	-84.67600	83.71400	-76.17190	0.00000	0.00000	0.00000	3	2	1	0
14 LUAM	10.04570	13.41400	6.27500	0.00000	0.00000	0.00000	3	2	1	0
15 LLAM	84.67600	83.71400	76.17190	0.00000	0.00000	0.00000	3	2	1	0
16 CAR	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1	2	3	0

LINEAR AND ANGULAR VELOCITIES HAVE BEEN SET EQUAL TO THE INITIAL VEHICLE VELOCITIES.

TABULAR TIME HISTORY CONTROL PARAMETERS

TYPE	KSG	SELECTED SEGMENTS OR JOINTS		
H.1	3	-1	-3	-5
REF		1	1	1
H.2	3	1	3	5
REF		0	0	0
H.3	3	1	3	5
REF		0	0	0
H.4	3	1	3	5
REF		0	0	0
H.5	3	1	3	5

REF		0	0	0
H.6	3	1	3	5
REF		0	0	0
H.7	0			
REF				
H.8	0			
REF				
H.9	2	3	4	
REF		4	5	

APPENDIX C - DESIGN EVALUATION RESULTS

C.2 Criteria Equation Data

NASS Variables

V405: Number of Occupants

V410: Occupant Role (Driver or Passenger)

V316: Accident Type

Rear: 20-23

Side: 44-47, 64-67

Front: 11-16, 34-42, 54-63

V124: Vehicle Type (Trucks, Buses, Etc.)

V612: OIC-AIS Severity

V425: Manual Restraint Usage

No Belt = 0

Belt = 3

Assumptions:

1. All vehicles other than passenger cars were excluded, V124=10-99
2. Variable 405, number of occupants in car, was set at 1 or 2 passengers in car. This was done on the assumption that both occupants were in the front seat, thus only the restraint system in front seat is analyzed.

INCLUDE V405=1-2 AND V410=1-2 AND V316=11-16,20-23,34-47,54-67
EXCLUDE V124=10-99

***Variable 316 ACCIDENT TYPE   Cases = 6924

	Code	Freq	*
Front	11	595.	*
	12	275.	*
	13	342.	*
	14	378.	*
	15	359.	*
	16	2.	*
Rear	20	1365.	*
	21	1076.	*
	22	301.	*
	23	14.	*
Front	34	2.	*
	35	2.	*
	38	6.	*
	39	4.	*
	41	1.	*
	42	24.	*
Side	44	339.	*
	45	252.	*
	46	193.	*
	47	24.	*
Front	54	77.	*
	55	71.	*
	56	21.	*
	57	16.	*
	58	18.	*
	59	68.	*
	62	40.	*
Side	64	386.	*
	65	407.	*
	66	246.	*
	67	20.	*

Dd & Dp

INCLUDE V405=1-2 AND V410=1-2 AND V316=20-23,34-47,54-67,11-16
EXCLUDE V124=10-99

***Variable 410 OCCUPANT ROLE   Cases = 6924

Code	Label	Freq	*
1	Driver	5291.	*
2	Passenger	1633.	*

Ed, REAR, NO BELT

INCLUDE V215=28-32 AND V405=1-2 AND V410=1 AND V316=20-23 AND V425=0
EXCLUDE V124=10-99
Cases Read = 84

Code	Label	Freq	*
----	-----	----	*
1	Minor injury	71.	*
2	Moderate injury	5.	*
3	Severe injury	4.	*
4	Serious injury	1.	*
5	Critical injury	1.	*
7	Injured, unk sev	2.	*

Ed, REAR, 3PT BELT

INCLUDE V215=28-32 AND V405=1-2 AND V410=1 AND V316=20-23 AND V425=3
EXCLUDE V124=10-99
Cases Read = 21

Code	Label	Freq	*
----	-----	----	*
1	Minor injury	21.	*

Ed, FRONT, NO BELT

INCLUDE V215=28-32 AND V405=1-2 AND V410=1 AND V316=34-43,54-63,11-16
AND V425=0
EXCLUDE V124=10-99

Cases Read = 44

Code	Label	Freq	*
----	-----	----	*
1	Minor injury	26.	*
2	Moderate injury	8.	*
3	Severe injury	7.	*
6	Maximum injury	1.	*
7	Injured, unk sev	1.	*
9	Unknown if inj	1.	*

Ed, FRONT, 3PT BELT

INCLUDE V215=28-32 AND V405=1-2 AND V410=1 AND V316=34-43,54-63,11-1
AND V425=3
EXCLUDE V124=10-99

Cases Read = 4

Code	Label	Freq	*
----	-----	----	*
1	Minor injury	4.	*

Ed, SIDE, NO BELT

INCLUDE V215=28-32 AND V405=1-2 AND V410=1 AND V316=44-47,64-67 AND
V425=0
EXCLUDE V124=10-99
Cases Read = 18

Code	Label	Freq	*
1	Minor injury	18.	*

Ed, SIDE, 3PT BELT

INCLUDE V215=28-32 AND V405=1-2 AND V410=1 AND V316=44-47,64-67 AND
V425=3
EXCLUDE V124=10-99
Cases Read = 7

Code	Label	Freq	*
----	-----	----	*
1	Minor injury	3.	*
2	Moderate injury	3.	*
7	Injured, unk sev	1.	*

Ep, REAR, NO BELT

```
?INCLUDE V215=28-32 AND V405=1-2 AND V410=0 AND V316=20-23 AND V425=0
?EXCLUDE V124=10-99
@Cases Read = 0
```

Ep, REAR, BELT

```
INCLUDE V215=28-32 AND V405=1-2 AND V410=0 AND V316=20-23 AND V425=3
EXCLUDE V124=10-99
Cases Read = 0
```

Ep, FRONT, NO BELT

```
?INCLUDE V215=28-32 AND V405=1-3 AND V410=0 AND V316=34-43,54-63,11-16
AND
V425=0
?EXCLUDE V124=10-99
@Cases Read = 0
```

Ep, FRONT, 3PT BELT

```
?INCLUDE V215=28-32 AND V405=1-2 AND V410=0 AND V316=34-43,54-63,11-16
AND
?EXCLUDE V124=10-99
@Cases Read = 0
```

Ep, SIDE, NO BELT

```
?INCLUDE V215=28-32 AND V405=1-2 AND V410=0 AND V316=44-47,64-67 AND
V425=0
?EXCLUDE V124=10-99
@Cases Read = 0
```

Ep, SIDE, 3PT BELT

```
?INCLUDE V215=28-32 AND V405=1-2 AND V410=0 AND V316=44-47,64-67 AND
V425=3
?EXCLUDE V124=10-99
@Cases Read = 0
```

E, FRONT, AIR CUSHION

INCLUDE V75=28-32 AND V99=12
Cases Read = 4

***Variable 600 OVERALL OCC INJ SEVERITY Cases = 4

Code	Freq	*
1	3.	*
3	1.	*

E, SIDE, AIR CUSHION

INCLUDE V75=28-32 AND V99=1-5,7-11
Cases Read = 15

***Variable 600 OVERALL OCC INJ SEVERITY Cases = 15

Code	Freq	*
0	2.	*
1	12.	*
2	1.	*

E, REAR, AIR CUSHION

?INCLUDE V75=28-32 AND V99=6
@Cases Read = 0

Appendix D – Alternate Designs

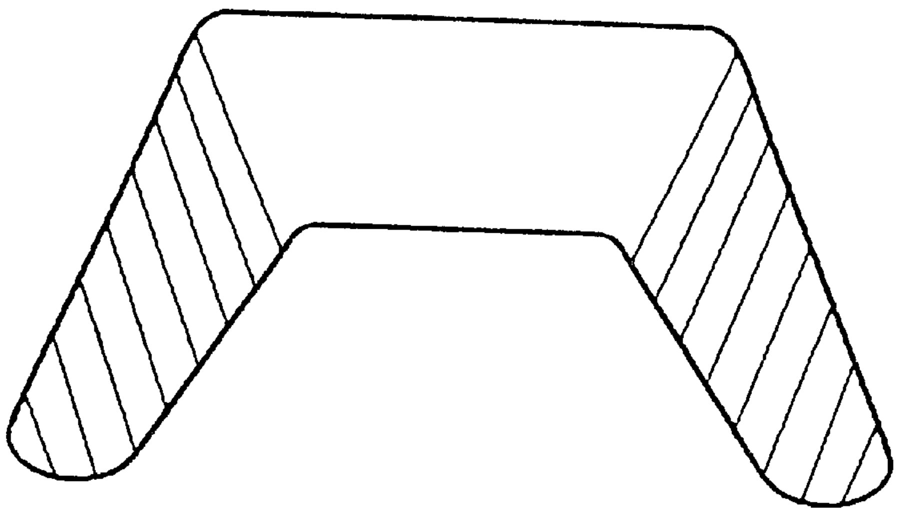
D.1 Dual Air Bags

A passive restraint system was designed that would increase stopping distance, provide uniform deceleration, and be easy to implement. The design is a contoured air bag system. It consists of two separate air bags, one for the legs and one for the torso and head. Both air bags are constructed using an internal string system similar to those used in airplane escape chutes. The shape and stiffness of each air bag is controlled by the positioning of the internal strings.

Current air bag systems consist of one air bag which is deployed from the dash. A major problem with this system is submarining. When the air bag is deployed from the dash, it stops the forward motion of the torso. The legs, however, continue to move forward, pulling the rest of the body under the air bag and causing neck injuries. The design proposed consists of an air bag for the legs which is deployed from under the dash. This air bag, which will be stiffer than the torso/head air bag, should quickly stop the knees and reduce the likelihood of submarining.

The proposed torso air bag is horseshoe-shaped. A top view is shown in Figure D.1a. By appropriately positioning the internal strings, the "wings" of this air bag will be stiff. In an angular collision, the occupant will be guided by these "wings" into the main part of the air bag where the majority of the energy absorption will occur. This is an improvement over the air bag systems used today since this design provides protection in crashes up to sixty degrees off-center. By using a lollipop accelerometer sensor, the air bags can be deployed in collisions from any angle. The main portion of the torso bag will be a single bag subdivided on the interior into several different size compartments. This is illustrated in Figure D.1b, which shows a cut-away view of the design. Separate nozzles for each subunit will insure that gas enters each subunit at the same rate. Because the same amount of gas is being forced into differently sized compartments, the smaller

(a) TOP VIEW



(b) CUTAWAY SIDE VIEW

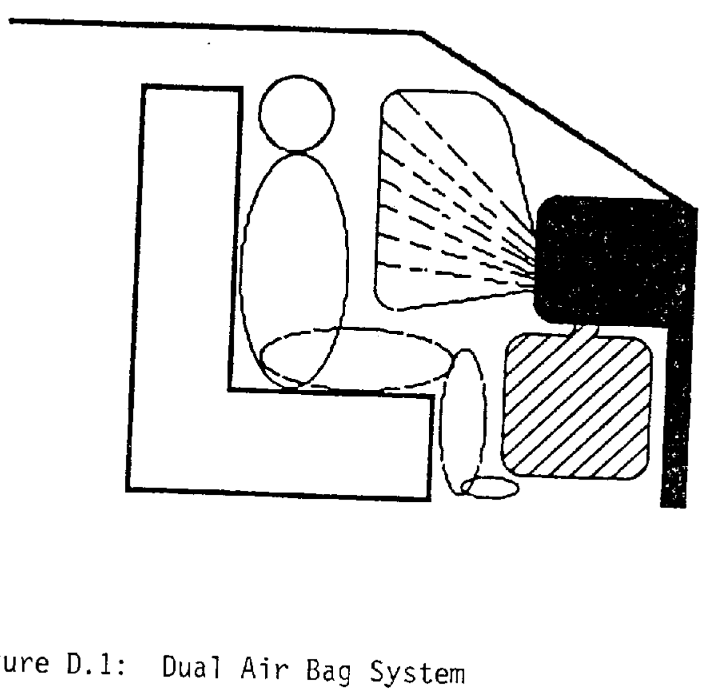


Figure D.1: Dual Air Bag System

compartments will be firmer than the larger compartments. This feature is useful and necessary to provide uniform deceleration.

The head area of the torso bag will have the largest internal units. Therefore, these units will be softer than the part of the bag cushioning the center of mass. This provides uniform deceleration of the head and the torso and prevents head and neck injuries.

The proposed contoured dual-bag system will reduce the likelihood of submarining, reduce neck injuries, and provide protection in off-center collisions. This design is a significant improvement over the currently available air bag systems. It would not be difficult to implement and it would not cost substantially more than the present air bag systems. Consumer acceptance should be the same as it is for the present air bag systems; consumer acceptance could be improved by educating the public about the benefits of the design.

D.2 Contoured Air Bag

The major problem with existing air bag systems is that they do little to prevent injury in non-frontal collisions of more than twenty or thirty degrees. Also, the shape of the bag allows the occupant to "submarine," causing serious neck, back, and leg injuries. Since approximately seventy percent of automobile collisions occur within sixty degrees of the centerline from front to rear of the car, it is desirable to have a system that is useful in collisions from all sides, does not allow submarining, and is as unobtrusive as possible.

A system was proposed which encloses the occupant and protects him in frontal and non-frontal crashes. The device is a contoured air bag shaped by an interior network of nylon fibers, similar to the inflatable escape chutes used by passenger airlines (see Figure D.2). Upon impact, the "arms" or "wings" surround the occupant; protecting him in non-frontal and even lateral collisions. The stiffness of the arms is controlled by the positioning of the interior fibers. By maximizing stiffness, the arms will direct the occupant into the center of the bag, thereby allowing him to ride out the crash for as long as possible. The stiffness of the center of the bag is also controlled by the fiber network. In this manner, the torso impact area can be made very stiff while the head impact area can remain relatively soft. This combination allows the head and torso to move forward the same distance, thus preventing the neck from being bent backward causing serious injury. Finally, the contoured bag also incorporates a tongue at its lower end to prevent the occupants' knees from moving forward. This reduces the likelihood of submarining and keeps the passenger in an upright position.

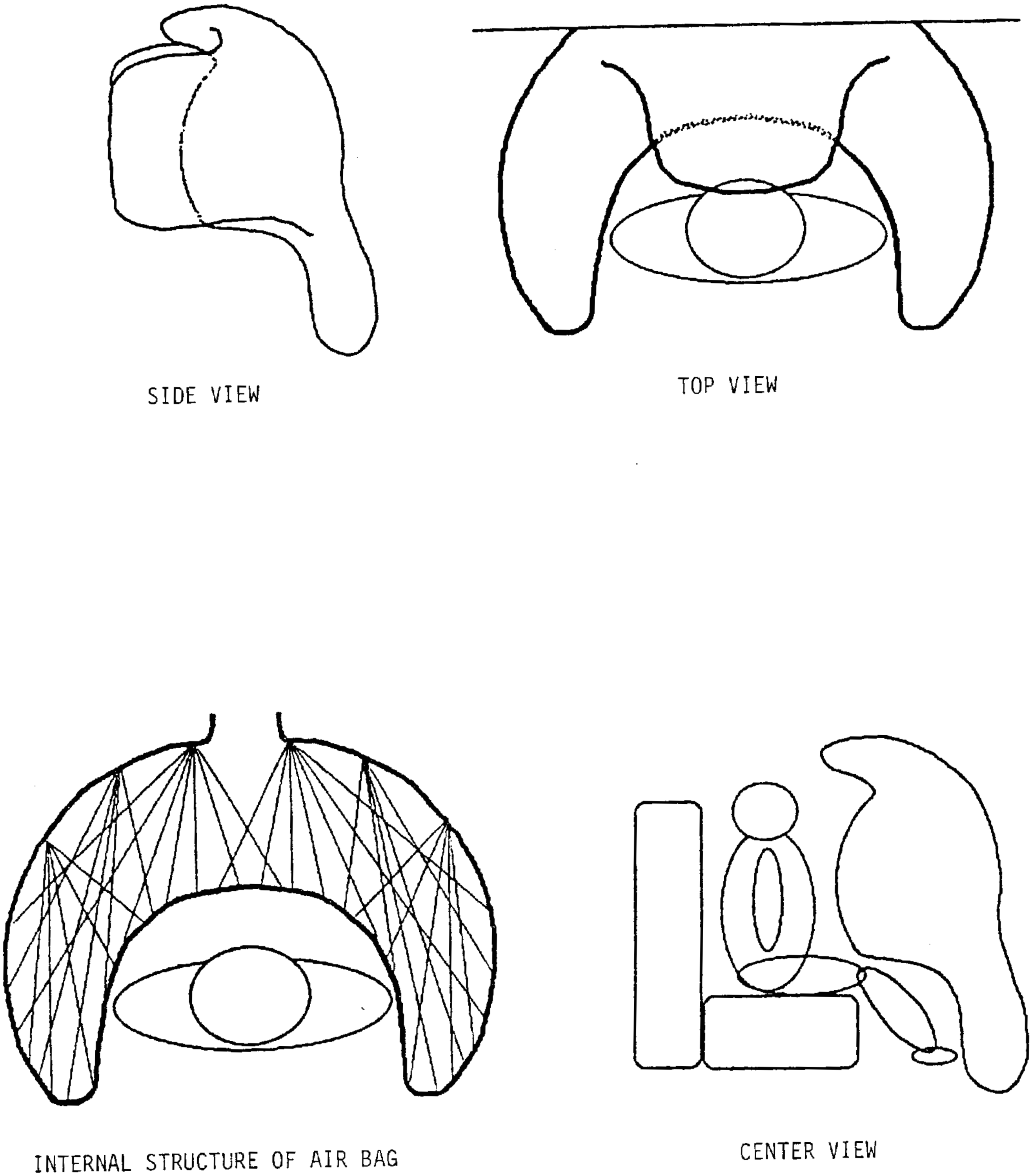


Figure D.2: Contoured Air Bag System

D.3 Overhead Air Bag and Joystick Steering

There are two basic approaches toward minimizing the collision forces of the motorist striking the car interior. The first is to keep him far from the rather hostile interior of the vehicle by providing substantial space around him. The second approach is to bring the passenger compartment snugly around him, modifying the car interior in form and energy-absorbing properties. A passive restraint system was developed that will increase the crush space around the motorist, allowing for comfort and easy placement of energy-absorbing devices.

One component of the proposed passive restraint system is a clear air bag cushion. The air bag is deployed from the roof of the automobile above the steering wheel. A chemical gas generator produces the inflation energy upon activation by an electrical signal from a bumper-mounted sensor. Sensors are available which can detect the velocity change of the bumper approximately seven milliseconds after vehicle contact (D.1). After activation, a clear air bag is released approximately one foot in front of the occupants head. The bag covers the windshield, dashboard, and extends below the occupants' knees. It has a crush distance of about ten inches to allow the energy of impact to be absorbed in the cushion.

Studies, by D. D. Campbell (D.2), of a collision with a stationary frontal barrier at 30 miles per hour (44 feet per second) were examined to determine the characteristics of the proposed system. Campbell noted that the distance from the occupant to the windshield is approximately 23 inches. If the clear air bag is placed 12 inches in front of the occupant, the occupant's head, after reaching the bag, can continue another 11 inches. Thus, the air bag crush should not exceed 10 inches. Assuming that the air bag can be described by a linear load-deflection relationship, the required stiffness would be 1212 pounds per foot.

The second component of the proposed system is a center console-mounted "joystick," which replaces the steering mechanism. The steering wheel and column are removed. The joystick would be placed to the right of the driver in a position where the driver could lean back comfortably while operating it with his right hand. Ideally, the joystick could be shifted manually to fit the individual driver. By removing the steering wheel and column, a cumbersome and potentially harmful piece of equipment is eliminated. The joystick idea is technologically feasible; it is currently used on Navy F-18 jets.

This system has three distinct advantages:

1. Inadvertent deployment would not be as dangerous; the air bag is clear, vision is not compromised, and the joystick operation would be relatively unaffected by the presence of the bag
2. There could be more room for energy-absorbing devices by eliminating the steering column
3. With overhead deployment, the problem of the air bag slapping the occupant in the face is eliminated.

D.4 Passive Belts

Several criteria were used to select the design of a restraint system using passive belts or bars. These criteria were based on desired and/or necessary performance and convenience characteristics. The performance criteria were:

1. The system must perform as well as active seat belt systems or better
2. It must be escapable
3. It must be reliable.

The convenience criteria were:

1. It must fit comfortably and in the correct place
2. It must allow the person to get into the car easily
3. It must allow person to get out of a running car
4. It must be relatively inexpensive
5. It must be aesthetic.

A passive belt system was selected with these criteria in consideration. The design concentrated on passive lap belt development since passive shoulder belt systems are already in production in Toyota and Volkswagen cars.

The basic design (shown in Figure D.3) uses a motor to drive one end of the lap belt along a track in the door, along the doorframe from the top of the door to the bottom rear of the door, where it would latch securely. The other end could be on a simple retractor, like the type used in present active shoulder belts, or it could be tightened by a motor utilizing the radar crash sensor. The motor, which moves the belt into place, would be activated when a person is sitting in the running car with the door closed.

Two major design problems had to be solved in order to make this system feasible. The first was how to allow a person to get into and out of a running car, (i.e., to drop off a friend at his house). When the door is opened, the belt would reel out and, at the same time, the motor would start the door-end of the belt moving out of the way. This may take a few seconds but should not be too inconvenient. Getting into the car should be no

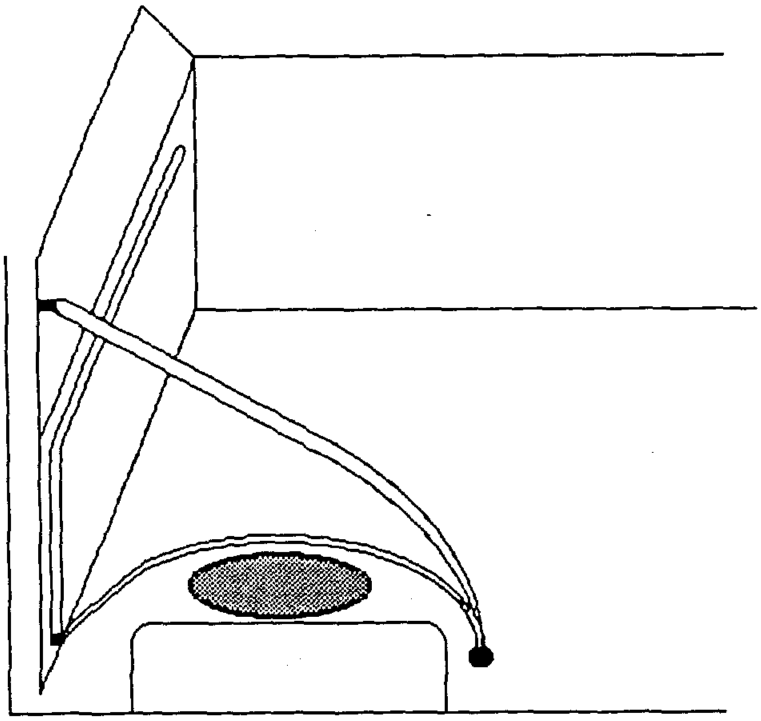


Figure D.3: Passive Belt System

problem since the belt would not be in place when the seat is unoccupied. The belt moves into place when the door is shut.

The second design problem is how to allow a person to escape the belt if necessary when the motor is incapacitated (i.e., after an accident). The belt could have a mechanical buckle, like the buckles in active systems, which could be unlatched. A problem arises, however, since the occupant can detach the belt permanently. The solution to this problem is simple; construct the buckle so that the car will not start if the belt is not attached.

Some alternative possibilities exist to activate the passive lap belt without a motor on the door. One alternative is to make the system purely mechanical, eliminating the need for and problems arising from electric motors. Another alternative is to design some sort of elephant-trunk belt which would come up and around from the floor and free the door from such obstructions.

D.5 Seat Belts

The passive restraint design proposed by the ME/EE design team consists of a pneumatically-guided lap belt and a crash-inflated shoulder sash in a conventional three-point configuration, as shown in Figure D.4. With no one in the seat, the lap belt's resting conformation is pointed toward the roof and lying alongside the outboard seat back with the shoulder sash attached at the top end; this is a similar orientation to those currently used for woven fabric seat belts of contemporary design. When a person sits in the seat, a weight sensor triggers a circuit that starts a small onboard air compressor pumping air into the uniquely constructed tubing that forms the core of the lap belt.

The lap belt is constructed of flattened elastomeric tubing, axially reinforced with stiff fibers on one side. The tubing may contain one continuous internal cavity with the axial reinforcement spiraling at a variable angle around its circumference to control its shape as it is inflated. Or the tubing may be segmented with the segments individually inflated similar to Wilson's Flexible Pneumatic Robot Arm (D.3), as shown in Figure D.5. The pattern, order of inflation, and therefore the three-dimensional path taken by the latching end of the belt as it is inflated will be controlled by an onboard microprocessor. As the tubing is inflated, its latching end moves down and forward, wrapping around the person's body; it is guided by the anisotropic structure of the tubing. A simple model demonstrating this principle is shown in Figure D.6; when the bicycle tire is inflated, the duct tape on one side restrains that side from inflating. The end of the belt is connected to a cylindrical rod with a channel cut into it. When the rod is directed into the latching mechanism, a circuit will be completed that will activate a solenoid. The solenoid will drive a restraining member into the channel, securing the belt. The latching mechanism, which is a stiff cylinder elliptical in cross-section located between the seats, is internally funneled to aid connection. It is also provided with an emergency user release button that will mechanically override the solenoid. Once the belt is latched, it will be tightened as the latch mechanism is drawn down and towards the rear seat. The shoulder sash supplements

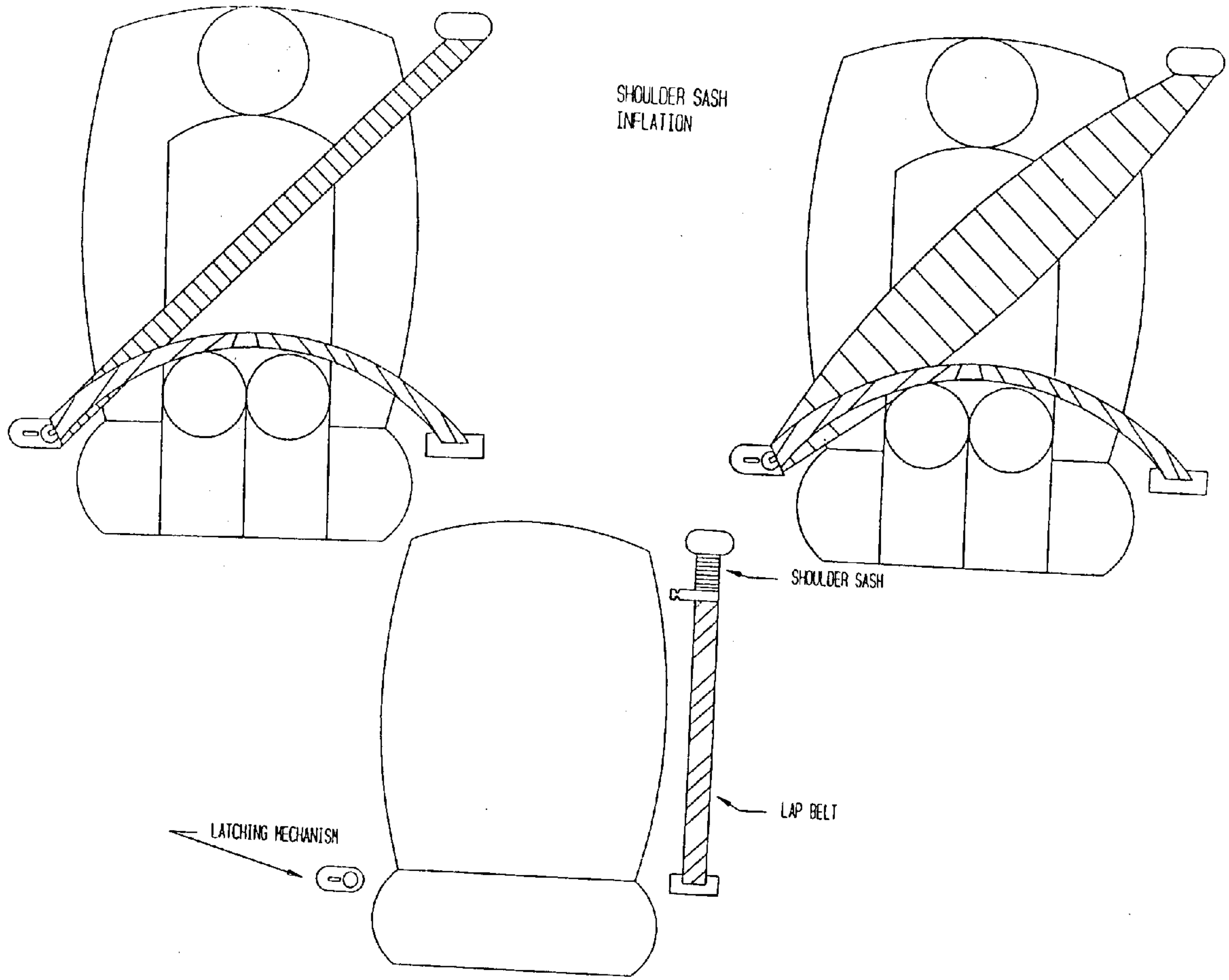


Figure D.4: ME/EE Design Team Passive Belt System

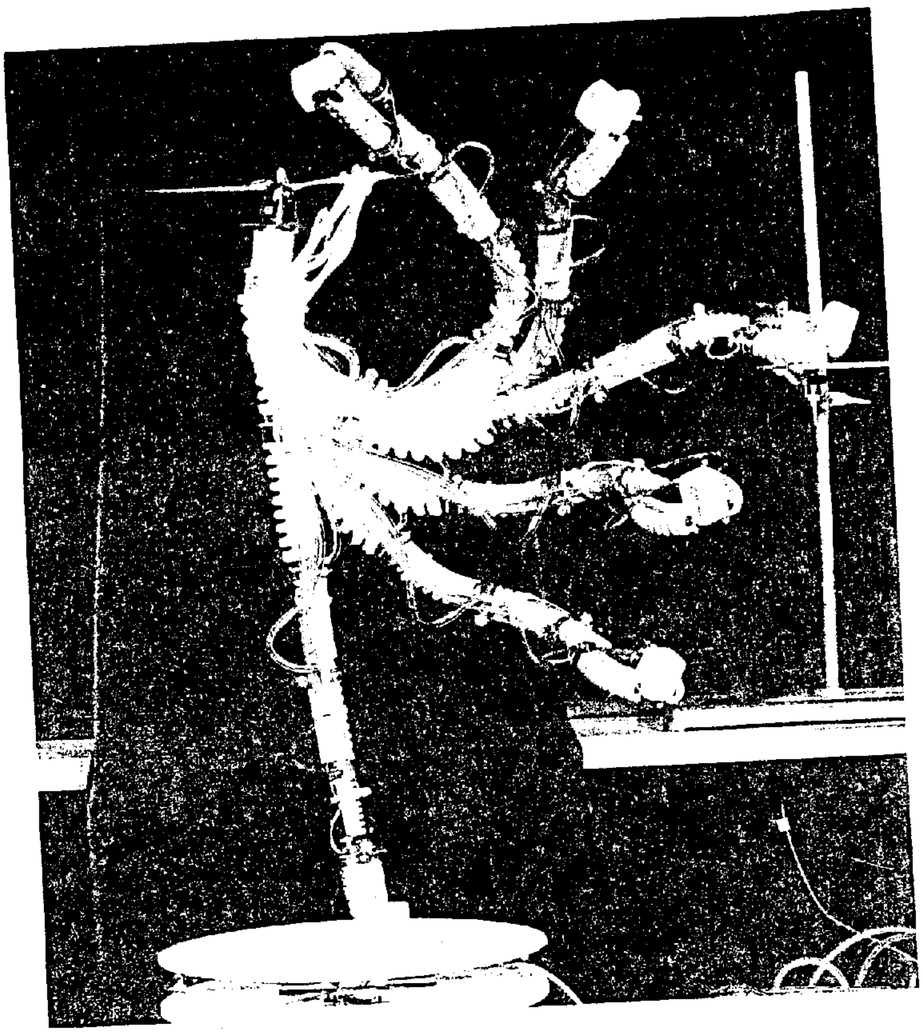
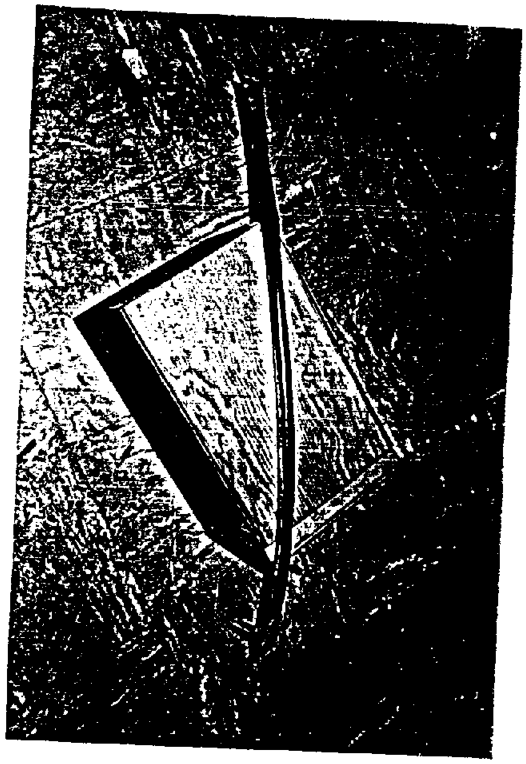


Figure D.5: Wilson's Flexible Pneumatic Robot Arm (abstracted from Scientific American)

(a)



(b)

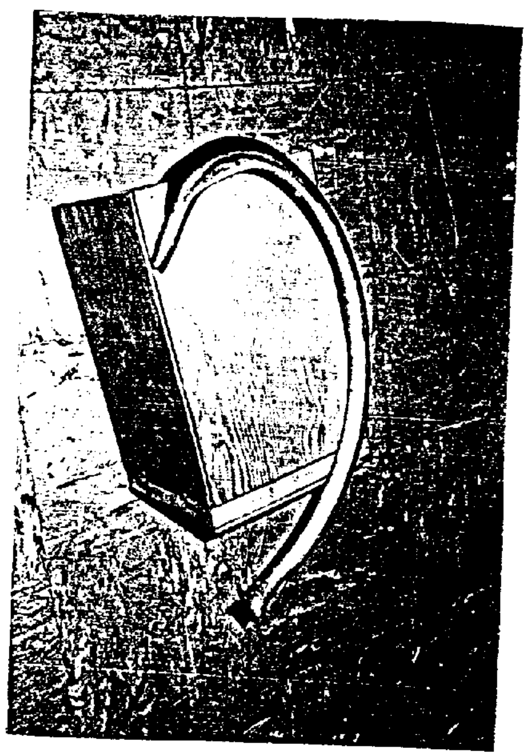


Figure D.6: Uninflated (a) and Inflated (b) Tubing for Lap Belt a normal shoulder belt with an inflatable bag between the body and the webbing of the belt, modeled after the system described by DeJeammes (D.4). This sash, which is inflated by a crash-triggered system, provides more occupant restraint than present systems and decreases the probability of submarining or otherwise slipping from the restraint of the belt.

The proposed restraint system would be particularly effective in side impacts and for small individuals. The limited volume of the sash, compared to an air bag, makes rapid inflation possible without the necessity of high-pressure gas cylinders; an accumulator filled by the air compressor should be sufficient. The inflated belt's circular cross-section and large surface area can absorb more energy and reduce the risk of neck laceration (D.5). The proposed lap belt and shoulder sash are at least as effective as present three-point belt systems, even if the inflation system malfunctions. With inflation, this system provides greater occupant protection with no increase in discomfort or inconvenience.

Since the lap belt functions as a "soft robot arm" and would not have the power to produce injury, it would be easy for the occupant to physically block the latch on the guided end from locking into the latching receptacle. An ignition interlock would be required to prevent the occupant from purposely defeating the system. Alternatively, the harness could be programmed to simply continue trying to wrap itself around the passenger until he or she finally gives up interfering with the process and succumbs to being restrained.

The initial optimization of the physical layout and vehicle installation can be inferred from studies that have been conducted previously for various seat-belt geometries (D.6,D.7). This local optimum is essentially the same as that used with present three-point belt systems. Testing will be required in Phase II. The occupants' responses to being "caressed" and restrained by a persistent and mildly intelligent safety harness should be evaluated. The structure of the belts and the adjustability of the latching mechanism needs to be optimized. One of these structures developed in Phase II might represent a global optimum of the design (i.e., a passive door-mounted system that utilizes the flexible pneumatic robot arm).

The proposed design should perform at least as well as conventional seat belts, even without inflation. Adding pneumatics provides a novel way to make the restraint unobtrusive when the passenger enters the vehicle and put the restraint into position around the passenger in a passive manner. The presence of a small air compressor has other advantages (i.e., it can be used to pump air into a tire that has gone flat or vary the pressure in the air-assisted shock absorbers). The microprocessor that controls the air flow into the safety belt's components could also control the stiffness of "smart" shock absorbers and engine mounts in an accident to minimize engine intrusion into the passenger compartment.

D.6 Moving Seats

A major problem in side collisions is that the occupant can easily be trapped by the crush of the vehicle when held stationary in his seat by a seatbelt. If the occupant is not wearing a seatbelt, the side impact may cause him to eject through the window. A passive restraint system was designed to move the occupant away from impact during a side collision. A movable seat shifts the occupant away from the impact site and allows the crush of the vehicle to occur without occupant contact.

The appearance of the seat would be similar to present seats. Some changes would be made in the cushioning of the seats (i.e. wings on the sides of the seat to help secure the passenger during the seat movement.) Also, extra cushioning may be added to the back and sides of the seat, to allow more padding for the person on the side opposite the point of contact. Because the seat would be translating and rotating at relatively high velocities, the occupant may also have to be restrained in some manner.

The movement of the seat would be controlled by a cable and pulley system which would be activated immediately upon impact by the crush of the vehicle. Simultaneously, the seat furthest away from impact would translate to the far door and the seat closest to impact would translate and rotate away from the impact. The purpose of the rotation in the near seat is to allow for maximum translation without crushing the occupant's legs (See Figure D.7). The design of this system is such that the forward-backward adjustment of the seat, for passenger comfort, is not inhibited. The system would incorporate a release mechanism for the seat that would allow the pulley system to pull the seat into its final position (a to a' and b to b'), regardless of how the seat is adjusted prior to the accident.

If the average deceleration of the incoming car after impact is 20 g's and the car was moving at a velocity of 44 feet per second before impact, the duration of the crash is 68 msec and the distance of the crush is 1.5 feet. In order to move the occupant far enough away from the door that the crush of the vehicle does not reach him, the occupant must be at least 1.5 feet from the original point of contact of the incoming car when the

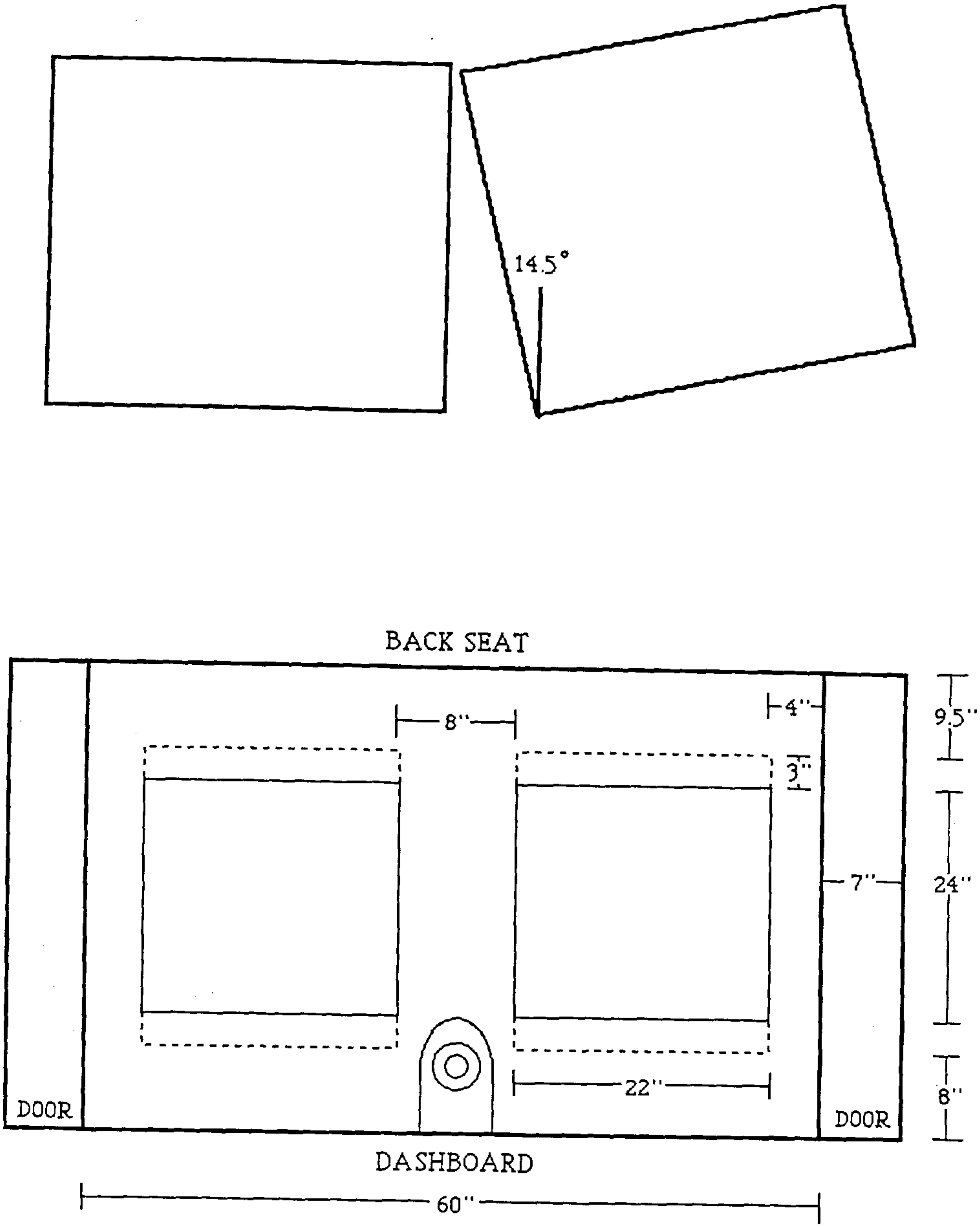


Figure D.7: Moving Seat System

movement is completed. The first point of the seat to be contacted by the crush is 1.5 feet from the outside of the door prior to crush. Since the time allowed for the movement of the seat must be less than the time it takes for the crash to occur, the movement time was set to 60 milliseconds. The average seat velocity must be 11.1 feet per second. To obtain this average velocity, the seat must be accelerated to twice the average velocity in half of the allowable time and then slowed to a stop in the remaining time. Thus, the average acceleration of the seat is 23 g's and the average deceleration of the seat is 23 g's.

At first inspection, these values appear to be both feasible and tolerable by the occupant. When the vehicle acceleration of 20 g's is added to the seat acceleration, the total acceleration of the occupant is 43 g's, which is beyond the limit of human tolerance.

From these calculations, it was determined that it would be harmful to the occupant to move him away from the side of impact far enough so that no contact is made with the vehicle crush. This problem, along with the fact that a restraint system is still required to hold the passenger in the seat, was the main reason why this design was abandoned.

D.7 Radar Sensor

A radar sensor was proposed for the passive restraint system. One purpose of the sensor is to prepare the occupants of the automobile before an oncoming frontal collision occurs. A second purpose is to use the sensor as an early warning device for a number of different passive restraint systems. The proposed sensor tightens the seat belts before a possible collision. This system could also be incorporated with other ideas.

The radar system consists of three units. The first unit is a sensing unit using Doppler Radar (better known as Police Radar). This determines the relative speed of any object at which the radar is aimed. By pulsing the signal and calculating the time for the received signal, the distance from the object may be determined. The speed of microwaves in air is approximately one nanosecond per foot. A reading from one-half mile away would take approximately five microseconds. The second unit is a microprocessor. The microprocessor is a simple system with an internal pre-programmed memory which contains a table with the car's stopping distance at various speeds. The microprocessor's task is to compare the measured relative speed and distance with the car's capable stopping distance at this speed. If it determines that the car cannot stop in time, then it will signal the control unit to tighten the belts. Microprocessor operations can be performed within a few hundred microseconds. The third unit is the control unit. This unit tightens the seat belt, by request from the microprocessor. The microprocessor will signal the control unit to tighten the seat belts when it is definite that a crash will occur. The microprocessor will already know the time that it takes the system to tighten the belts and will allow this much time to react.

The radar sensor has other options. First, the amount the belts are tightened could be variable. Therefore, the microprocessor would tell the control unit to tighten the belts depending on how far off the car is from its capable stopping distance. Second, the device could be mounted on the exterior of the car to measure moisture. This would be used to alert the system to adverse road conditions and, upon such a situation, the microprocessor would automatically switch to an alternate set of tables designed for more conservative stopping distances.

There are a number of problems with this system. First, the cost of the radar and microprocessor could be excessive. Second, the sensitivity of the system could be problematic. The radar must be set so that it does not deflect from objects that are not perfectly perpendicular to the ray propagating axis. However, if set too sensitive, the system may react to rain droplets or leaves. Third, the time required to record relative speed and distance, to compare this data to the microprocessor's stored data, and finally to tighten the belts is a crucial factor for this system's application. The more readings that may be made, the more successful the system will be at preparing the occupants, especially for the variable tightening system. Other factors to be considered are stability, power requirements, and performance at curves and stoplights.

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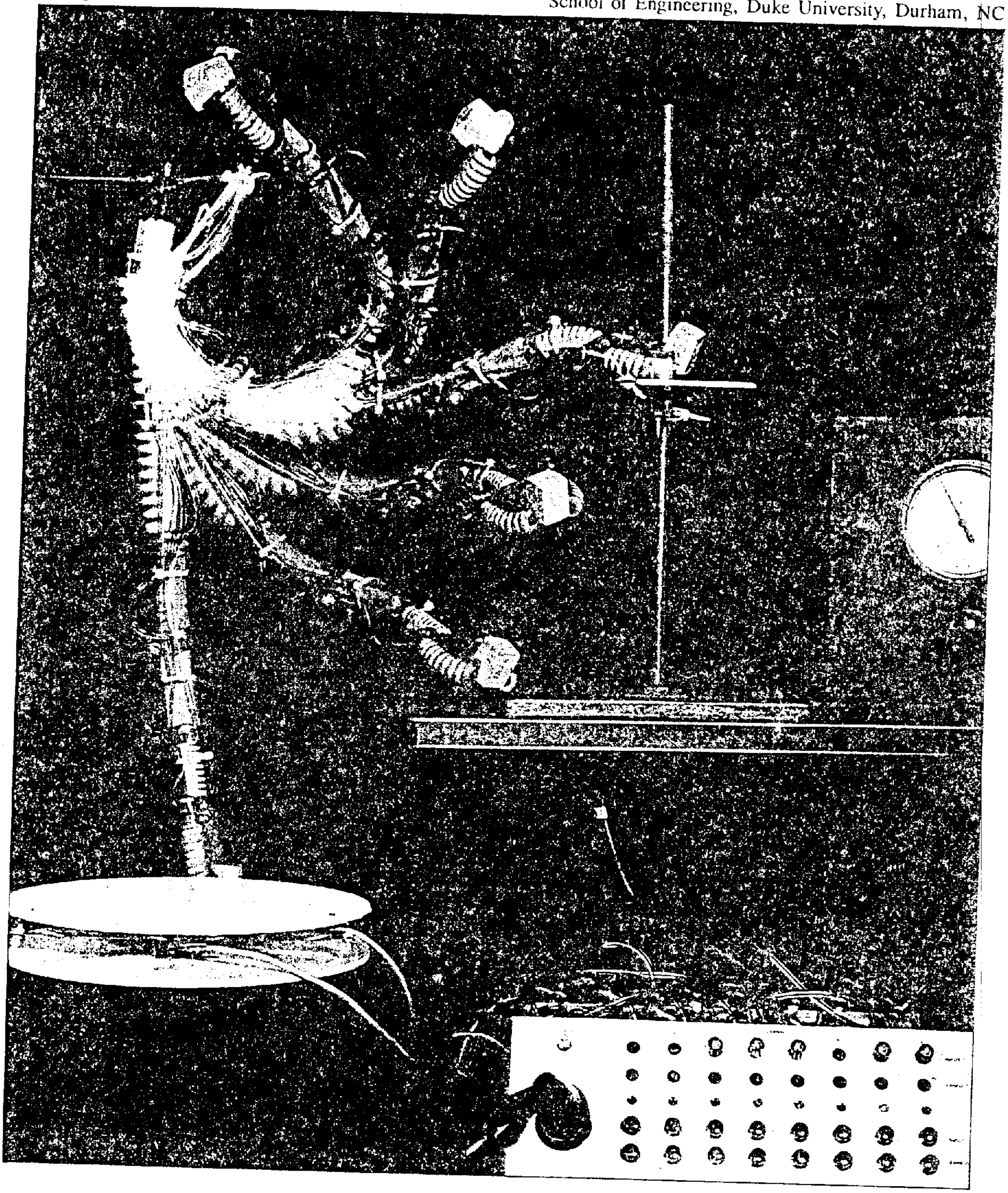
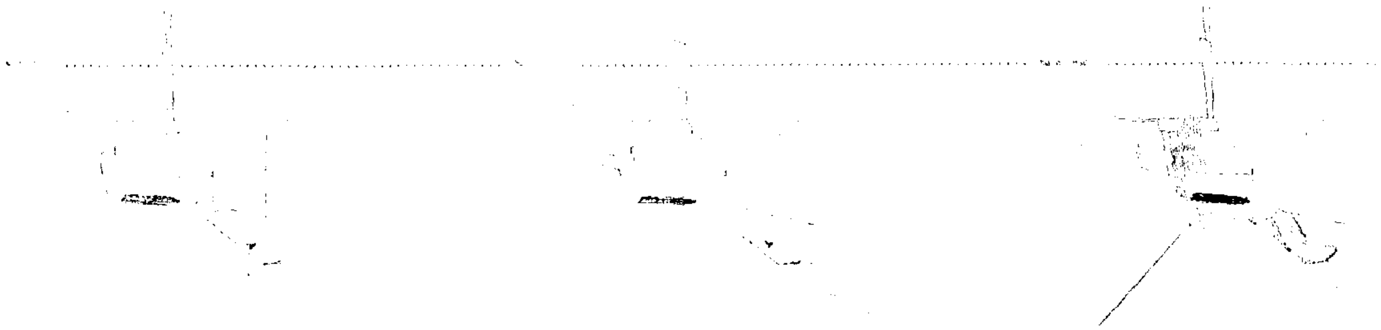
School of Engineering, Duke University, Durham, NC



Passive Restraint System



Last winter when students signed up for BME 230 they thought that they would be taking Biomechanics. Instead, these students were welcomed back from the holidays with an engineering project needing a research and development team. Duke had been selected by the General Motors Corporation to compete in designing passive restraint systems for automobiles.

Twenty-eight schools submitted proposals to GM for the university competition. The four schools selected to compete are Duke, Tennessee Tech, Purdue, and Texas Tech. Each school received $25,000 to fund the first phase of the competition involving background research and concept development. On April 30, 1987 the schools will present their conceptual designs, and by May 15 the winner of the $100,000 award will be announced. The winning university will then continue their work and present a final prototype design in early December.

The purposes of this program are to develop alternative passive restraints that are acceptable and functional and to expose university students and faculty to the automotive design process. A passive restraint is defined as a design providing restraint in cars but requiring no action on behalf of the occupant. There already exists a number of forms of passive restraint including automatic belts and airbags. Another approach has been the development of "friendly interiors" which are aimed at reducing the effects of impacts between the occupant and various vehicle components. Extension of these ideas and development of new concepts in passive restraint design are the primary reasons General Motors sponsored the contest.

Duke's research team is headed by Dr. James McElheny and Dr. Jacqueline Paver. McElheny's BME 230 class is the main research team, and Paver is coordinating the project. McElheny's class began their semester brainstorming. Many ideas were considered until six design categories were chosen. These categories were crushable vehicles, cushioning of interior, passive belts and bars, deployable cushions, pivoting seats or passenger cushions, and miscellaneous. In addition, groups were formed to look at other aspects of the problem. These groups investigated statistics, computer modelling, and criteria.

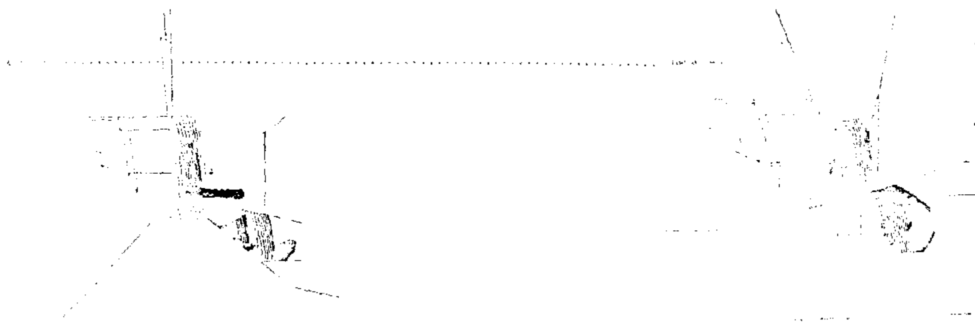
The statistics group looked at relevant literature on passive restraint systems. Much of their searching utilized computer data banks, specifically two U.S. Air Force computers, the DB 56 and DB 57, and the HSRI system. These data banks pro-

Dr. McElhaney

Dr. James H. McElhaney is a graduate of Villanova University. He received his masters degree from the University of Pennsylvania, and his doctorate from West Virginia University. McElhaney has taught and participated in research projects at West Virginia and Villanova, and also at the University of Michigan, where he was the head of the Biomechanics department. He has been a part of Duke's Biomedical Engineering department since 1973, and currently serves as the chairman of the department and as a professor of Biomechanics.

Competition

by Jennifer Lindquist



Sequence shows a 30 m.p.h. frontal barrier crash simulation with a Part 572 dummy in a 1981 Dodge Aries. Courtesy of Dr. Jacqueline Paver, BME Department.

vided much information on past accidents such as car type, injuries, and impact information.

The computer modelling group is using a program to simulate human body performance in an accident relative to controllable parameters. The program incorporates thirty-four degrees of freedom and twenty joints. The students varied the parameters to find the optimum accident behavior.

The criteria group considered many outside factors and tried to model constants into an algorithm to estimate the overall effectiveness of a particular passive restraint design. This algorithm takes the form of a performance index, which is the sum of all the pertinent factors of restraint system effectiveness multiplied by appropriate weighting factors. The performance index has the general form:

$$I = (\text{frontal term}) + (\text{side term}) + (\text{rear term})$$

A typical term has the form:

$$\text{term} = ABD(N2C2 + N3C3 + N4C4 + N5C5)$$

where A is the percentage of crashes in the relevant direction, B is a term which excludes oblique collisions, C2-C5 describe the distribution of occupants per car, N2-N5 are the number of interaction casualties per car, and D is the percentage of measured dummy loads (which correspond to injury severity) due to interactions.

Student teams considered several design possibilities. Some of the ideas worked on included contoured air bags designed for improved cushioning, a deployable dashboard which is padded or will fill with air upon impact, swivelling seats to increase crush distance in side impacts, detectors and microprocessors to determine an impact before it actually occurs, and ways to make present seat belt systems more passive. These competing designs were presented to General Motors in late February. The corporation chose one of these designs prior to Spring vacation. This final design will be developed and presented along with designs from the four other competitors to General Motors in Michigan at the end of April.

The students in BME 230 learned much about the engineering product development process. The passive restraint competition provided the students with a look at engineering from a professional perspective. Many of the procedures used by the students varied considerably from normal classroom activity. Brainstorming became very popular among the class. As one student remarked, "brainstorming is cool."

Regardless of the outcome of the competition, it has been a valuable experience for the students and faculty involved. ■

Jennifer Lindquist is a junior in Biomedical and Electrical Engineering.

Dr. Paver

Dr. Jacqueline G. Paver is a graduate of Harvey Mudd College. She received her M.S. and Ph.D. degrees from Duke University in 1980 and 1984, respectively. Paver has varied interests in Biomedical Engineering, and her dissertation topic was the Biomechanics of Head and Neck Injury and Protection. She is a Research Assistant Professor in the School of Engineering.