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TECHNICAL REPORT

INTEGRATED SEAT AND OCCUPANT RESTRAINT PERFORMANCE

CAL No. YB-2499-V-1

Prepared For:

U.S. Department Of Transportation
Federal Highway Administration
National Highway Safety Bureau
Washington, D.C. 20591

Final Report
Contract No. FH-11-6631
September 1967

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NATIONAL HIGHWAY SAFETY BUREAU
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FOREWORD

This report presents the results of a research planning effort performed by the Cornell Aeronautical Laboratory, Inc. (CAL) under Contract No. FH-11-6631 with the National Highway Safety Bureau (NHSB), Federal Highway Administration, Department of Transportation.

This report has been reviewed and is approved by:

Robert A. Wolf, Head
Transportation Research Department

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CAL is indebted to Mr. A. W. Blackburn and Mr. W. D. Crater of the NHSB for their guidance and advice in conducting the present program. Also, the cooperation afforded CAL in consultations with personnel of the General Motors Corporation and the Ford Motor Company is gratefully acknowledged.

Within CAL, the following individuals contributed to this study: Raymond R. McHenry, Robert H. Dufort, Frank A. DuWaldt, Hans G. Reif, Kenneth N. Naab, Robert A. Wolf and Edwin A. Kidd.

SUMMARY

The integrated seat concept has potential value primarily as a means for promoting increased use by automobile occupants of restraint systems. Lap belts and appropriate upper torso restraints that are attractively integrated with the seat structure and that are convenient to use should provide early payoff in injury reduction in head-on impacts, the major source of injuries and fatalities in both rural and urban accidents. If more use of lap and upper torso restraints can be achieved, injuries can also be reduced in a secondary source, rollover accidents. Lateral restraint and protection against compartment penetration are required before injury reduction in side impacts can be achieved. Occupant restraint for rear impacts may be achieved with yielding seat-backs and appropriate head rests.

All of these requirements should be achievable to some degree in an integrated seat design. A program is recommended that is directed toward the short term determination of performance requirements for this integrated restraint system and toward long range research and development to provide improved integrated occupant restraint.

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1.0 INTRODUCTION

The general concept of an integrated safety seat for passenger type automobiles is frequently proposed as one possible means of improving the protection of occupants in collisions and other highway accidents involving impact. For purposes of this study an Integrated Safety Seat is defined as one in which the major components of the occupant restraint system are functionally incorporated into a seat structure which in turn is designed to carry the impact reactive forces of the occupant through it and into the vehicle structure. This principle may apply to individual type seats or bench types and would admit such concepts as 3 or 4 point harness systems, tilt seats, retractable clamp type devices, etc. The hope is that the concept can be realized in forms with improved restraint system effectiveness and with sufficient convenience and styling appeal that they will induce people to buy and voluntarily use restraint systems which otherwise would not be tolerated by the majority of motorists.

In contrast, another basic approach to improved passenger restraint is the development of an Integrated Station in which the restraining function is accommodated by a restraint system (seat belt attached to floor) working in combination with other vehicle structural elements such as steering assemblies and door padding (driver station) or cut-away instrument panels for jackknifing clearance (right front passenger station). The trend of such evolution in American cars is arbitrarily characterized as the Integrated Station approach and is outside of the scope of this study. The present phase of American restraint systems may be characterized as "the seat belt era" and it is assumed that a next phase will introduce a new generation of three point restraint systems, an "advanced" form of harness type restraint not yet subjected to large scale public acceptance trials. Presently available harness systems are so crude and cumbersome that in a full vehicle installation the car interior becomes a distressing clutter of straps, buckles, fittings, and obstructions to entry and egress that discourages even the most fervent safety enthusiast.

This study does not ignore the station approach but it seeks to explore the potential of the integrated seat approach as a separate entity and to outline a program to maximize its performance and to determine its relative benefits compared to the station system.

A strong emphasis in this study is placed on improving "convenience". The term is used here not only to mean convenience in entry to and egress from the vehicle, ease of adjustment to the occupant, and comfort while wearing, but also to imply that the aesthetic sense must be satisfied. In other words, we are seeking a solution which is not only technically sound but also aesthetically acceptable.

The ideal restraint system would be one which is not visually apparent and would require no active participation by the user. The safety door latch is an example of an effective passive restraint device which keeps passengers inside of the car during an impact. Its function is to reduce ejection of passengers through doors that open under impact. This is a partial restraint function but unfortunately, even with closed doors, the passengers are still free to be thrown violently about inside of the car and to be injured by contacting surfaces, structures, and controls in the so-called "second collision". Thus, even with a first stage of gross restraint (safety door latches), a second stage (individual passenger restraint) is needed to allow the passengers to decelerate with the car, and without violent contact with interior components of the vehicle. The familiar lap belt, effective as it is, reaches only part way toward this goal and it does not prevent contact impact with such objects as steering assemblies, windshields, control knobs, instrument panels, door posts etc. Also it is not widely used. Most usage surveys show that only about one third of the people who have them consistently use seat belts even though they are being made more appealing through use of retraction reels, simpler buckles, etc.

In summary, the main question facing this investigation is:

> Can a more effective and more convenient individual passenger restraint system be reached through the integrated seat concept?

The purpose of this study is to review and restate the basic restraint system functions, describe various integrated seat concepts and outline both a program of needed research and a program to define, design, develop, and evaluate promising examples of integrated seats. In this manner, the way may be pointed toward eventual specification of safety performance requirements and compliance tests for application of the principles to passenger carrying motor vehicles.

Performance Objectives

The desired overall objectives of an integrated safety seat development program are to provide concepts of passenger restraint with improved --

- Comfort
- Convenience
- Aesthetic Appeal
- Effectiveness

over the current generation of seat belt and harness type restraint systems which are attached to the vehicle body structure.

Functional goals are:

- Improved restraint from all directions of impact -- front, side, rear, and rollover.
- Upper torso restraint.
- Improved head restraint.
- Minimization of contact injury.
- Tolerable freedom of movement while riding.
- Ease of adjustment to persons of both sexes and of various sizes.
- Fixed restraint system geometry, e.g., not critically changed by fore and aft seat adjustment.
- Maximum use of energy absorption in the seat structure and mountings.
- Avoidance or minimization of passenger-to-passenger impact.
- Minimization of injury induced by restraint system itself.

The investigation of potential effectiveness (Section 2 of this report) has been approached by means of (1) a review of the existing state of knowledge of pertinent accident statistics, (2) a review of pertinent human tolerance data, (3) preliminary applications of an existing CAL analytical simulation of the crash victim for longitudinal impacts, (4) preliminary analytical studies of the problems of lateral impact and rollover, (5) a review of existing integrated seat concepts in the open literature, and (6) discussion with automobile and equipment manufacturers. On the basis of the findings, a discussion of needed knowledge is presented in Section 3, and a program of recommended research, development and evaluation is outlined in Section 4.

The recommended program is divided into two phases:

Short Term: A set of tasks which may be undertaken immediately and which will provide useful output in about a year from initiation.

Long Term: This encompasses a set of tasks which can be started within a year but may require several years to produce results.

Estimated costs of future research are discussed in Section 5, and a list of references is presented in Section 6.

2.0 STATE OF KNOWLEDGE

2.1 Automobile Accident Statistics

It is the aim of this section of the report to present actual highway accident statistics on the types of accidents that are most prevalent and to thereby establish which areas of research on occupant seating and restraints will be most beneficial to the motoring public. The following two sets of accident data were examined, one published by the National Safety Council and the other from ACIR files.

2.1.1 National Safety Council Data

To estimate the relative importance of various directions of impact, use is made of accident data published on page 46 of "Accident Facts, 1967 Edition". The results will have to be taken with extreme reservation due to the nature of the basic data and due to the simplifying assumptions made in the estimation procedure. The crucial points are as follows:

1. The accident data are from 23 states and 170 cities (over 10,000 population) only.
2. The cities are not necessarily all in those 23 states although a spokesman of NSC thinks that the urban and rural data can be fairly safely combined.
3. The data include all motor vehicles, i.e., buses, trucks, motorcycles, cars, etc.
4. Excluded are several types of accidents, for example those involving pedestrians or parked cars or fixed objects on road, accidents

Automotive Crash Injury Research project at CAL sponsored by the Public Health Service, Department of Health, Education and Welfare, and the Automobile Manufacturers Association.

connected with driveways, and others. The exclusions amount to 42 percent of all reported urban accidents in the 170 cities and 34 percent of all reported rural accidents in the 23 states. It is impossible to determine the effect of these exclusions on the following analysis.

5. Only fatal accidents were shown as a separate category, not injury accidents.

6. The basic number of accidents (total and fatal, urban and rural) was given in four categories:

a) Head-on collision
b) Rear-end collision
c) Angle collision
d) Ran-off road (which includes rollovers without collision, object collisions, and their combinations).

7. For estimation purposes the following assumptions were made:

a) Each head-on collision involves two vehicles, both in a frontal impact

b) Each rear-end collision involves two vehicles, one in a rear-end impact, one in a frontal impact

c) Each angle collision involves two vehicles, one in a side impact, one in a frontal impact

d) Each ran-off accident involves one vehicle. ACIR data has shown that rural ran-off accidents are composed of frontal impacts, side impacts, and rollovers in proportions of 45-10-45 percent. Based upon this information and allowing for a lesser frequency of rollovers in cities, the urban ran-off accidents were allocated in proportions of 68-10-22 percent.

Obviously, the number of vehicles thus estimated is somewhat low, there being accidents with three or more vehicles.

8. It was assumed that each fatal accident involves just one fatal vehicle (vehicle with a fatality in it). Of course, this is also underestimation, there being accidents with fatalities in more than one vehicle.

9. Finally, it was assumed that in head-on collisions and angle collisions the relative frequency of fatal vehicles was the same among striking vehicles as among struck vehicles. On the other hand, for rear-end collisions it was assumed that the relative frequency of fatal vehicles among struck vehicles (rear impact) was one-half of that among the striking vehicles (front impact).

With these provisions and assumptions, calculations result in the following summary:

	Events: Number of Accident Vehicles	Risk: Fatal Vehicles per 1000 Accident Vehicles	Result: Number of Fatal Vehicles
Urban			
Front	5,940,000	0.73	4,300
Side	1,850,000	0.71	1,320
Rear	3,000,000	0.09	270
Rollover	110,000	4.36	480
All Urban	10,900,000	0.59	6,400
Rural			
Front	2,395,000	5.43	13,010
Side	510,000	4.51	2,300
Rear	800,000	0.68	540
Rollover	495,000	8.18	4,050
All Rural	4,200,000	4.74	19,900
All Vehicles	15,100,000	1.74	26,300

To show emphasis, the four leading figures in each column are underscored.

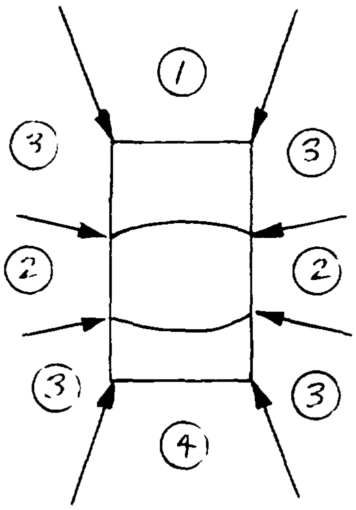
2.1.2 Automotive Crash Injury Research Data

A tabulation of nearly 25,000 accident cases in the ACIR files has been formed to aid in defining types of accidents and causes of injuries sustained by occupants for which an integrated seat design may prove to be most beneficial in reducing the frequency and/or severity of injuries. The data were obtained only for "pure" accidents, i.e., grazing, sideswipes, and various types of angled hits were omitted. The general classification is as follows: (1) frontal impact, from 11 to 1 o'clock (12 o'clock being the front-center of the car), (2) side impact in the region of the passenger compartment, from 2 to 4 o'clock, (and 8 to 10 o'clock), (3) side non-compartment impact (fender regions), (4) rear impact, from 5 to 7 o'clock, (5) rollover without a collision, (6) rollover before a collision and (7) rollover after a collision.

The relative frequency of occurrence of these types of accidents in rural areas (ACIR cases represent predominantly rural area accidents and only those in which at least one occupant was injured) is shown in Table 2.1-1. This table also presents information for comparing the severity of the accidents, frequency of dangerous or fatal injuries sustained by front seat occupants (driver and right front passenger) and how often these occupants were ejected from the vehicles. From Table 2.1-1 it may be seen that the majority of all accidents were frontal collisions with nearly 10 percent of this type classified as severe or extremely severe accidents. Rollover accidents are the next most frequent type and are more often of a greater severity, particularly if the vehicle is involved in a collision either before or after overturning. A larger percentage of the accidents in which the vehicles are struck on the sides in the region of the passenger compartment are also of high severity but this type of accident occurs less frequently.

Table 2.1-1
ACCIDENT TYPE COMPARISONS

ACCIDENT TYPE	NUMBER AND PERCENT	SEVERE OR EXTREMELY SEVERE ACCIDENTS* (%)	DANGEROUS OR FATAL INJURIES (%)		EJECTION (%)	
			DRIVER	R.F. PASS.**	DRIVER	R.F. PASS.**
FRONTAL	14541 (59.1)	9.5	9.6	9.7	3.7	4.3
COMP.	2257 (9.2)	30.0	18.3	18.9	17.7	19.2
N. COMP.	1009 (4.1)	7.0	11.1	10.4	19.5	20.3
REAR	1700 (6.9)	4.5	1.9	2.8	2.0	2.0
R.O. NO. COLL.	2906 (11.8)	17.8	15.7	13.0	28.8	27.1
R.O. BEFORE	241 (1.0)	31.1	20.6	14.5	33.1	30.0
R.O. AFTER	1938 (7.9)	29.8	18.1	15.5	29.6	30.2



CAR REGION	ACCIDENT TYPES
1	FRONTAL (11 TO 1 O'CLOCK)
2	SIDE - PASS. COMP. (2 TO 4 AND 8 TO 10 O'CLOCK)
3	SIDE - NON. COMP. (FENDERS)
4	REAR (5 TO 7 O'CLOCK)
R.O.	ROLLOVER - NO COLLISION
R.O. B.	ROLLOVER - BEFORE COLLISION
R.O. A.	ROLLOVER - AFTER COLLISION

*BASED ON EXTENT OF DAMAGE FROM PHOTOGRAPHS
**RIGHT FRONT PASSENGER

The table also shows a general correspondence between the rankings of percentages of severe accidents and dangerous or fatal injuries for the several accident types. This result is logical because an accident type for which the frequency of severe accidents is high would also be expected to show a correspondingly high percentage of dangerous or fatal injuries to the vehicle occupants. However, it is well to note that, in terms of reducing the actual number of dangerous or fatal injuries, the greatest potential lies within the frontal accident category, simply because this type of accident occurs most frequently. To illustrate, consider the distribution of 100 accidents. Approximately 59 of these accidents would be of the frontal type in which nearly 6 drivers (9.6%) would be dangerously or fatally injured. This is to be compared with approximately 9 accidents of the side compartment impact type in which less than 2 drivers (18.3%) would sustain dangerous or fatal injuries.

The dependency on the direction of impact of the probability of occupants being ejected from the vehicle (one of the primary causes of injury) is also evident from the data of Table 2.1-1. Note that frontal and rear accident types have low occupant ejection frequencies. However, in those accident types which produce lateral or spinning motions (side-compartment and/or side-noncompartment) or rollovers of the vehicle, occupant ejections are much more frequent. The frequency of ejection can be reduced through the use of suitable restraint systems and by keeping the doors closed. However, the reluctance on the part of the motoring public to use seat belts, even when they are available in the vehicle, suggests that an integrated seat incorporating design innovations which provide the needed passenger restraint (either automatically or a passive system that promotes greater acceptance and use than currently available restraint systems) would be a worthwhile objective.

The frequency of injury to each body area of the driver by accident type is presented in Table 2.1-2 for all degrees of injury. In Table 2.1-3 the distribution of only dangerous or fatal injuries to the several body areas is shown. These tabulations show that the head and thorax are the areas generally most frequently injured in all types of accidents and that dangerous or fatal injuries most frequently concentrate on these body areas. Note that rear impact accidents are an exception for which most of the dangerous and fatal injuries are to the neck. These severe neck injuries probably are a reflection of the lack of head support in rear-end collisions and for which an integrated seat that provides a suitable means for supporting the head could be beneficial. The upper and lower extremities also are frequently injured (about one-third of the time) but, as one would expect, these injuries are rarely of a degree to be dangerous or fatal.

The sources of driver head and thorax injuries by accident type are presented in Tables 2.1-4 and 2.1-5, respectively. It should be understood that these tabulations include injuries of degrees ranging from minor to fatal the current listing of data does not permit the determination of the source(s) responsible for the most serious injuries. Thus, for example, although the windshield may be the source of frequent injuries in a given type of accident, these injuries may be predominantly minor in degree whereas some other less frequent source of injury such as ejection or the steering wheel assembly may be the principal source of dangerous or fatal injuries.

It is clear from Table 2.1-4 that for frontal or rear impacts the steering assembly causes driver head injuries most frequently whereas in impacts occurring at the sides of the vehicle, the door is the major source of head injury. The windshield and its immediate environs produces many head injuries for all types of accidents except rear impacts. It is also evident that ejection is a frequent cause of injury, particularly in rollover accicents and those involving the side-noncompartment regions of impact which tend to produce spinning motions of the vehicle.

Table 2.1-2

PERCENT FREQUENCY OF INJURY TO EACH BODY AREA
(DRIVER)

ACCIDENT TYPE	INJURED AREA					
	HEAD	NECK	THORAX	ABDOMEN	UP. EXT.*	LO. EXT.**
FRONT	60.5	5.0	28.0	8.0	24.9	34.4
COMPARTMENT	53.8	8.3	34.9	14.9	28.0	27.5
NON-COMP.	51.1	6.8	24.8	12.4	22.0	27.7
REAR	13.5	24.5	12.7	9.8	8.7	12.2
R.O. NO COLL.	50.7	9.2	30.8	17.1	30.7	30.1
R.O. BEFORE	61.7	10.3	39.7	17.0	28.0	33.8
R.O. AFTER	58.2	8.5	33.1	17.8	33.7	33.0

Table 2.1-3

PERCENT DISTRIBUTION OF
DANGEROUS OR FATAL INJURIES BY INJURED AREA
(DRIVER)

ACCIDENT TYPE	INJURED AREA						
	HEAD	NECK	THORAX	ABDOMEN	UP. EXT.*	LO. EXT.**	TOTAL %
FRONT	33.7	11.3	35.1	17.6	0.4	1.8	100
COMPARTMENT	31.4	13.7	33.4	20.1	0.0	1.4	100
NON-COMP.	40.6	11.9	28.0	18.7	0.0	0.8	100
REAR	21.2	39.4	27.3	12.1	0.0	0.0	100
R.O. NO COLL.	37.6	13.5	28.4	19.9	0.2	0.4	100
R.O. BEFORE	41.8	14.5	25.5	16.4	0.0	1.8	100
R.O. AFTER	40.9	12.7	27.6	18.8	0.0	0.0	100

*UPPER EXTREMITY
**LOWER EXTREMITY

Table 2.1-4

PERCENT DISTRIBUTION OF HEAD INJURIES BY SOURCE (DRIVER)

ACCIDENT TYPE	SOURCE OF INJURY											
	WIND SHIELD GLASS	WIND SHIELD AREA	INST. PANEL	STEER ASSY.	DOOR	BACK REST	ROOF	EJECT.	COMP- RESSION	UNKNOWN INSIDE OBJECT	UNKNOWN FORWARD OBJECT	OTHER
FRONT	18.1	15.7	2.3	44.0	2.6	0*	2.1	2.1	0*	2.6	8.7	1.6
COMPARTMENT	14.1	15.2	2.1	7.7	23.0	0.1	4.5	11.9	0.1	17.1	0.6	3.6
NON-COMP.	10.9	17.3	1.5	9.9	17.9	0.2	4.1	21.0	---	14.1	0.3	2.6
REAR	5.2	10.5	1.2	16.6	11.4	2.2	9.2	4.6	1.5	30.5	0.9	6.2
R.O. NO COLL.	10.2	12.3	1.2	5.5	8.8	0.1	13.9	24.0	0.3	19.7	0.2	3.8
R.O. BEFORE	12.5	12.5	---	5.4	6.5	---	15.5	26.2	---	15.5	---	6.0
R.O. AFTER	12.4	14.7	1.2	8.1	6.9	0.3	11.6	20.4	0.1	20.8	0.2	3.4
TOTAL	15.7	15.1	2.0	31.1	6.3	0.1	4.8	8.0	0.1	8.6	5.7	2.4

Table 2.1-5

PERCENT DISTRIBUTION OF THORAX INJURIES BY SOURCE (DRIVER)

ACCIDENT TYPE	SOURCE OF INJURY											
	WIND SHIELD GLASS	WIND SHIELD AREA	INST. PANEL	STEER ASSY.	DOOR	BACK REST	ROOF	EJECT.	COMP-* RESSION	UNKNOWN INSIDE OBJECT	UNKNOWN FORWARD OBJECT	OTHER
FRONT	0.2	0.5	2.1	74.9	1.9	0.2	0	2.0	0.8	3.7	12.6	1.2
COMPARTMENT	0.1	1.2	4.8	27.8	23.6	0.8	---	11.7	1.6	23.6	0.3	4.6
NON-COMP.	---	2.0	3.9	27.8	18.0	0.7	---	21.2	1.6	19.6	---	5.2
REAR	---	0.3	---	27.3	5.0	9.3	1.0	3.0	20.3	31.3	---	2.3
R.O. NO COLL.	0.5	1.0	1.2	19.2	5.4	1.3	3.9	32.3	4.0	27.1	0.5	3.4
R.O. BEFORE	---	0.9	---	18.3	11.0	0.9	4.6	33.0	4.6	24.8	0.9	0.9
R.O. AFTER	0.8	2.2	1.1	29.0	4.0	0.8	4.1	26.7	3.3	24.5	0.3	3.3
TOTAL	0.3	0.9	2.2	54.8	5.6	0.8	1.0	10.1	2.3	12.3	7.6	2.2

*INCLUDES SPINAL COMPRES., FLEXION, AND TORSION.

Driver thorax injuries are mostly caused by the steering assembly. Note however, that in rear-end types of accidents, injury to the thorax caused by compression is also a frequent occurrence. This suggests that an integrated seat that would be more effective in absorbing energy in a vertical direction than current seats might contribute significantly to a reduction of spinal column compression injuries in these types of accidents. Note too that the door is a source of injuries to both the head and thorax principally for those accident types involving impacts to the side of the vehicle.

2.2 The Longitudinal Impact

2.2.1 Analytical Simulation

The CAL computer simulation of an automobile crash victim is utilized herein to investigate the potential effectiveness of an integrated seat in longitudinal impacts (fore-aft).

The present version of the simulation consists of an eleven-degree of freedom nonlinear mathematical model of (1) the human body, (2) a belt type restraint system (lap belt or combination of lap belt and shoulder restraint), (3) contacted surfaces in the vehicle interior, and (4) the vehicle or test cart. The model is shown in Figure 2.2-1. A digital program, in Fortran IV has been developed for the IBM 360/65 computer. The system response is calculated in the form of time-histories of the forces, accelerations, velocities, and displacements at various points in the dynamic system. A time history of the detailed energy distribution within the system is also calculated. The model has been programmed to permit the use of either (1) a direct tabular entry of vehicle deceleration as a function of time or (2) a general polynomial form of vehicle-stopping force, which is a function of both the displacement and the velocity of the vehicle. The former permits application of experimental data or idealized waveforms for vehicle deceleration. Dummy-to-cart interactions are simulated in the latter form of solution.

The validity of the mathematical model was investigated in 1966 by means of comparisons with a series of fifteen instrumented sled tests using an anthropometric dummy. This work is presented in Reference 1. Comparisons were made of measured and calculated forces in restraints and on contacted surfaces, accelerations of the dummy, and detailed kinematics of the dummy. Repeat experimental runs of all but one of the test conditions were compared in order to establish the repeatability of the

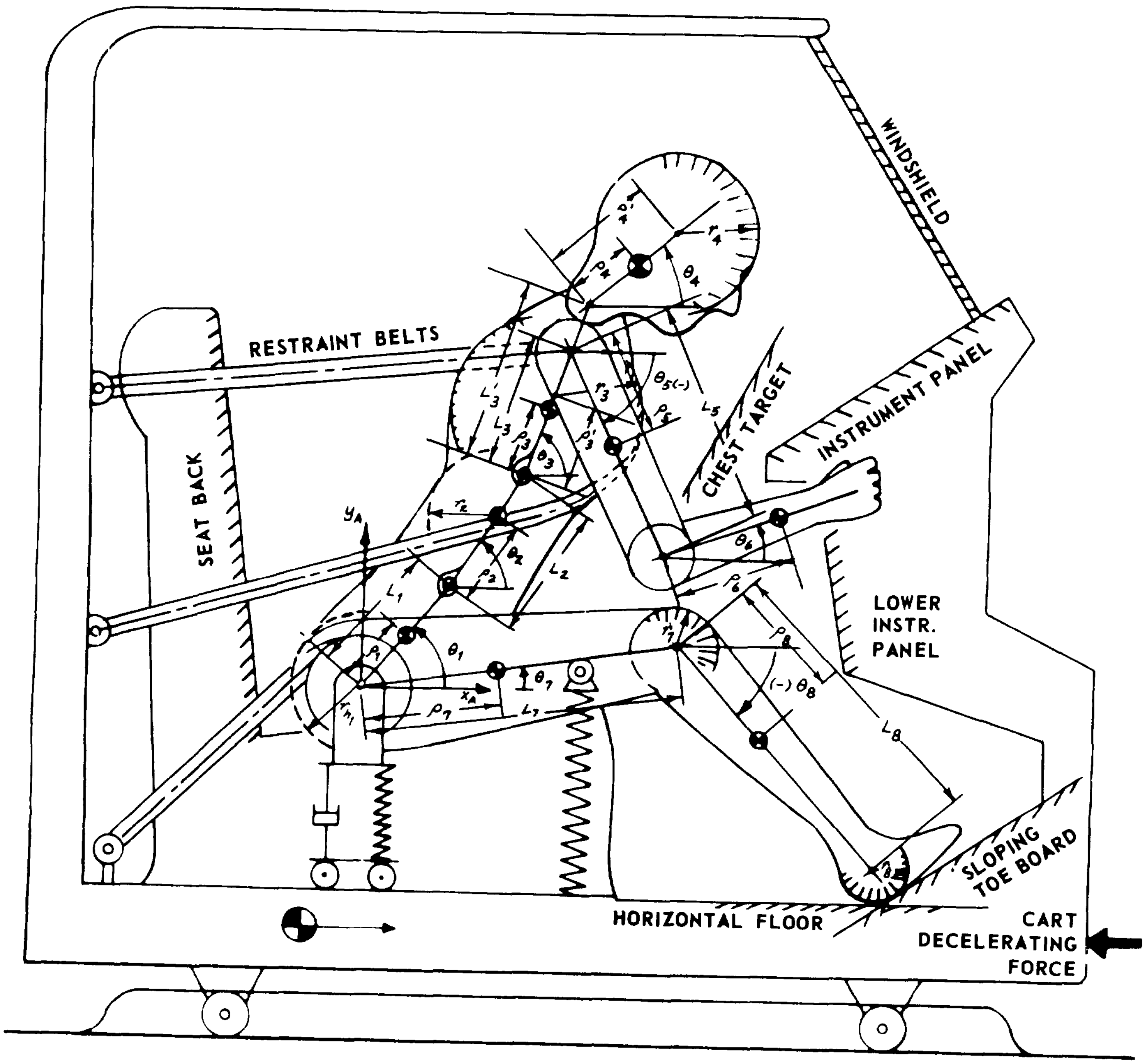


Figure 2.2-1 MATHEMATICAL MODEL OF HUMAN BODY AND RESTRAINT SYSTEM ON TEST CART (11 DEGREES OF FREEDOM)

sled test responses. It was concluded that the comparisons between simulated and experimental time-histories showed good agreement in the timing of events, the occupant kinematics, the general levels of peak values, and the general waveforms of responses. However, the direct interpretation of calculated accelerations in terms of injury potential is not possible at the present stage of development.

The articulated, rigid-body representation of the occupant in combination with the simulated step discontinuities (e.g., coulomb friction) tends to generate response frequencies that are higher than those of the actual physical system (i.e., the occupant sample). Also, the data gathering equipment used in experiments for the generation of human tolerance data has inherent filtering characteristics which act as a low-pass filter. For these reasons, the unfiltered output of the computer simulation tends to include response frequencies that are substantially higher than those in experiments with which comparisons have been made. Therefore, the calculated peak values and peak rates-of-onset of acceleration cannot be directly related to existing tolerance data.

Further development of the simulation is currently in progress under another CAL contract. That development will include the incorporation of an adjustable low-pass digital filter in the output to produce compatibility of frequency content with that of human tolerance experiments. It is anticipated that the filter, in combination with other planned simulation improvements, will yield acceleration responses that can be interpreted in terms of injury potential.

For a preliminary analysis of integrated seats, in which comparisons are made between occupant responses in a modified bucket seat and in a conventional automobile bench type seat, the CAL computer program was modified to permit the simulation of a head rest and restraint belt anchorages located directly on the seat. The head support capability was added so that direct comparisons could be made for rear impacts.

A separate output subroutine was added to the simulation program to sum the seat anchorage loads in the two types of seats being compared. Note that the calculated anchorage loads correspond to rigid pin-joint support at the anchorages. Figure 2.2-2 shows the analytical model of the integrated seat and the forces imposed on it during a typical crash sequence. Force components were summed in the horizontal and vertical directions and the total moments due to these components were determined. With a specific seat configuration, these output data are listed in the form of total vertical and horizontal shear forces at the seat anchor points.

In connection with the resolution of the seat forces on the floor structure, it is apparent that when a driver alone is seated on a bench type seat, the floor anchor forces are not symmetrical. In order to account for asymmetric loading on a wide 3-dimensional seat, the simulated seat width is specified along with 4 seat anchor point locations instead of 2 points as in the 2-dimensional case. Horizontal and vertical loads of the floor reactions, at each of the four anchor points, are calculated and printed out.

2.2.2 Forward Impact

The forward impact, as indicated in Section 2.1, occurs most frequently in automobile accidents. This section of the report presents the results of a preliminary investigation of two different types of car seats in a purely frontal impact. The aim of the analysis has been to explore gross differences between the occupant responses that occur in a conventional bench type seat and those that occur in a modified-bucket form of integrated seat. In order to evaluate the effects of the integrated seat, the kinematics, forces, and accelerations that occur in the bench seat are used as a basis for comparisons.

The simulated frontal impact condition corresponds to a barrier-type collision from an initial velocity of approximately 30 mph. The assumed car deceleration wave (g vs. time) is in the form of a half-sine with a peak of 19.6 g's and a total deceleration time of .115 seconds.

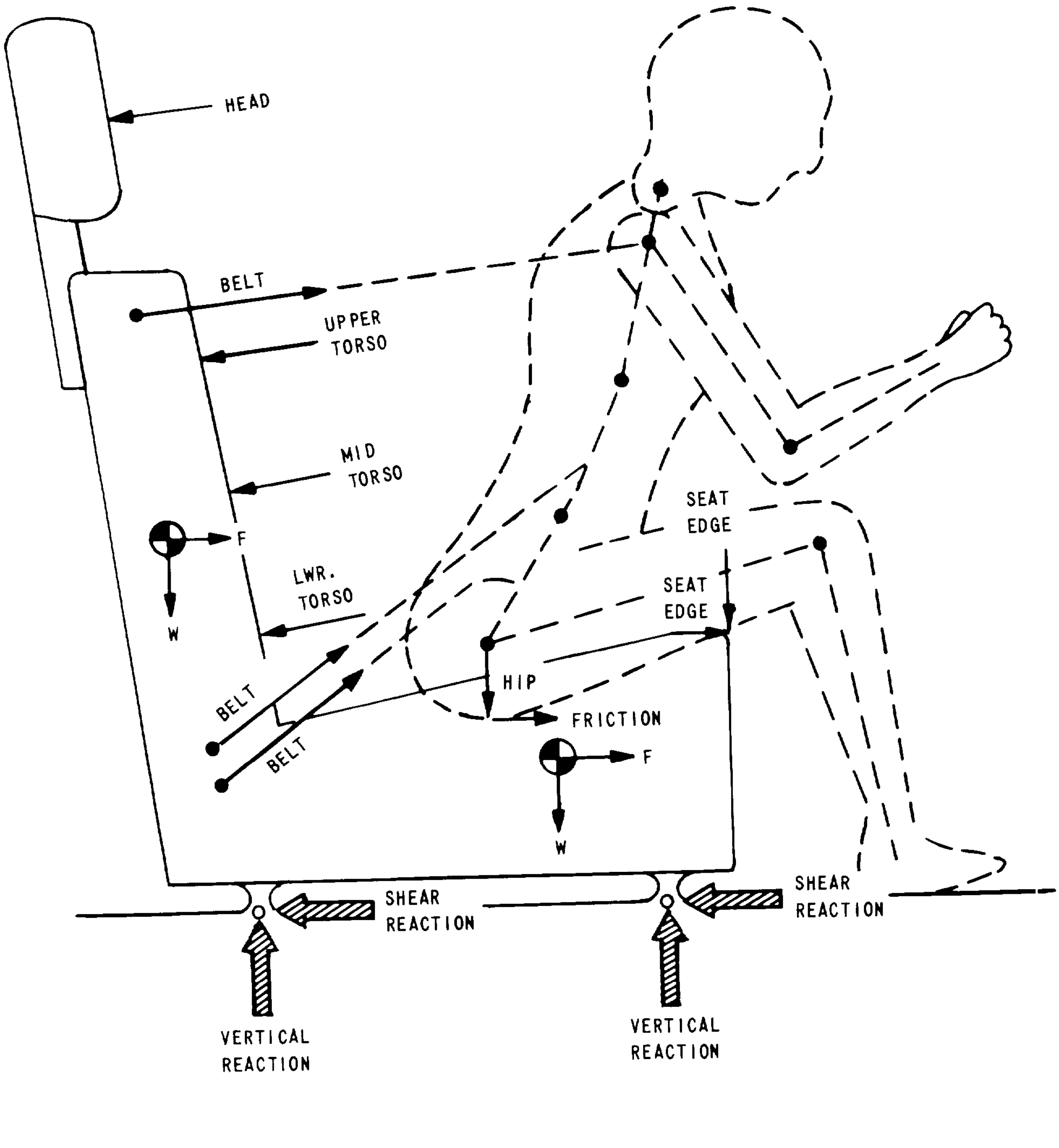


Figure 2.2-2 SIMULATED SEAT FORCES

Inputs to the computer program for definition of the vehicle compartment interior (i. e., dimensions and angles of the instrument panel, steering wheel, etc.) are based on measurements made in a late-model, full size American automobile. Force-deflection characteristics of contact surfaces (e.g., the instrument panel and lower dash panel) are taken from Reference 2. The assumed restraint belt material properties, used for both the lap belt and the upper torso harness, are based on those that were measured and applied in Reference 1. Those properties correspond to an elongation of approximately 17% at 2500 pounds load.

The bench seat configuration that serves as the basis for the present comparisons, has dimensions that were measured on a late-model American automobile seat. Restraint belt anchorage locations are "typically" located on the floor directly behind the seat (lap belt) and on the roof rail, approximately 10 inches behind the occupants head (upper strap of torso harness). The bench seat is anchored to the floor at its 4 corner points, the fore-aft anchors are 13 inches apart and the lateral distance between anchors is 47 inches.

The integrated seat configuration that is simulated is similar to the bench seat except in three areas. First, the modified seat contains a head rest, second, the restraint belt anchor points are located directly on the seat, and third, the seat cushion is slightly stiffer than the bench seat.

It is felt that the location of the belt anchor points on the seat structure constitutes the major modification from a bench to an integrated seat for this 2-dimensional frontal impact analysis. The fore-aft distance between seat anchor points is 13 inches and the lateral distance between anchors is 26 inches.

2.2.2.1 Lap Belt Responses

SEAT COMPARISON - DRIVER

For the case of a 50th percentile driver wearing a lap belt only, a direct comparison was made of collision responses in a bench seat and in a modified bucket, or integrated, seat. The results are presented in Figures 2.2-3 and 2.2-4. The effects of the short, relatively stiff lap belt of the integrated seat are seen in the belt forces of Figure 2.2-3. The loop load of the short belt rises quicker than that of the long bench-seat strap. Both belts, however, reach approximately the same maximum loop load of 3000 pounds. Note in Figure 2.2-4 that the calculated head accelerations are very similar except for the relatively late 80 g spike of the integrated seat curve. At that point in the collision sequence, large tangential forces on the head suddenly reversed as the head unloaded from the instrument panel, causing a jump in the head acceleration. The peak value of the calculated head force was 1210 pounds at .120 seconds for the bench seat driver and 1195 pounds at .118 seconds for the integrated seat occupant.

Chest accelerations of both simulated drivers were similar, peaking at approximately 20 g's. Both occupants were subjected to the same maximum chest load of 1000 pounds because of the use of a constant force characteristic for the simulated steering wheel. The bench seat occupant deflected the steering wheel 8.2 inches as compared to a maximum of 5.7 inches for the integrated seat occupant. A graphical comparison of dummy kinematics for the two runs is displayed in Figure 2.2-5.

On the basis of the analytical results, for the case of a 50th percentile driver in a frontal impact and restrained by a lap belt only, there appear to be no significant benefits provided by the simulated system changes.

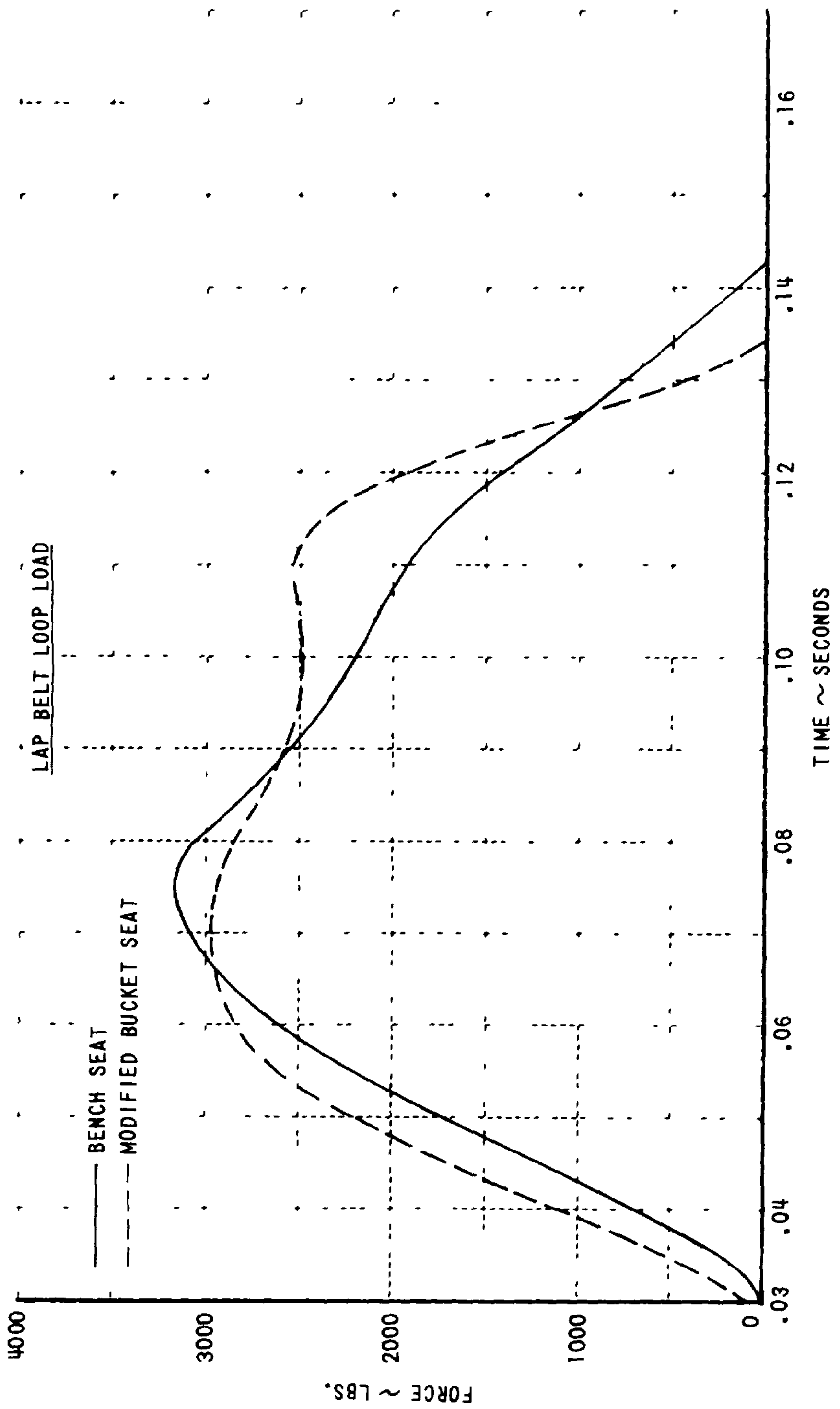


Figure 2.2-3 COMPARISON OF LAP BELTED DRIVERS

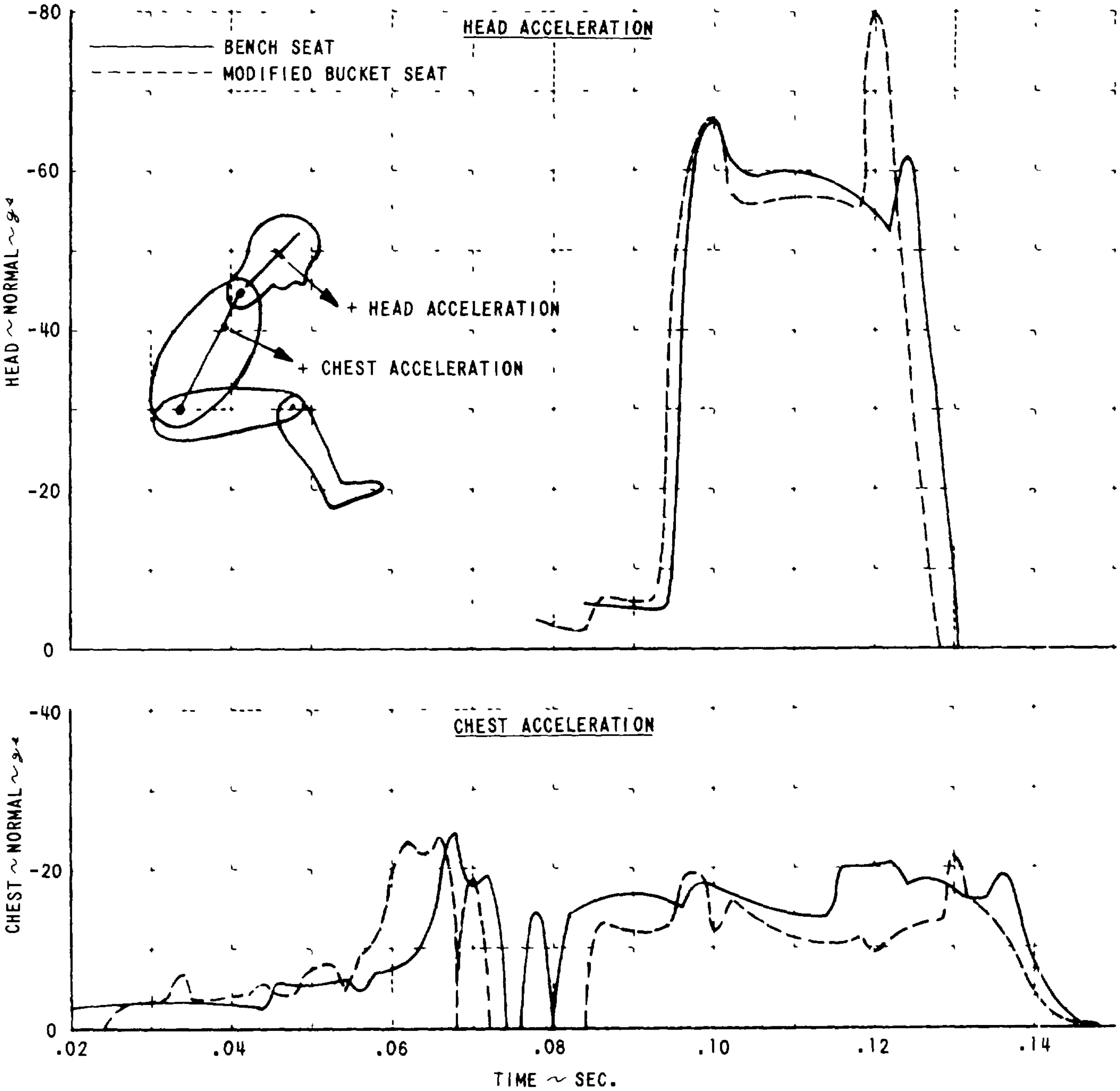


Figure 2.2-4 COMPARISON OF LAP BELTED DRIVERS

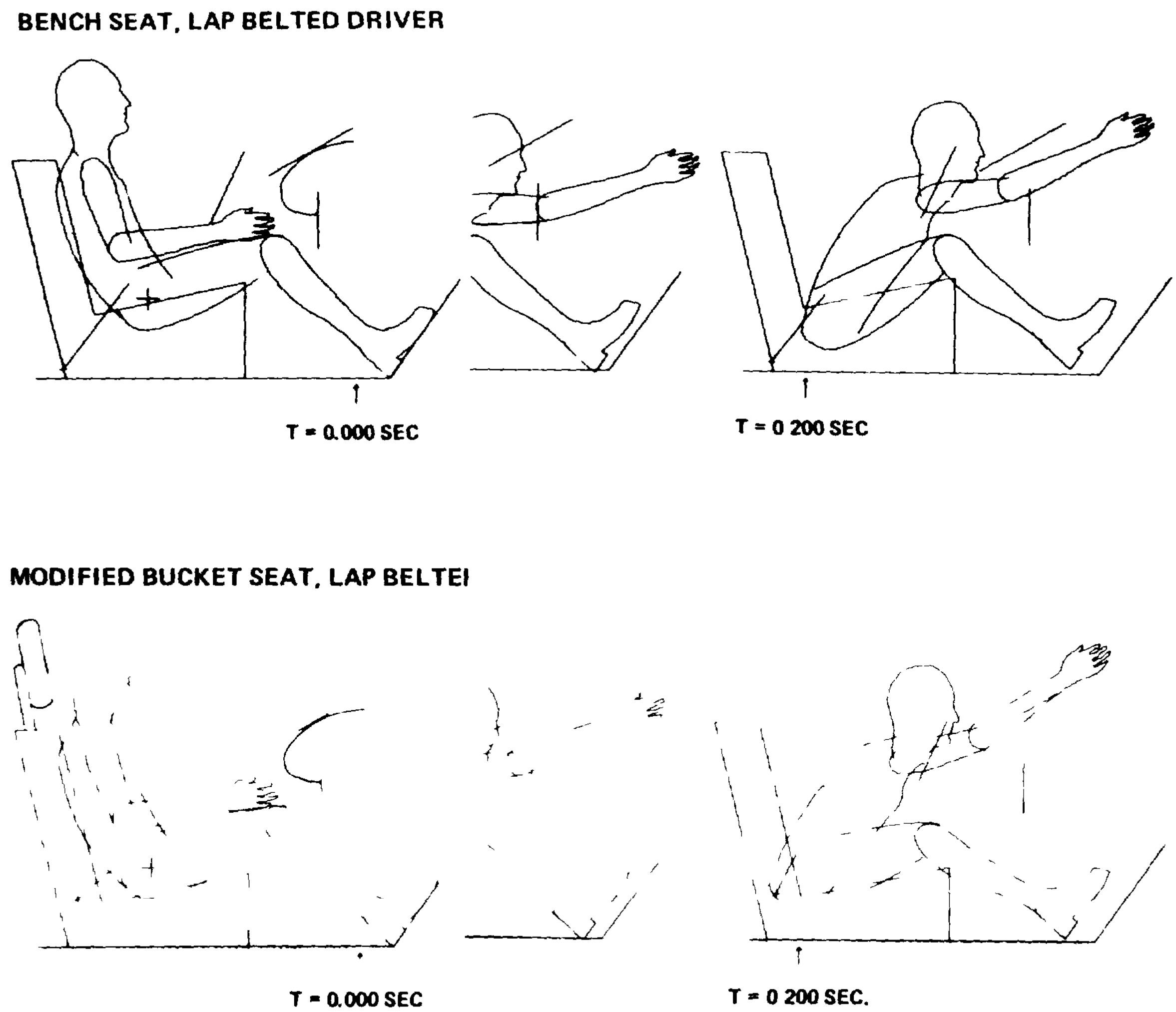


Figure 2.2-5 DRIVER KINEMATIC COMPARISION
~ LAP BELT ONLY

SEAT COMPARISON - PASSENGER

Two runs of the simulation were performed to compare the responses of a 50th percentile passenger in a bench seat with those in a modified bucket seat. The simulated system differs from the previous driver comparison only by the absence of the steering wheel. Figure 2.2-6 shows the calculated lap belt loop loads which again are similar, both peaking at approximately 3000 pounds. The head and chest accelerations presented in Figure 2.2-7 also show very similar trends. The occupant of the bench seat is subjected to a peak head acceleration (unfiltered, calculated values) of approximately 90 g's when the head strikes the instrument panel as compared to the peak of approximately 84 g's that occurs for the occupant of the integrated seat. Consistent with these data are the calculated peak forces on the head, 1480 pounds at .122 seconds and 1356 pounds at .120 seconds for the occupants of the bench and integrated seats, respectively. The performance of the integrated seat displays a slight advantage in that its belt forces peak earlier, causing the aft velocity of the hips to be higher, relative to the seat, at the time of head contact. Head contact velocities are 506 inches/second for the bench seat and 487 inches/second for the integrated seat or a decrease of approximately 4%. Maximum calculated chest loads are at the same level of 1636 pounds for the occupants of both seats.

On the basis of the analytical results, for the case of a 50th percentile front seat passenger in a frontal collision and restrained by a lap belt only, there appear to be no important benefits provided by the simulated system changes. However, the system changes, as discussed previously, are relatively minor with respect to restraint for forward impact. This comparison serves primarily to demonstrate the usefulness and capability of computer simulation for a developmental study.

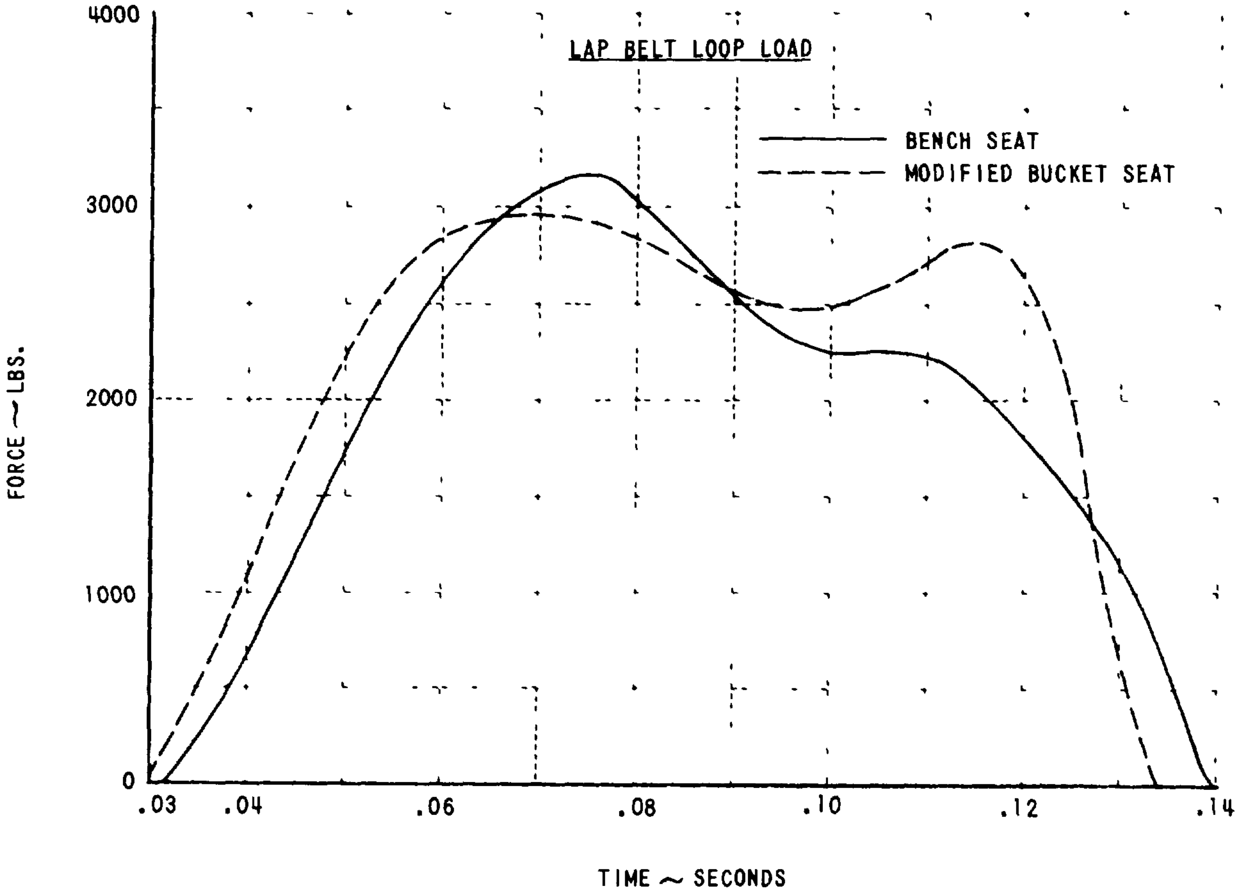


Figure 2.2-6 COMPARISON OF LAP BELTED PASSENGERS

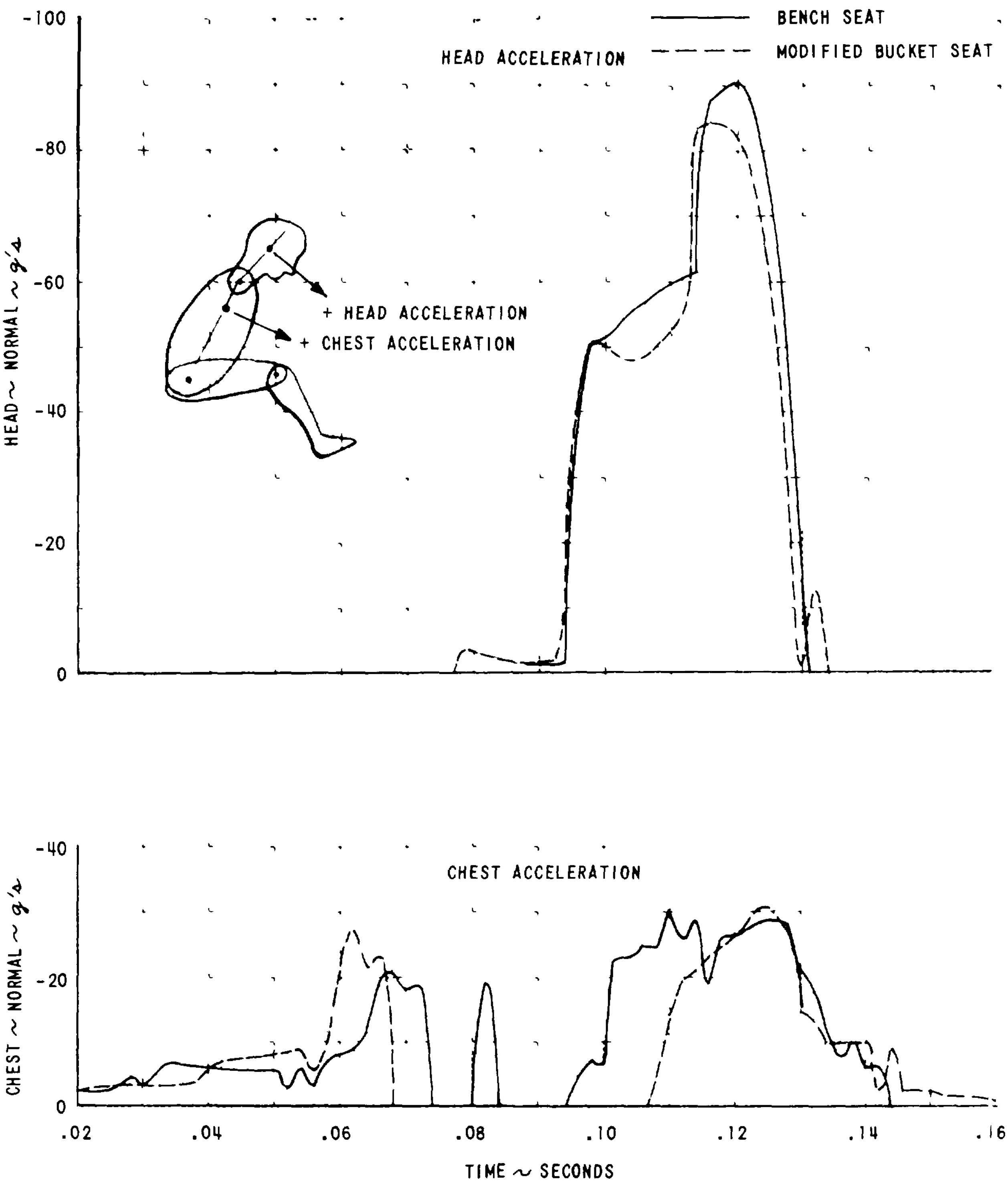


Figure 2.2-7 COMPARISON OF LAP BELTED PASSENGERS

2.2.2.2 Lap and Torso Belt Responses

SEAT COMPARISON - DRIVER

The responses of a 50th percentile driver with lap belt and upper torso restraint were compared in the bench and integrated seats. Belt forces and body acceleration data are shown in Figures 2.2-8 and 2.2-9. The peak lap belt loop load in the case of the integrated seat is 1930 pounds, or a decrease of approximately 20% from that which occurs with the bench seat, a peak of 2400 pounds. Note that the peak load in the upper torso belt in the case of the integrated seat is also decreased from that of the bench seat, a peak of approximately 1000 pounds compared with approximately 1900 pounds. However, the shorter, seat-frame anchored belts of the integrated seat cause the loads to be produced quicker and with higher onset rates.

Figure 2.2-9 shows the peak values of head accelerations (unfiltered, calculated values) in both seats to be essentially the same, although the shorter straps of the integrated seat produce higher onset rates. The calculated head acceleration in the case of the integrated seat tends to remain at a higher "g" level than that which occurs in the bench seat.

Chest accelerations (unfiltered, calculated values) are displayed in Figure 2.2-9. The integrated seat curve is seen to increase more rapidly than the bench seat curve thereby producing much higher onset rates.

Occupant kinematic comparisons are shown in Figure 2.2-10 for various times during the crash sequence. Note that there is a tendency for both occupants to "submarine" (see Reference 3 for a discussion of the "submarining" phenomenon). The bench seat occupant assumes a more nearly horizontal position at .200 seconds.

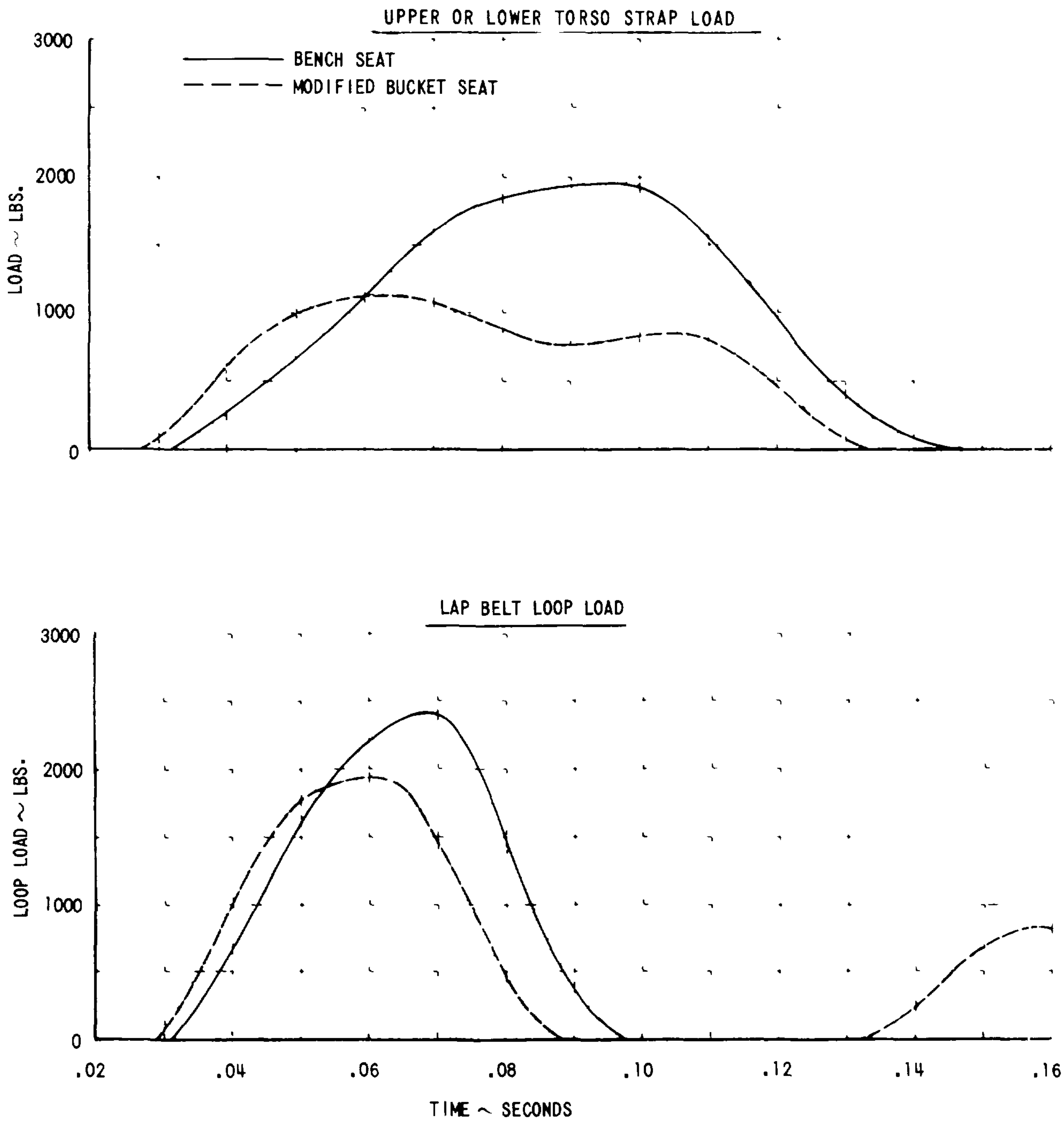


Figure 2.2-8 COMPARISON OF FULLY RESTRAINED DRIVERS

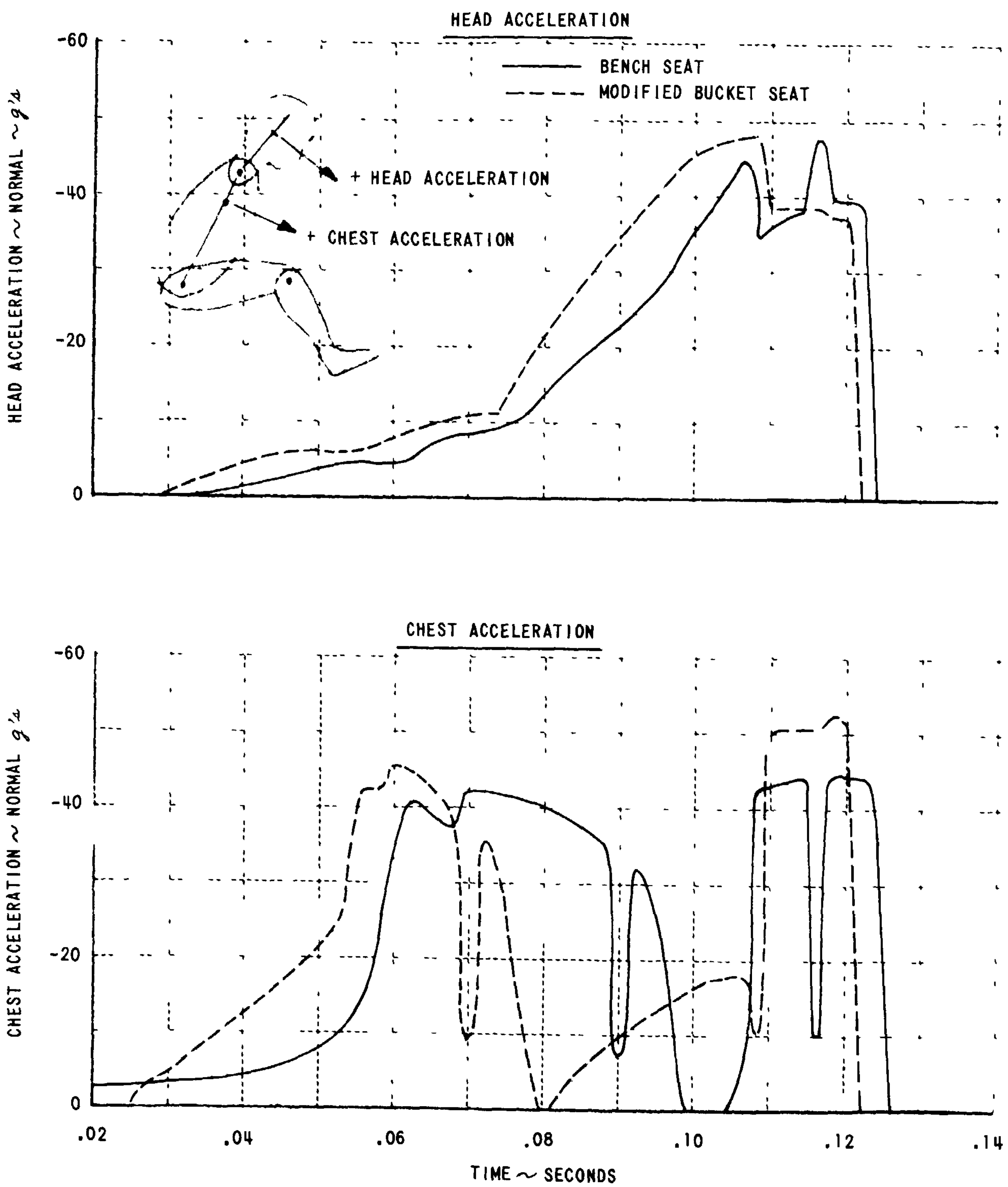


Figure 2.2-9 COMPARISON OF FULLY RESTRAINED DRIVERS

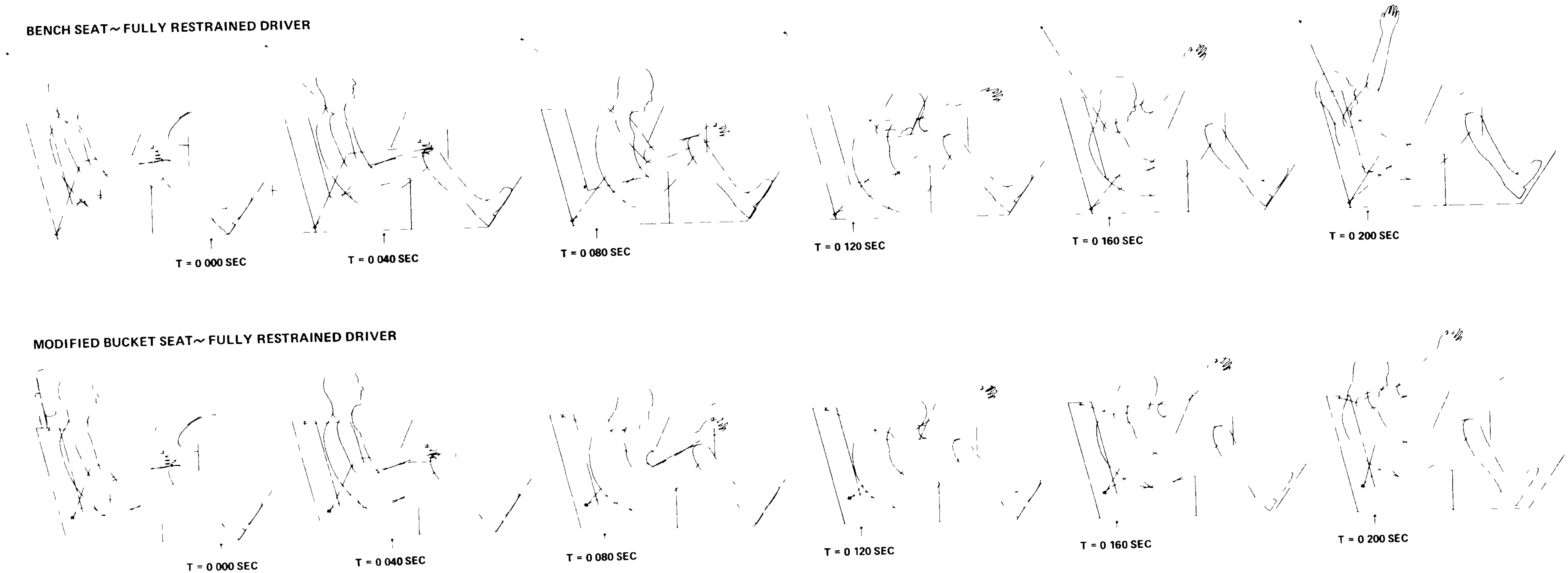


Figure 2.2-10 DRIVER KINEMATIC COMPARISION LAP AND TORSO RESTRAINTS

In order to show the general magnitudes of seat anchor point loads at the floor structure of an automobile during collision, Table 2.2-1 is presented for a bench seat. The floor reactions correspond to a 50th percentile driver secured with a conventional lap and torso harness. Maximum values occur at .070 seconds, when the vertical floor loads on the left side are 1422 pounds and -959 pounds and the horizontal shear forces are 541 pounds at each anchor.

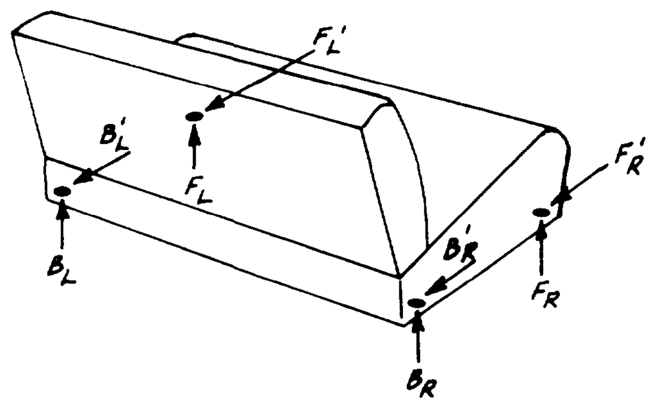
Table 2.2-2 shows floor reactions for an integrated seat in which the belts are anchored to the seat structure. At .070 seconds, in this case, vertical floor reactions are 2302 pounds at the front and -2467 pounds at the rear, or an increase of roughly 2000 pounds over a bench seat configuration.

On the basis of these analytical comparisons, the integrated seat does not have clear-cut functional advantages over a bench seat in a frontal collision if three-point restraints are used in each case. Note, however, that the integrated seat may induce a greater usage of three-point, or four point, restraints by making them more convenient and aesthetically appealing. The magnitudes of the response differences indicated in the presented comparison are considered to be within the ranges of response changes that can be achieved with belt property modifications. Therefore, they are not considered to be indications of important functional differences.

It is possible that the indicated reduction in the tendency toward a "submarining" response may be a significant benefit. However, as discussed in Reference 3, "submarining" has not yet been demonstrated to occur with living humans. It may therefore constitute only a reflection of deficiencies in the design of anthropometric dummies.

Table 2.2-1

FLOOR ANCHOR REACTIONS FOR BENCH SEAT ~ LAP AND TORSO BELTED DRIVER



TIME FROM START OF IMPACT ~ SEC.	SEAT ANCHOR REACTIONS ~ LBS							
	F_R	B_R	F_L	B_L	F_R'	B_R'	F_L'	B_L'
.030	307.	-217.	831.	-652.	335.	335.	361.	361.
.040	374.	-275.	1032.	-835.	408.	408.	440.	440.
.050	425.	-311.	1185.	-934.	452.	452.	494.	494.
.060	464.	-326.	1301.	-979.	468.	468.	523.	523.
.070	504.	-319.	1422.	-959	457.	457.	541.	541.
.080	385.	-172.	1064.	-516.	310.	310.	209.	209.
.090	346.	-112.	948.	-337.	223.	223.	112.	112.
.100	298.	-41.	806.	-123.	116.	116.	-3.	-3.
.110	256.	52.	679.	157.	-12.	-12.	-157.	-157.
.120	228.	96.	595.	289.	-76.	-76.	-228.	-228.
.130	211.	88.	542.	263.	-68.	-68.	-206.	-206.
.140	155.	71.	376.	215.	-49.	-49.	-148.	-148.

Table 2.2-2

FLOOR ANCHOR REACTIONS FOR INTEGRATED SEAT ~ LAP AND TORSO BELTED DRIVER

TIME FROM START OF IMPACT SEC.	SEAT ANCHOR REACTIONS RIGHT SIDE ONLY LBS.			
	F_R	B_R	F'_R	B'_R
.030	440.	-378.	229.	229.
.040	1365.	-1788.	660.	660.
.050	2094.	-2784.	1022.	1022.
.060	2384.	-2933.	1168.	1168.
.070	2302.	-2467.	1097.	1097.
.080	1740.	-1413.	641.	641.
.090	1786.	-1107.	687.	687.
.100	1862.	-1045.	703.	703.
.110	1291.	-513.	116.	116.
.120	802.	-212.	14.	14.
.130	457.	-90.	138.	138.
.140	110.	-11.	17.	17.

DRIVER SIZE COMPARISON

Two comparison runs were made using a small, 5th percentile driver and a large, 95th percentile driver. Both occupants were seated in the integrated seat with lap and torso harnesses anchored at the same locations on the seat structure as in previous runs. The resulting restraint strap loads are presented in Figure 2.2-11. Lap belt loop loads show the same general trend as that which occurred in the case of the average sized driver, with an increase and decrease of maximum loads for the large and small size drivers, respectively. The peak lap belt load, in the case of the large occupant, is approximately 3000 pounds compared with approximately 1450 pounds for the small occupant. The upper strap of the torso harness shows the same trends, the maximum load for the large occupant is 1600 pounds and that for the small occupant is approximately 1000 pounds.

Head and chest accelerations are shown in Figure 2.2-12. The peak value of head acceleration (unfiltered, calculated values) for the 5th percentile driver is slightly higher than that for the 95th percentile, 44 g's compared to 39 g's. Note the rapid increase in head acceleration for the small occupant as compared to the large occupant and the corresponding higher onset rate.

The calculated chest accelerations of Figure 2.2-12 are similar to each other, with the smaller occupant receiving a slightly higher initial rate of onset. These data are similar to the accelerations received by the average size driver shown in Figure 2.2-9.

For the two extremes of driver size in an integrated seat with full restraints, seat anchor loads are presented in Table 2.2-3. Maximum floor loads for the 95th percentile occupant occur around .070 seconds, showing 3415 pounds vertical load at the front anchor (right side) and -4162 pounds at the rear anchor. These are an increase in load of 48% for the front and 69% for the rear anchor over the average size occupant seat reactions shown in Table 2.2-2.

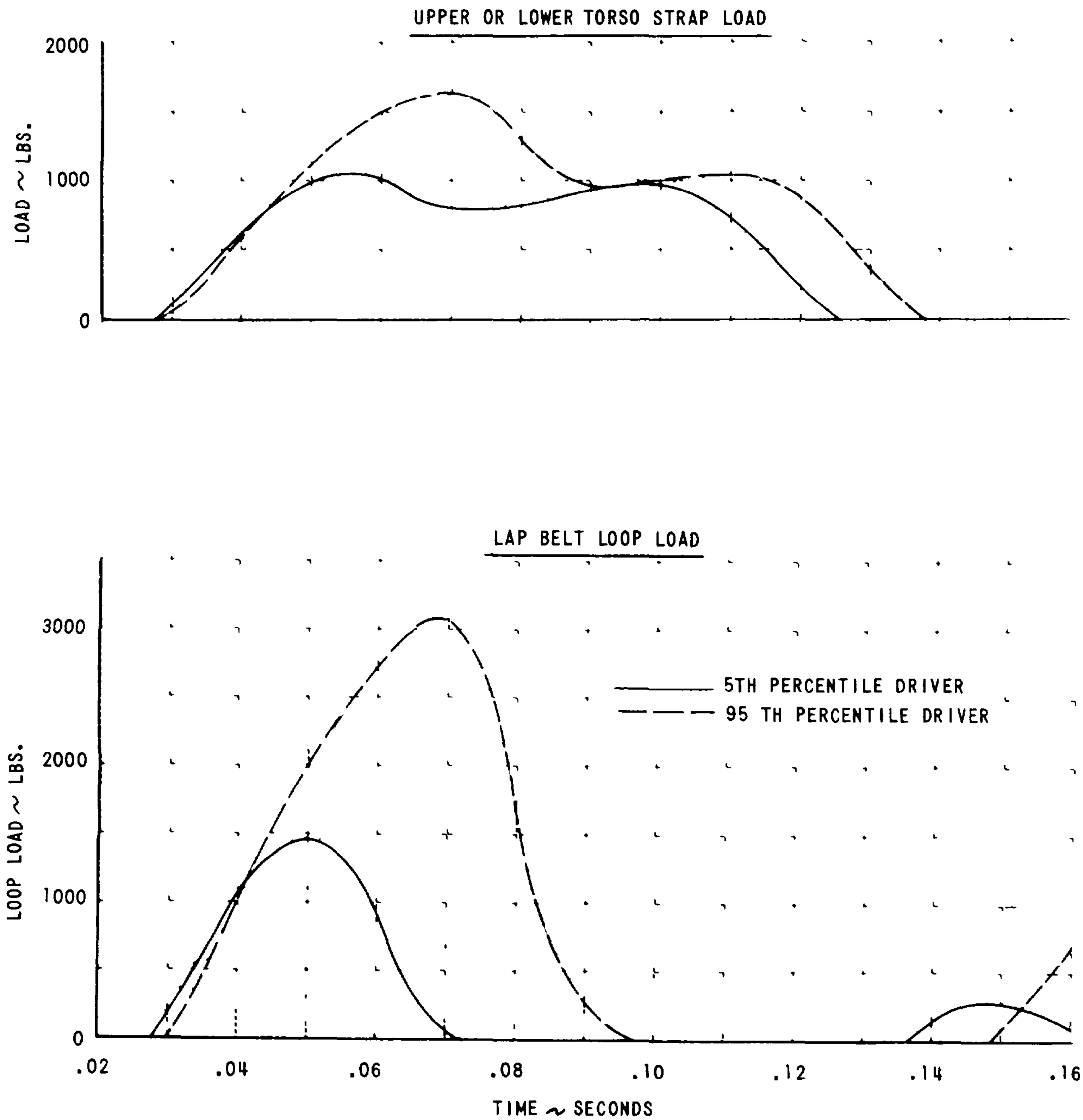


Figure 2.2-11 DRIVER SIZE COMPARISON-MODIFIED BUCKET SEAT

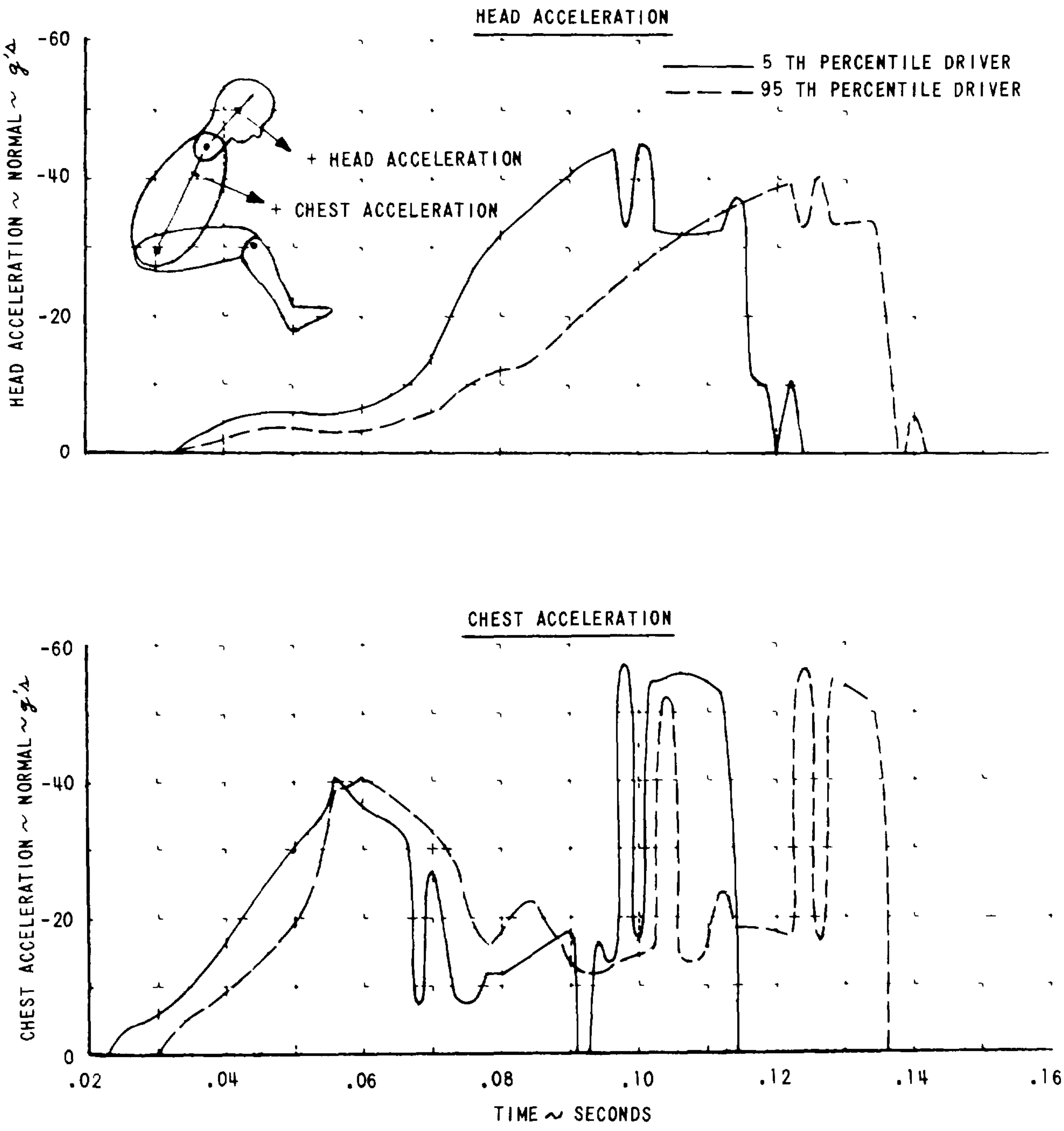


Figure 2.2-12 DRIVER SIZE COMPARISON-MODIFIED BUCKET SEAT

Table 2.2-3

FLOOR ANCHOR REACTIONS FOR
TWO DRIVER SIZES ~ INTEGRATED SEAT.

TIME FROM START OF IMPACT ~ SEC.	SEAT ANCHOR REACTIONS- RIGHT SIDE ONLY ~ LBS.							
	5TH PERCENTILE DRIVER				95TH PERCENTILE DRIVER			
	F_R	B_R	F_R†	B_R†	F_R	B_R	F_R†	B_R†
.030	467	-457	257	257	356	-239	200	200
.040	1319	-1716	659	659	1352	-1821	628	628
.050	1907	-2432	941	941	2332	-3253	1089	1089
.060	1924	-2099	903	903	3071	-4061	1475	1475
.070	1492	-1277	646	646	3415.	-4162	1701.	1701.
.080	1527	-1147	651	651	2751	-2785	1294	1294
.090	1619	-1143	682	682	2257	-1546	893	893
.100	1259	-776	296	296	2404	-1266	889	889
.110	896	-479	168	168	1867	-555	98	98
.120	331	1	-11	-11	1527	-404	52	52
.130	104	92	0	0	829	4	-78	-78
.140	55	20	5	5	543	-20	150	150
.150	55	-68	37	37	117	107	-45	-45
.160	-13	3	1	1	173	-263	128	128

The presented comparisons demonstrate the rather obvious need to consider the extremes of occupant sizes in the design of an integrated seat. When further development of the existing simulation has been completed, to the extent that calculated accelerations can be interpreted directly in terms of injury potential, the capability for readily varying occupant size will make it a valuable tool for design studies of integrated seat concepts.

MODIFIED INTEGRATED SEAT

The integrated seat configuration of the previous analyses was modified to allow the seat back to flex under a constant 500 pound force. This type of seat deformation occurs in several of the experimental integrated seats now being developed, such as the Cox seat of Watford, England. The analytical results are preliminary in nature because of the fact that the present version of the digital simulation does not allow for seat-back movement relative to the car. Deflection of seat back under load was therefore approximated by a saturating type force-deflection characteristic for the torso restraint belt.

A comparison is presented in Figure 2.2-13 of belt forces in the yielding-back, integrated seat and those in the non-yielding integrated seat. Since the lap belt anchor points, mounted on the lower corner of the seat, were assumed to yield very little, maximum values of lap belt loads in both seats are approximately equal, at 2000 pounds. The upper torso strap, of course, shows a reduction of force on the chest in the case of the yielding seat-back, from a peak of approximately 1100 pounds to a peak of 700 pounds.

Head and chest acceleration data are shown in Figure 2.2-14. Head accelerations for the yielding seat show a significant decrease over the standard seat response, up to approximately .093 seconds. However, at .096 seconds for this particular case, the yielding seat occupant's head contacted the instrument panel and produced the high acceleration spike shown at .098 seconds. Without head contact, which is influenced by the interior geometry of the car, head accelerations would have been expected to

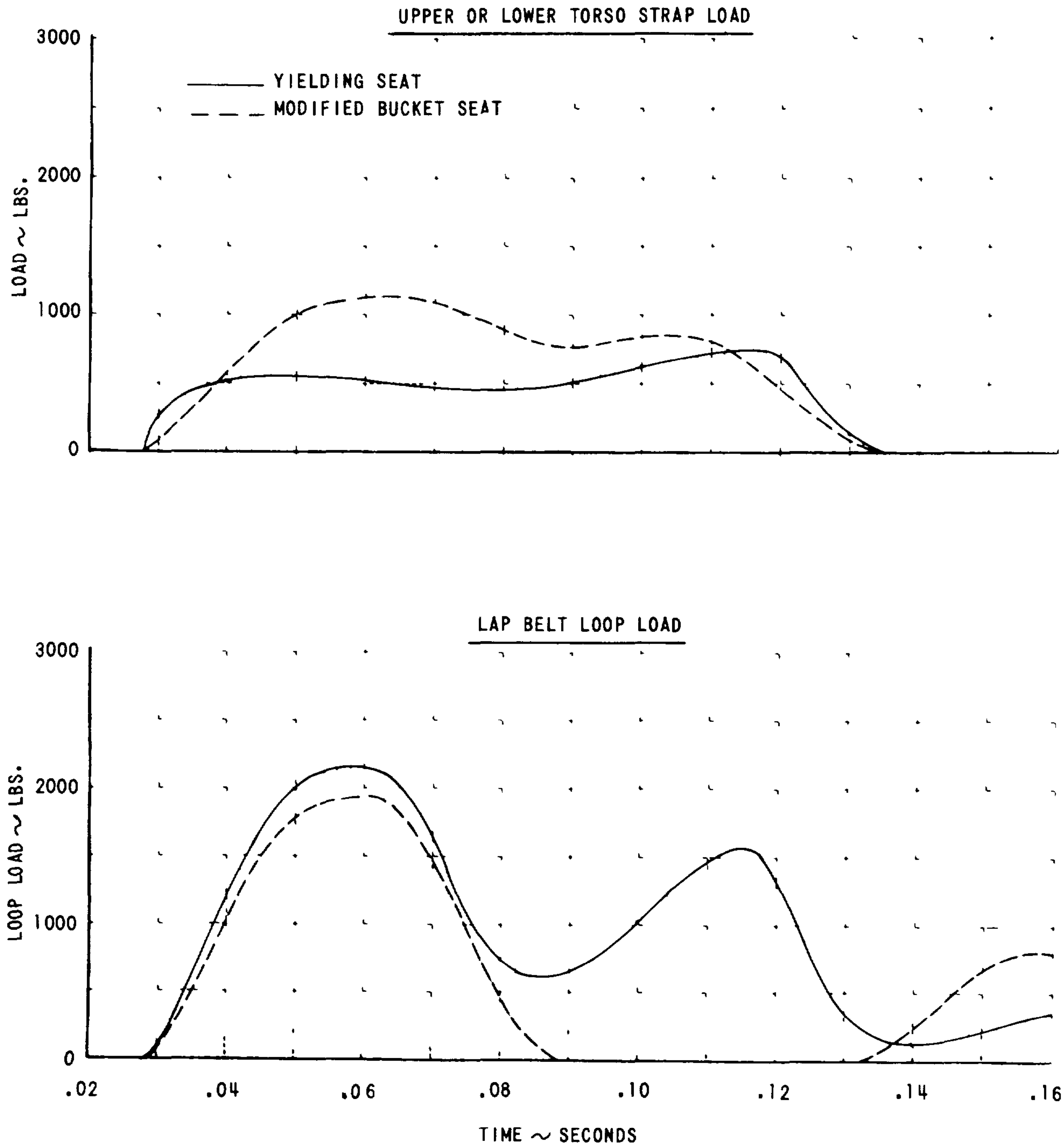


Figure 2.2-13 MODIFIED SEAT COMPARISON

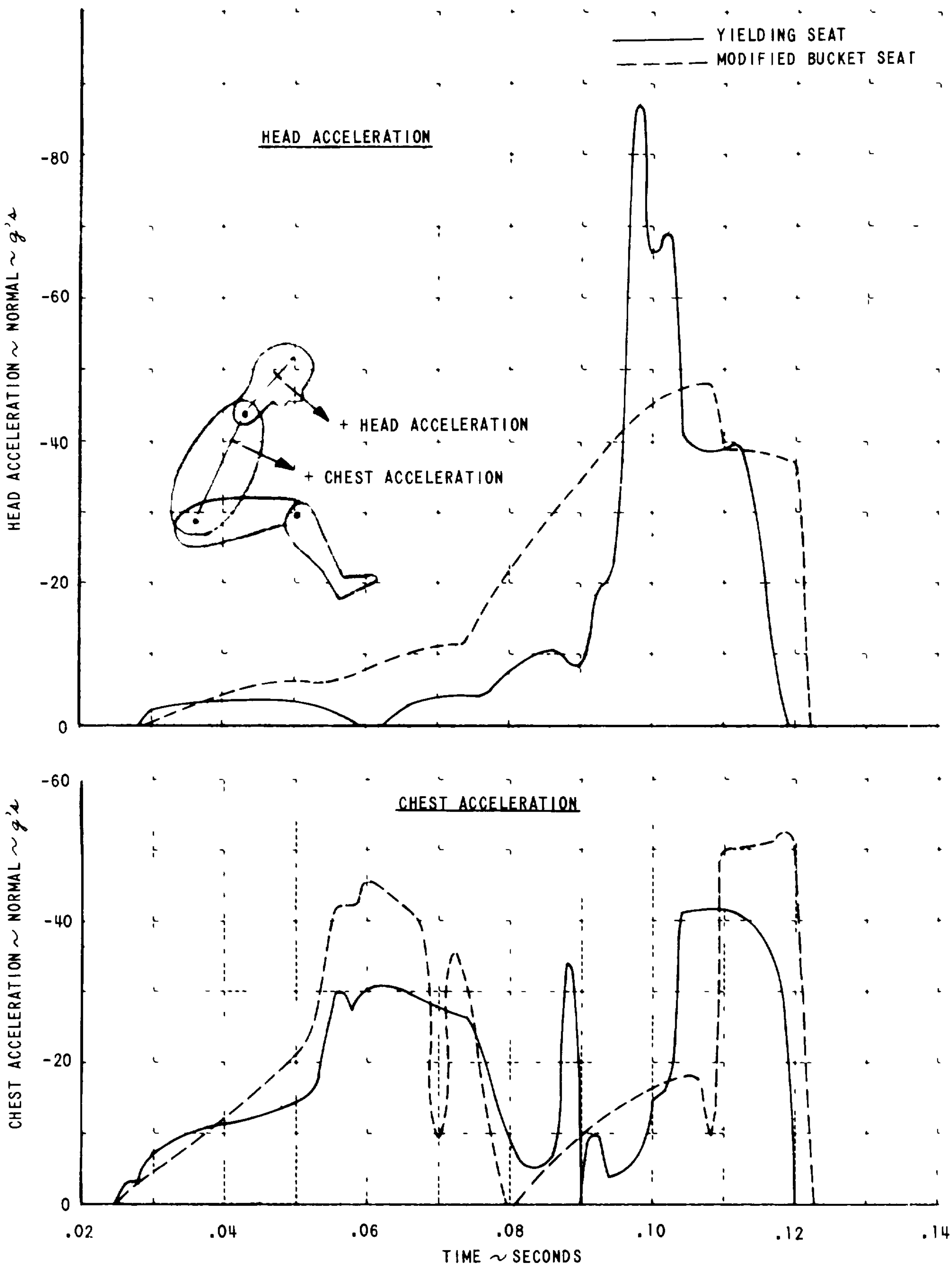


Figure 2.2-14 MODIFIED SEAT COMPARISON

remain below those that occur in the standard seat. The maximum forward deflection of the seat back, measured at the top, was approximately 10 inches.

The calculated chest accelerations in Figure 2.2-14 indicate a general decrease in level for the yielding seat. It is noteworthy that the order of magnitude of the reduction in chest acceleration attributable to the seat yield is the same as that reported for the Cox seat in Reference 4. A summary comparison is presented in Table 2.2-4.

Table 2.2-4 Comparison of Simulation and Experiment	CAL Computer Simulation	Cox Seat Experiment (Reference 4)
Impact Speed	30 mph	36.8 mph
Vehicle Deceleration Time	0.115 sec.	0.120 sec.
Vehicle Deceleration Waveform	Half Sine	Irregular With Spikes
Peak Chest Acceleration:		
(1) Yielding Seat	31 g's at .061 sec.	35 g's at .057 sec.
(2) Nonyielding Seat	45 g's at .060 sec.	55 g's at .068 sec.
(3) Reduction Attributable to Seat Yield	31%	35%
Total Movement of Seat Back at Top	10 inches	6+ inches

The presented response comparisons indicate that the major benefit from integrated seats in frontal collisions may come from the use of a selected rate of yielding in the seat structure. The same general effect (i.e., saturating belt loads) can be achieved by means of yielding devices in series with body-anchored belts. However, the fixed geometry and the potential increase in convenience, and thereby usage, of upper torso restraints in the case of seat-frame-anchored belts would appear to constitute important advantages of an integrated seat for application of load-saturation effects in restraints.

The head impact that occured in the simulation run demonstrates a problem inherent in the use of restraint loads that saturate. Motions of the occupant relative to the vehicle will, of course, be larger than those with non-yielding restraints. Therefore, clearance or padding must be provided even for the case of full restraint.

2.2.3 Rear Impact

A preliminary analysis of the potential benefits of an integrated seat in a rear collision was performed by means of three simulation runs. The automobile was accelerated from rest to 17 mph in a period of .130 seconds. A half sine curve was used to simulate the acceleration-time history, with a peak of approximately 9.3 g's. These input data are approximations of an actual rear end collision in which a car traveling at 30 mph strikes a parked vehicle. An actual acceleration-time history of a vehicle impacted from the rear is not, of course, as smooth as the applied half-sine curve, but this approximation was considered to be adequate for a preliminary investigation.

An average-size, fully restrained driver was used in the three comparison runs. The first run employed a typical bench seat configuration, the second, a bench seat plus a head rest, and the third, an integrated seat. Figure 2.2-15 presents the head and chest accelerations of the three comparisons. The head acceleration of the two "head rest" seats are very similar, each having a peak (unfiltered, calculated values) of approximately 47 g's. The bench seat without a head support shows an acceleration delay and then an increase to a peak value of approximately 31 g's. During the high acceleration, the head is rotated counterclockwise as viewed from the right side of the occupant, as shown in Figure 2.2-16. The indicated rate of head-neck rotation during this time interval is 800 degrees/second. The maximum head rest force (normal force) was approximately 667 pounds for both of the head-supporting seats, and it occurred at approximately .074 seconds.

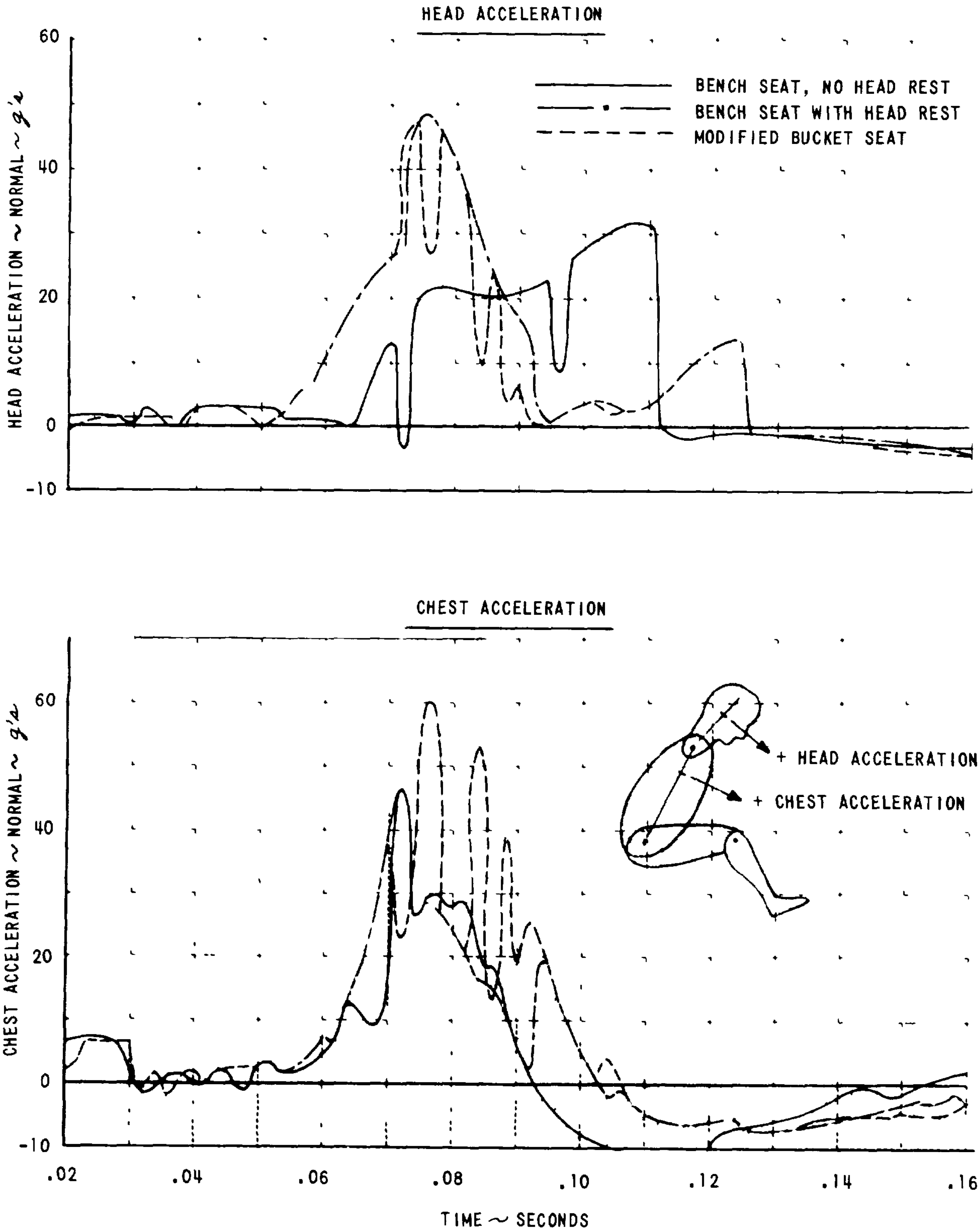


Figure 2.2-15 SEAT COMPARISONS-REAR IMPACT

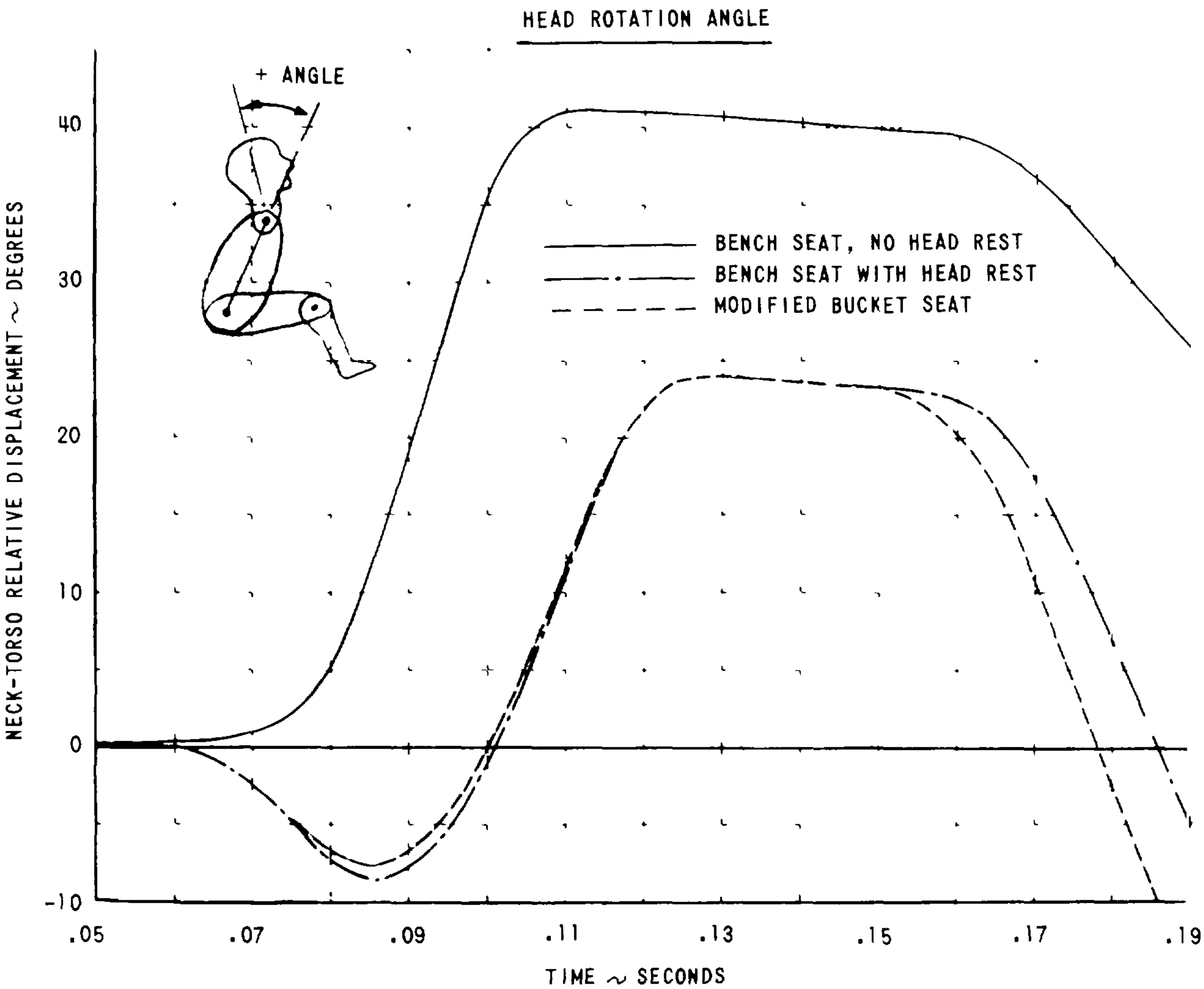


Figure 2.2-16 SEAT COMPARISONS-REAR IMPACT

Chest accelerations are shown in Figure 2.2-15. All traces are similar except the integrated seat curve which shows several "spikes". Since the upper torso is fully supported during these calculated (unfiltered) high accelerations, the probability of contact injury would appear to be small. Interpretation of the calculated accelerations in terms of probable internal organ damage is, of course, not possible at the present stage of development of the simulation.

Figure 2.2-16 shows limited angular rotation of the head for the head supported seats, up to 24 degrees. The rotation is due to the upper torso being accelerated forward, away from the seat back, thus adding to the counterclockwise relative deflection angle of the head (as viewed from the right side of the occupant).

Occupant kinematics for the three seat configurations are presented in Figure 2.2-17. Note the large angular displacement of the head-neck in the non-head support bench seat at .120 seconds.

Seat floor reactions for the integrated seat in a rear impact are presented in Table 2.2-5. Right side anchor forces are equal to left side forces, hence, data for only one side is shown. Maximum floor loads occur at approximately .080 seconds, producing -3578 pounds and 4586 pounds for vertical front and vertical rear anchor reactions, respectively. Shear forces at this time are -977 pounds at each anchor.

From the presented response comparisons for the three seat configurations it is seen that the occupant responses in a bench seat that includes a head rest are essentially the same as those that occur in an integrated seat. The generally recognized injury potential that exists in a bench seat without head support is demonstrated by the large flexion that occurred in the corresponding simulation run.

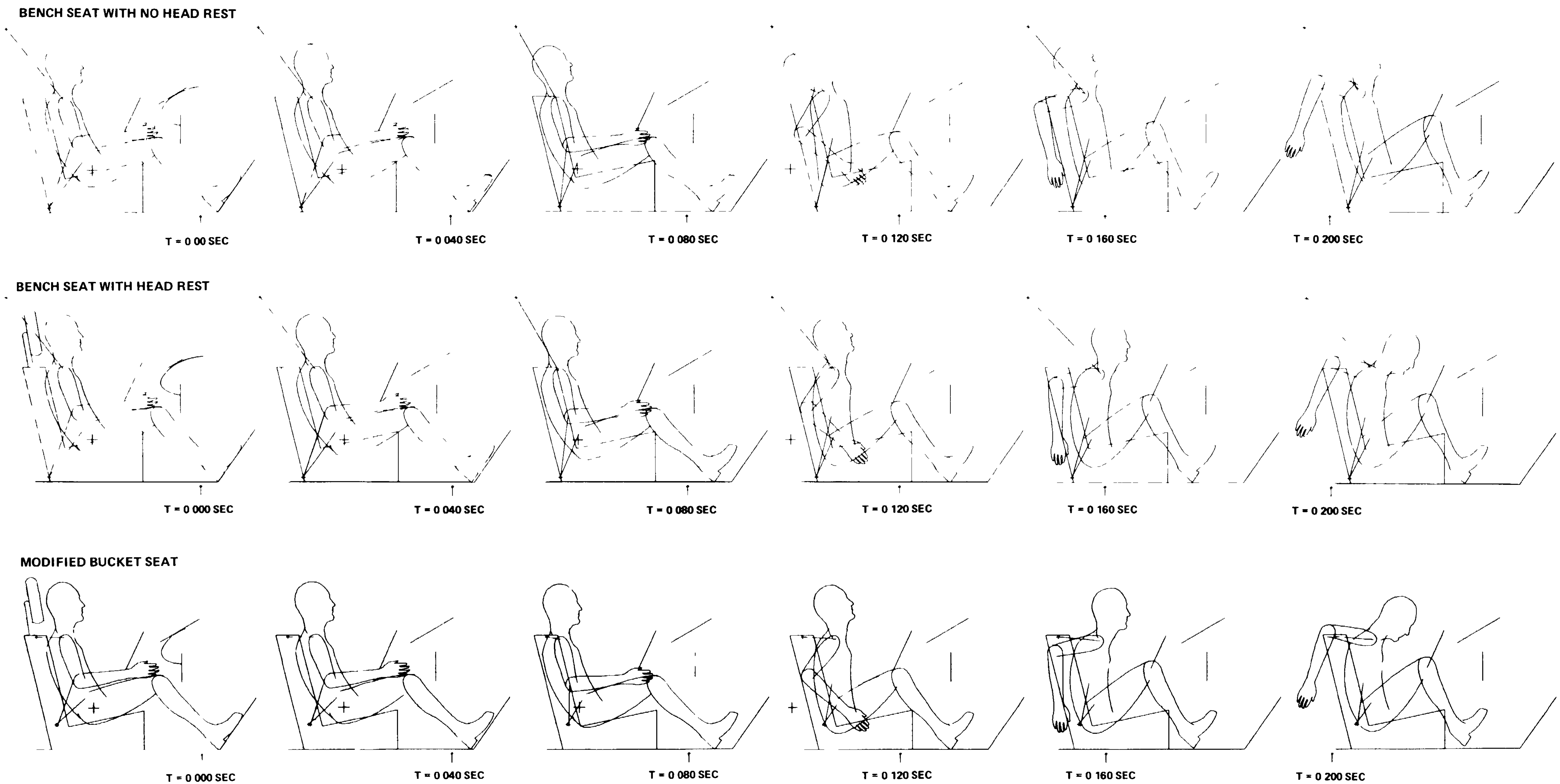
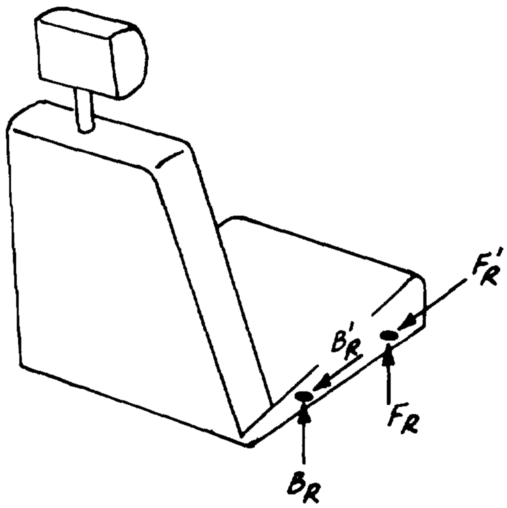


Figure 2.2-17 DRIVER KINEMATIC COMPARISION
~ REAR IMPACT

Table 2.2-5
FLOOR ANCHOR REACTIONS FOR
INTEGRATED SEAT ~ REAR IMPACT



TIME FROM START OF IMPACT ~ SEC.	SEAT ANCHOR REACTIONS RIGHT SIDE ONLY LBS.			
	F_R	B_R	F_R'	B_R'
.030	-182.	235.	-115.	-115.
.040	-242.	280.	-143.	-143.
.050	-325.	338.	-178.	-178.
.060	-882.	789.	-336.	-336.
.070	-2374.	1925.	-848.	-848.
.080	-3578.	4586.	-977.	-977.
.090	-1787.	2004.	-668.	-668.
.100	-759.	739.	-377.	-377.
.110	-173.	410.	-76.	-76.
.120	-28.	324.	-7.	-7.
.130	35.	141.	7.	7.
.140	65.	86.	13.	13.

2.3 The Side Impact

The side impact problem has been studied experimentally in References 5 and 6.

Attempts to describe the side impact analytically have been relatively crude. Two aspects of the problem have been dealt with. According to Reference 7, a limited analysis was carried out in Reference 8 to find the effectiveness of an air bag restraint system for the particular case in which the struck car was stationary. The deceleration time histories of the compartment were assumed. Compartment motion was the subject of the study reported in Reference 9. In Reference 9, the trajectories were treated in three successive phases, namely:

1. An impulse phase in which the struck vehicle rotated slightly.
2. An intermediate phase during which the two vehicles moved as a hinged body about the translating point of impact.
3. A final phase initiated when the vehicles break contact and pursue their separate courses.

Generalization of both of these efforts (that is, References 8 and 9) is necessary in the analysis of the side impact. Relative motion of the occupant with respect to the restraint anchor points will determine the loads on the restraint system -- the same situation that exists in the frontal barrier impact case.

Intersection collisions encompass a wide range of variables. Some of the more obvious ones affecting compartment trajectory are:

1. Momenta of the individual vehicles.
2. Angle of contact.
3. Point of impact.
4. Energy dissipation (that is, braking) occurring at the time of impact.
5. Crush characteristics of both the striking and struck car.

That the breadth of the problem is large because the mechanics of the struck and striking vehicles are not the same is evident from Figure 2.3-1. The longitudinal force component acting on the striking car passes through (approximately) the center of gravity. The tangential component force acting on the striking car tends to translate and rotate this vehicle toward the initial path of the struck car. It is to be noted particularly that the entire tangential force produces the moment imbalance. The struck car, on the other hand, is acted upon by moments due to the normal and tangential force components which are of opposite sign. In one special case, the force vector along the line of the striking vehicle goes through the center-of-gravity position of the struck vehicle. In this case, it is especially clear that the accelerating moment on the struck vehicle is appreciably less than the corresponding moment on the striking vehicle. That is, both moments arise from the same tangential force and the ratio of the moment arms is the characteristic length-to-width ratio of the automobile.

The remarks in the preceding paragraph hold only in the instant of impact. Non-conservative and nonlinear forces are rapidly brought into play. Energy dissipation occurs through the braking system, tire skidding and plastic distortion of the vehicle shells. In addition, the effective centers of rotation (for yaw and roll) can change very rapidly as the wheels alternately skid or roll. Coriolis' forces arise from such center shifts in addition to the expected centrifugal forces.

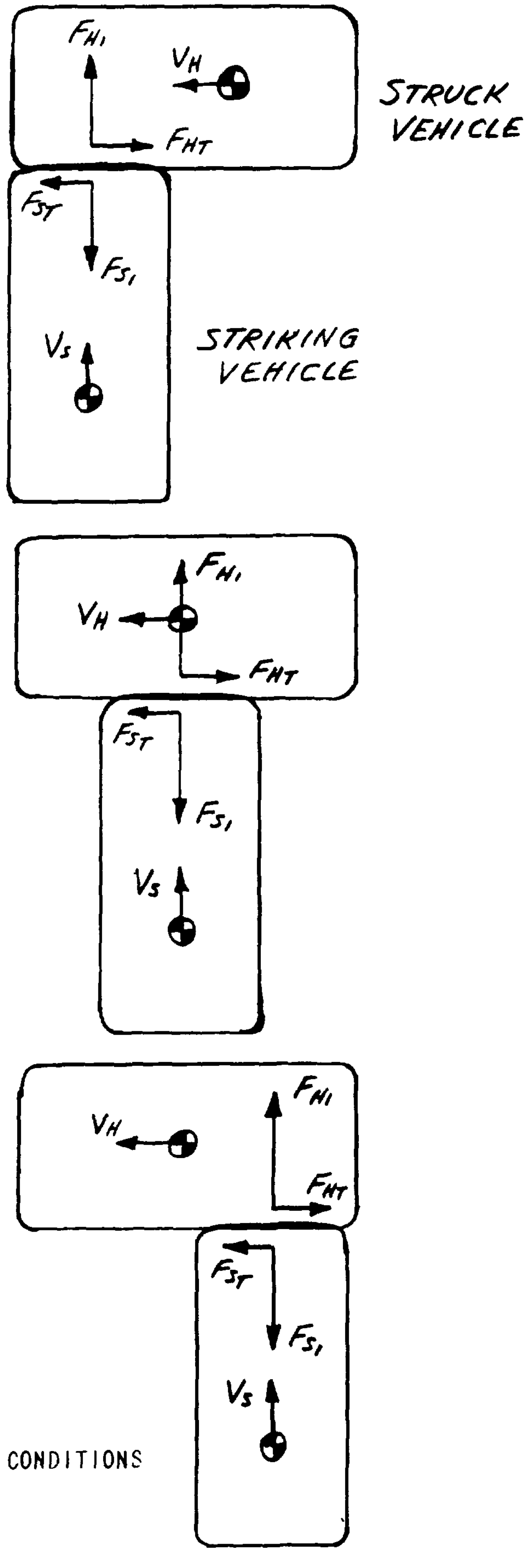


Figure 2.3-1 VARIOUS INITIAL CONDITIONS FOR SIDE IMPACT

Occupant motions are closely coupled with occupant positions and impact conditions. That is, the occupant of the striking car could come into contact with virtually any part of the dashboard, windshield, side window, or the appropriate supporting structures, depending upon the conditions of the initial impact. This situation arises because the occupant takes on a ballistic trajectory and the vehicle rotates and translates relative to the trajectory. Compartment penetration is apt to be a problem in single car side impacts and for the struck car in an accident involving two automobiles.

2.4 The Rollover Case

Little research effort has been devoted specifically to the restraint of occupants for a rollover trajectory. As far as is known, Reference 10 was the only research study on this topic. Rolling introduces forces on the occupant perpendicular to the seat and centrifugal forces (provided the occupant remains in contact with the seat) that depend on the body position relative to the vehicle center of rotation. As pointed out in Reference 10, the initial roll axis is a longitudinal line passing through the ground contact points of the front and rear wheels. After the vehicle has rotated approximately 90 degrees, the axis of rotation shifts to approximately the vehicle geometric center line.

At initiation of the rollover the spine is compressed by a force proportional to the product of the body weight, distance from body c.g. to the axis of rotation, and the square of the angular acceleration. Subsequent motion depends on the amplitude of this acceleration, the seat characteristics, and the restraint employed. There could be a tendency to submarine under this initial acceleration load. If the initial acceleration is sufficiently high, elastic response of the deformed seat structure can catapult the occupant so that he tends to leave the seat (with a consequent removal of a centrifuging force component) and strike his head on the roof or on the side door structure farthest from the axis of rotation. If the initial acceleration is low, the gravitational force dominates and the occupant tends to slide toward the axis of rotation until he hits the vehicle structure. These tendencies are shown in Figure 2.4-1 taken from Reference 10.

It appears that the protection of the occupant in a rollover situation requires both a harness to keep him in the seat and a roof support structure sufficiently strong to prevent the collapse of the compartment.

Either of two mechanisms can produce a rollover. One of these is a driver-induced oscillation and, at least for present-day cars, is unlikely to occur unless triggered by a tire blowout. The other mechanism is a trigger of the rollover by a side impact against an obstruction. (Rollover due to transversing a steep embankment is another category which will not be considered here.) It is apparent that the vehicle accident in these cases is related to a mulfunction of a part (that is, a tire) or to the presence of a trigger (that is, an obstruction). Passenger restraint requirements are thus intermixed with maintenance and highway design.

2.5 Existing Concepts

2.5.1 Cox Seat (Reference 4)

The British engineering firm known as Cox of Watford, Ltd. has looked at a number of car seat configurations. Their "safety" seat (Figure 2.5-1) is one in which the primary structure is tubing and the tie-down to the flooring is accomplished through rodlike supports capable of absorbing energy through inelastic structural deformation. The general appearance is that of a bucket seat so that some lateral restraint is introduced and further lateral restraint is available from a diagonal belt. Both the diagonal and lap belts are anchored on the seat frame. A head rest is provided to restrict the head motion in the event of a strike from the rear.

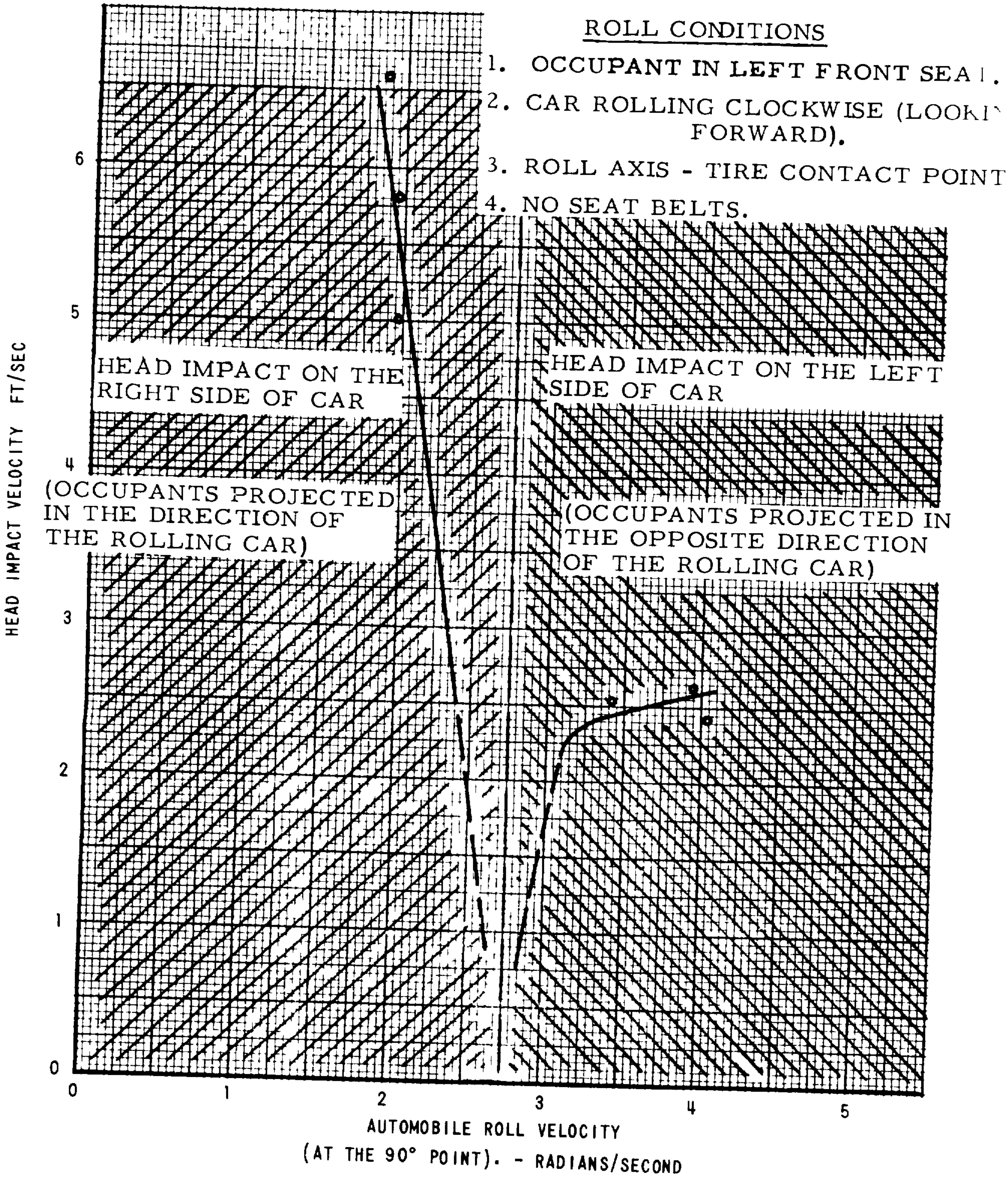


Figure 2.4-1 HEAD IMPACT VELOCITY VS CAR ROLL VELOCITY

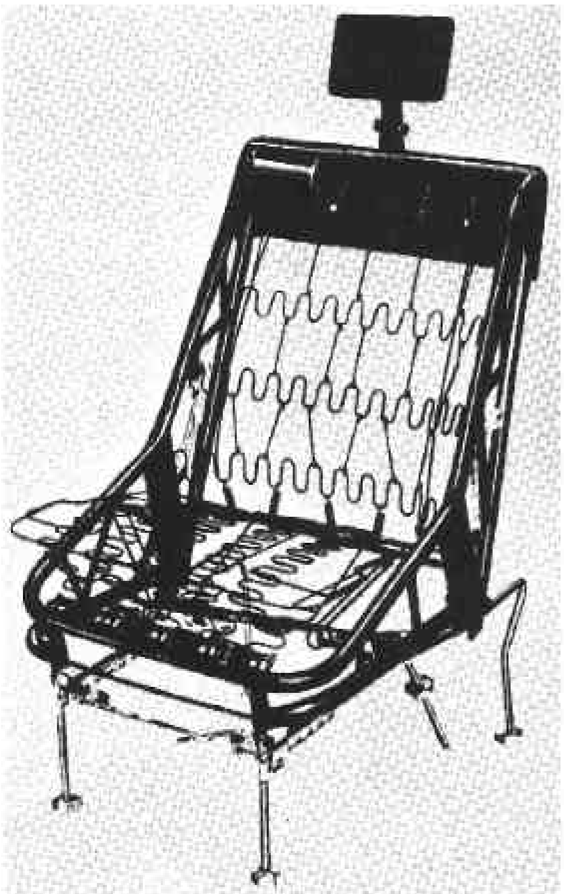


Figure 2.5-1 - Cox Safety Seat

2.5.2 Liberty Mutual Integrated Seat (e.g., Reference 11)

A safety car study performed by Liberty Mutual Life Insurance Company, Inc., featured an integrated seat (Figure 2.5-2). The main characteristics are an exaggerated bucket arrangement to lend lateral support for the torso and head. Two shoulder straps were incorporated in addition to a lap belt. Again, the straps were anchored to the seat structure and all loads were transmitted to the passenger compartment through the seat tie-down structure.

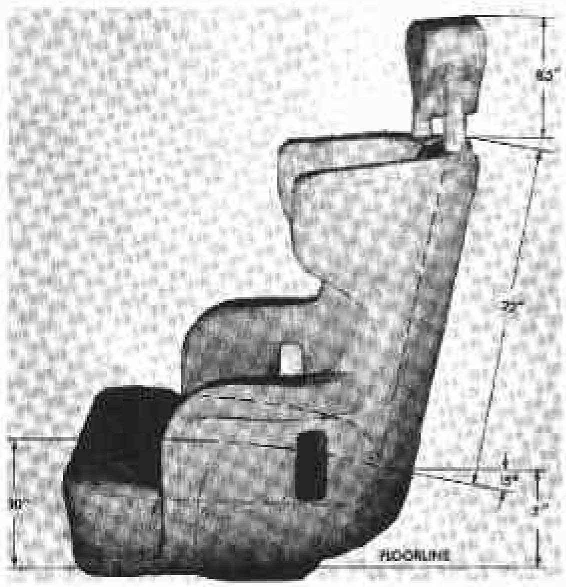


Figure 2.5-2 - Liberty Mutual Capsule Seat

2.5.3 Aircraft Seats (References 12 and 13)

Numerous aircraft seats have been developed to increase the survivability of pilots, Figure 2.5-3. In these developments, however, advantage is taken of the fact that the pilot himself recognizes the benefits of restraint. This is, of course, especially true of the military pilot. In addition, the military pilot may very well be using a helmet since his communication system is an integral part of that safety device. Use of automatic means for removing belt slack is common.

Of some interest is a proposal for a passenger seat which was made in Reference 14. This design features an energy absorbing pedestal as the seat-to-floor structural element, Figure 2.5-4. Energy is absorbed by plastic deformation of corrugated cylinders making up the pedestal.

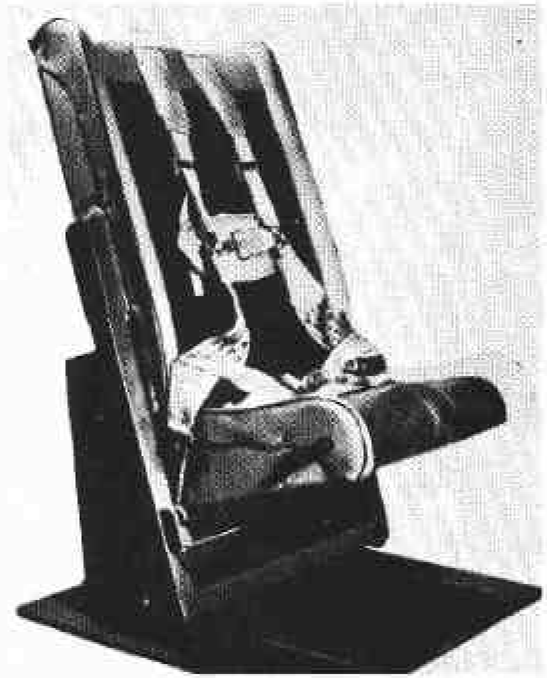
2.5.4 Farina Sigma (Reference 15)

Pinin Farina of Turin, Italy, suggested -- and, in fact, built an unpowered demonstration model of a "safety" car. A bucket seat arrangement was incorporated in the Farina car. The contour of the seat provided some lateral restraint and the headrest is built into the passenger seats. (The driver's seat does not have a headrest since the Pinin Farina engineers believe that driver drowsiness and over-relaxation are greater dangers than the possibility of a head injury of the "whiplash" type.

2.5.5 Tilt Seat (References 16 and 17)

An active tilt seat mechanism (Figure 2.5-5) has been proposed under the trade name "Protect-O-Matic" (Reference 16). Frontal impact at any speed over eight miles per hour triggers a hydraulic system which actuates a scissors linkage and tilts the seat back approximately 45 degrees. The arrangement is usually shown without a belt of any kind. One of the arguments for such a system is that it is activated automatically and does not require any operation by the driver or passenger (for example, buckling of seat belts).

Net Crew Seat Configuration for Navy P3A Aircraft Fabricated by Burns Aero Seat Co.



Sikorsky CH-53A Pilot and Co-Pilot Seat Configuration Proposed by Stanley.

Figure 2.5-3 - Aircraft Seats

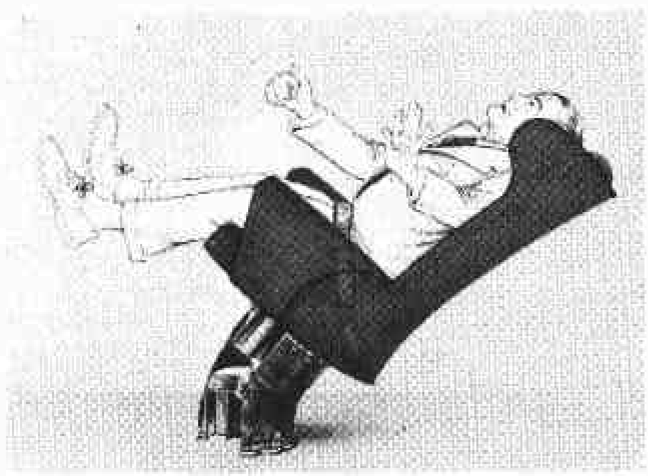


Figure 2.5-4 - Experimental Duplex Seat; Impact From Rear

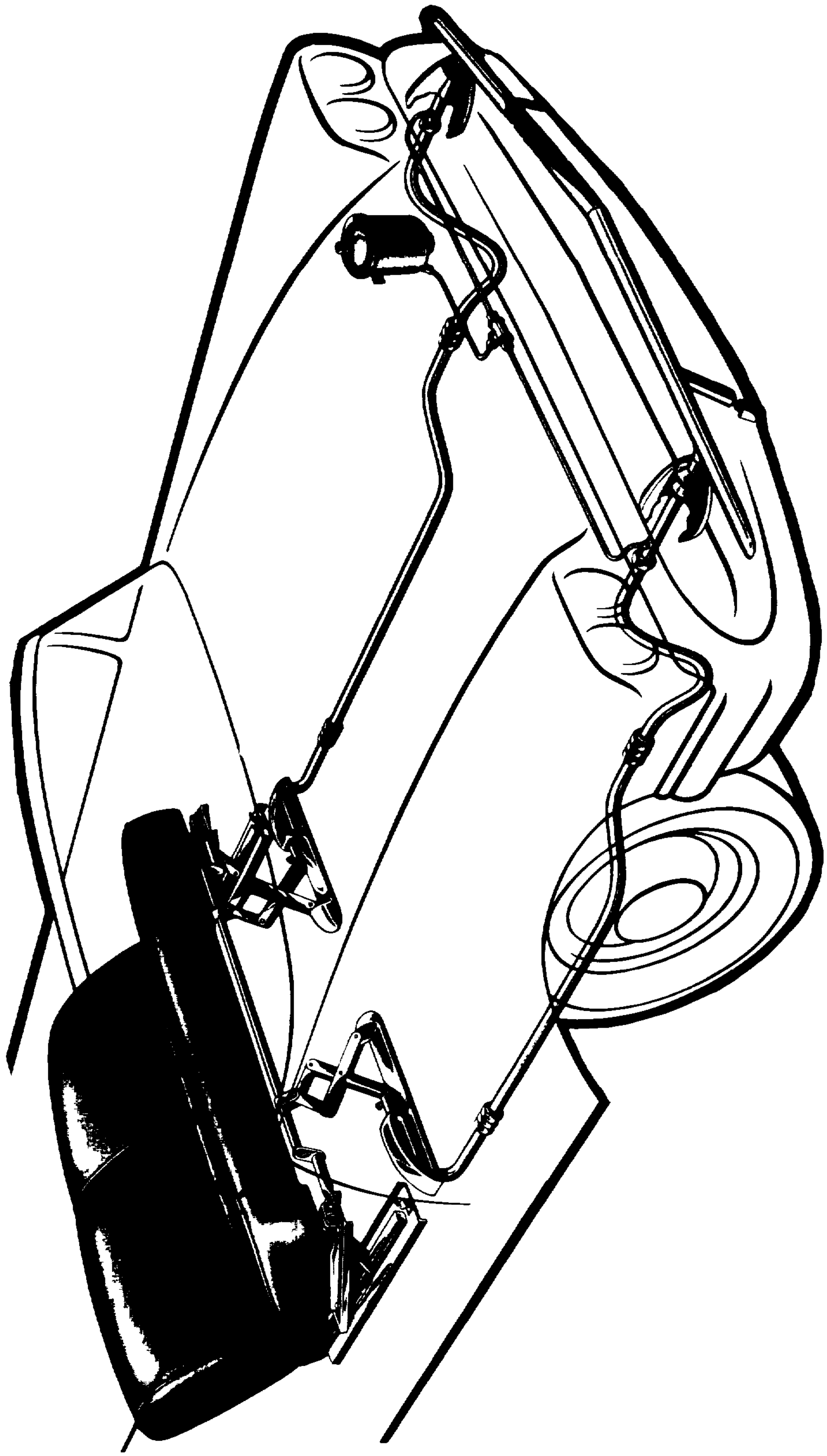


Figure 2.5-5 - Active Seat Tilt - Protect-O-Matic Version

In Reference 17, a disclosure was made of a pendulum device. That is, the point of support for the passenger seat is above the head. The theory here is that the inertial forces tending to keep the passenger in motion would bring into play a decelerating force which increases as the "pendulum" displaces. Obviously, such a device requires an overhead structure and a structural capability of supporting the applied inertial loads.

2.5.6 Dye Restraint (Reference 18)

Mr. Edward Dye of Cornell Aeronautical Laboratory, Inc., proposed a bucket seat and movable dashboard chest protector as an element in the Liberty Mutual Safety Car I research program. In essence, the bucket seat with lap belt restraint was combined with a padded shelf on a scissors arrangement which could be pulled out from the dashboard. The purpose of the shelf was to provide support for the thorax.

2.5.7 Ryan (Reference 19)

Professor James J. Ryan of the University of Minnesota proposed a hydraulic shock absorbing bumper which also actuated a seat belt tightener.

2.5.8 ESSEM Safety Belt

Svenska Metallverken -- a Swedish firm -- is marketing a combination lap-and-chest belt with a three-point anchorage, Figure 2.5-6. Tie-downs are placed on the floor and center posts rather than on the seat itself. The belt can be worn relatively loose and it operates in what is described as two modes: emergency and retardation locking. Emergency locking occurs if the belt is pulled rapidly on the reel (inertia reel action). The retardation action is brought into play during braking maneuvers. When the deceleration due to braking ceases, the belt winds up on the spindle as the belt wearer leans back.

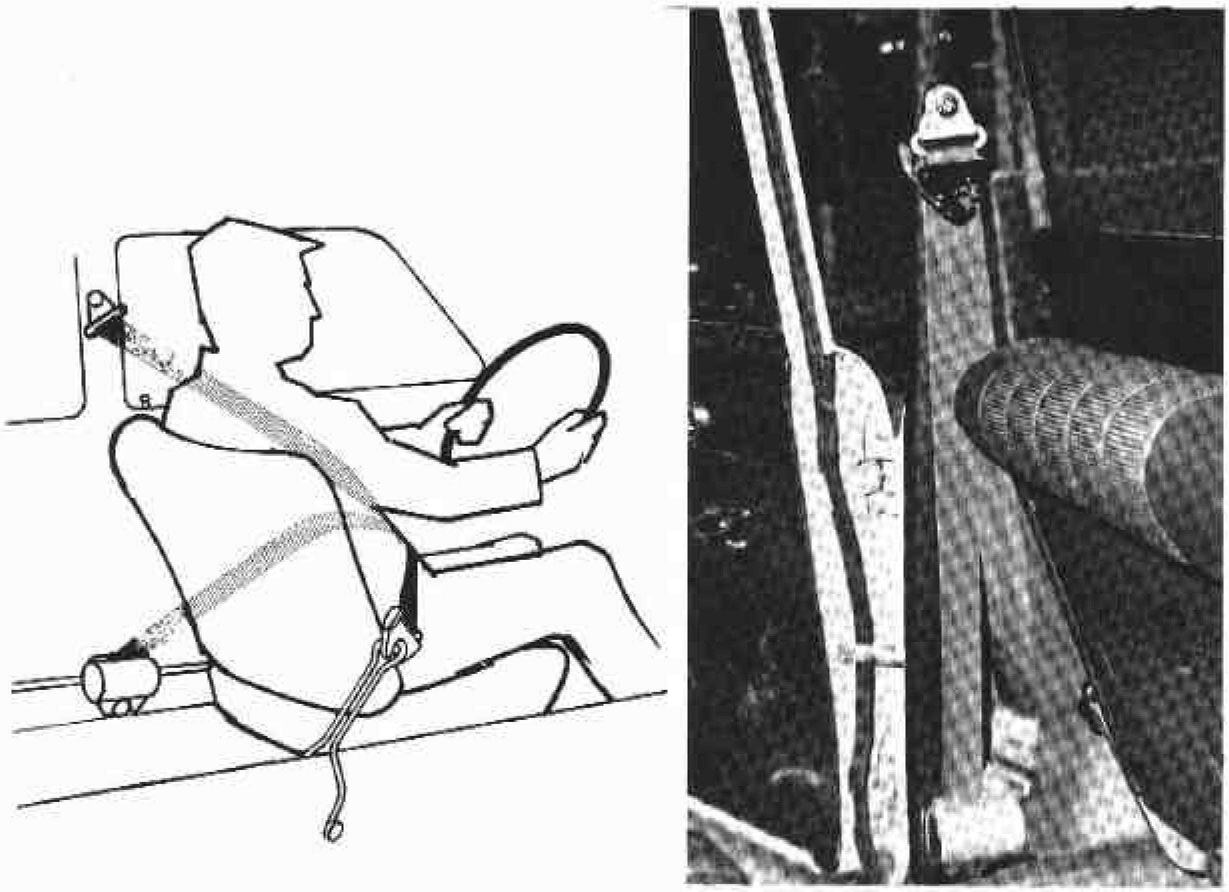


Figure 2.5-6 - ESSEM Safety Belt

Precautionary notes accompanying the installation and adjustment instructions point out the vulnerability of the inertia reel to moisture and dirt.

2.5.9 Air Bag Restraints (Reference 7)

Recent interest in air bag restraints comes from requirements for restraining astronauts and/or aircraft passengers during high "g" accelerations and decelerations. This effort is reviewed in Reference 7 and, in this same reference, attention was called to early proposals for automotive passenger restraint systems. Figure 2.5-7 shows a sketch of such an automotive system contained in a patent disclosure. A recent mockup is pictured in Figure 2.5-8. The object of the system is evident. It provides a spring and damper with, effectively, a relatively large travel. Proposals have also been made for installation of the bags in the frame side walls to provide protection against lateral decelerations. It is postulated that, with a proper sensing system and mechanical ingenuity, the deployment time would not be an insurmountable problem.

2.5.10 Rearward-Facing Seats (Reference 31)

In Reference 31, a car was designed around the proposition that all effort would be devoted to the survival of the occupants in the event of a crash. The resulting vehicle is shown in Figure 2.5-9. The configuration is an automobile with molded seats, all of which are rearward facing. Navigation of the car is performed by a periscope and TV scanners and displays. Also included is a radar system (apparently for detecting obstacle range and range rate). The interior of the car contains crushable plastic behind the seats. It was postulated by the proposer that the material be homogeneous so that only deceleration necessary for the particular crash situation would be encountered. The periphery of the

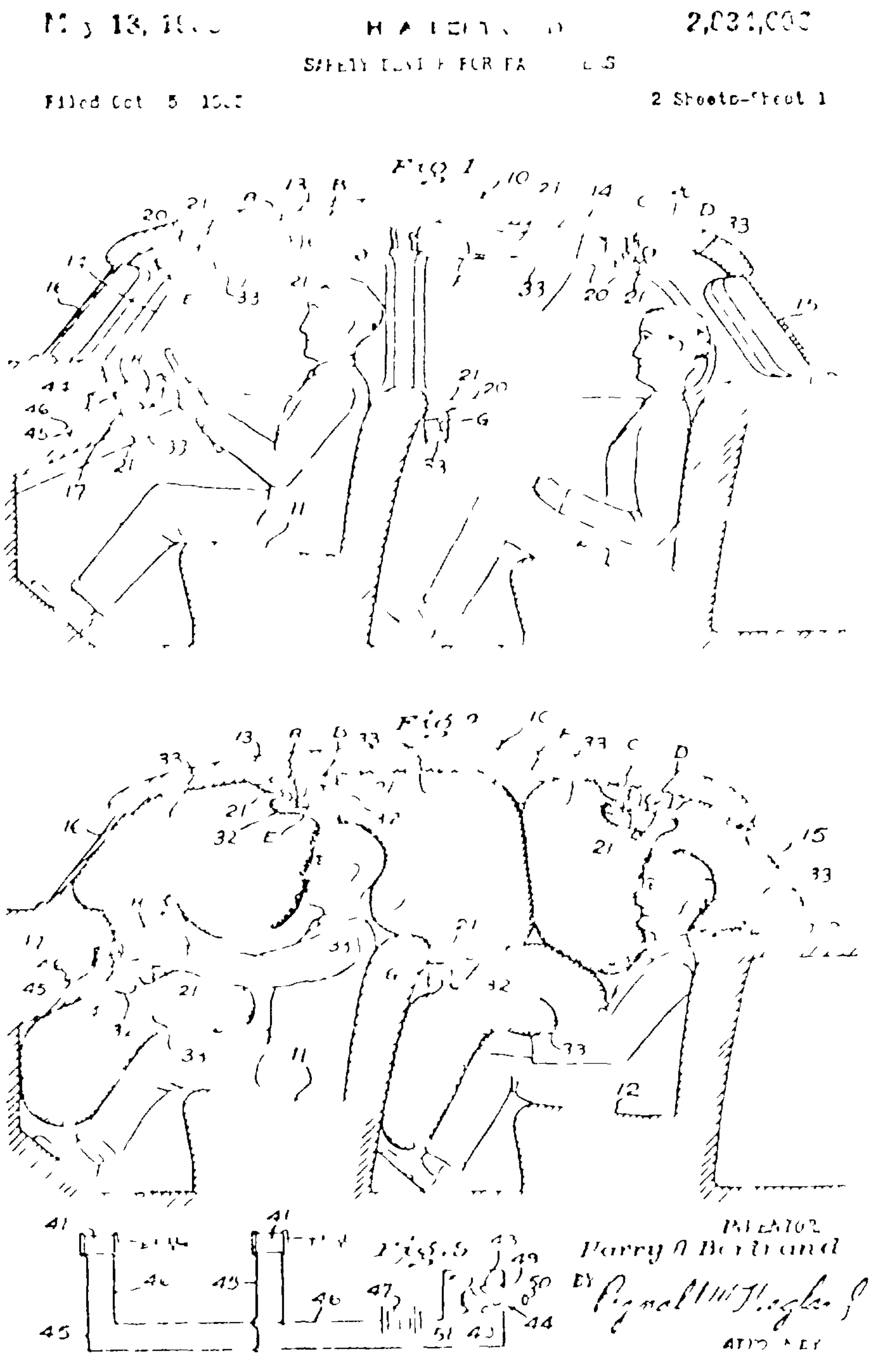
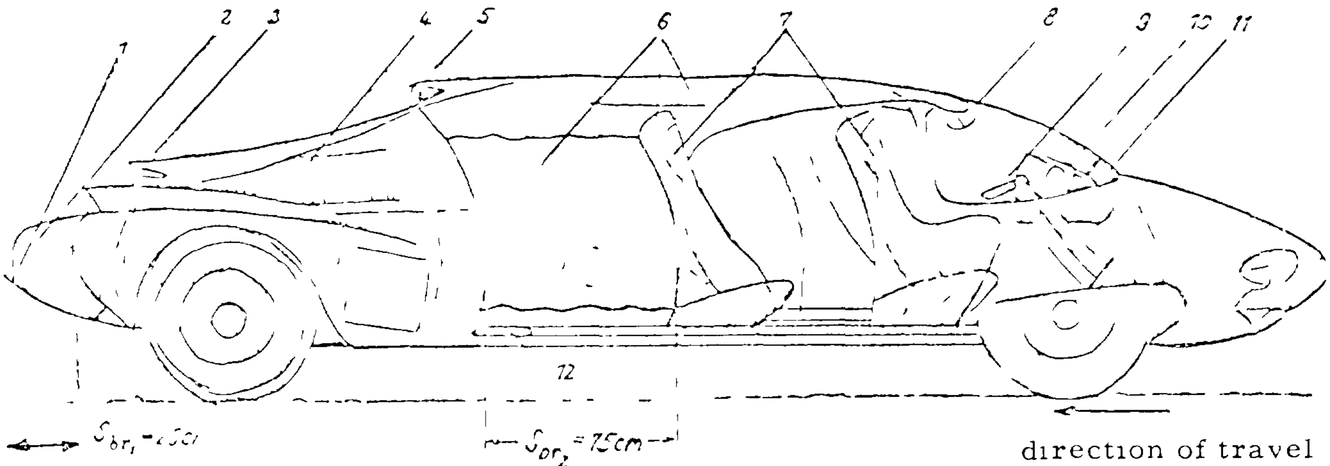


Figure 2.5-7 - Air Bag Restraint System

Figure 2.5-8 - Mockup of an Automobile Airstop Restraint



direction of travel

1. Radar - antenna - system
2. Surrounding brake - plastics
3. TV - cameras (3 Vidicon)
4. Radar - electronics to
5. Wide angle periscope
6. Inhomogen brake plastics
7. Seats, front seats slide back when door is open, connected to rear seats when vehicle is moving
8. Mirror for periscope

Figure 2.5-9 - von Ardenne's Safety Car

automobile would contain a crushable layer designed for energy absorption. It is difficult to take this proposal seriously in view of the reliability requirements associated with the navigation system, and the difficulty in obtaining a driver presentation that would enable him to react as though he were driving a conventional car form in the conventional position.

2.5.11 Integrated Front Seat Concept (Reference 32)

A conceptual integrated front seat (Reference 2.5-10) was presented in Reference 32. It incorporated lap belt and shoulder belt arrangement in conjunction with a bucket seat and folding hip restraint pads. An inertial lock was considered to be a part of the combination's strap restraint in accordance with aircraft practice. Equally important was the recognition given to the necessity for providing sufficient structural restraint to prevent the rupture of the seat anchorage. This latter point is of some importance since the anchorage must withstand both the inertial loads due to the seat mass and the loads due to body restraint reactions.

2.6 Human Tolerance Data

An ideal integrated seat design should provide an effective restraint system so that impacts of the head and chest will be avoided for selected levels of accident severity. In practice it may not be practical to expect tight upper torso restraint adjustments to preclude driver chest impacts with the steering wheel. These impacts should occur at a lower energy

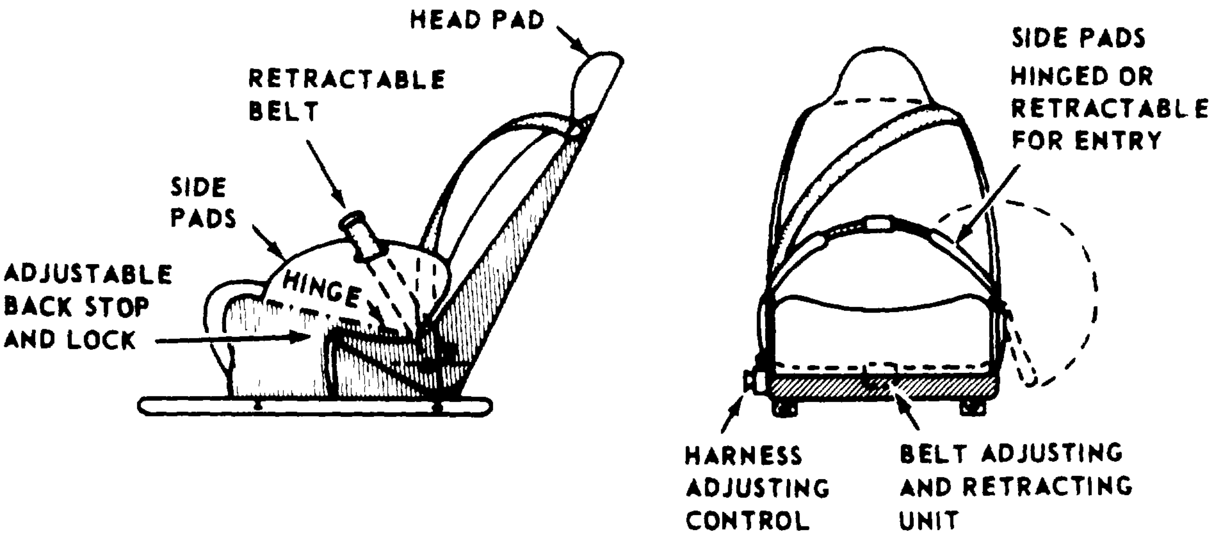


Figure 2.5-10 - Integrated Front Seat Concept

level than the lap belted or unbelted driver, hence, some increased level of protection should be realized. Reasonable care must be exercised to assure that an injury hazard is not created due to belt loadings, or free head acceleration, which may be more severe than the simple lap belted occupant injuries currently reported. This section is addressed to a review of the human tolerance knowledge available to make injury severity evaluations of integrated seat restraint system performance.

If the idealized objective of the integrated seat (no head or chest impacts) is achieved the required human tolerance data falls into one or more of the following categories:

1. Head accelerations forward about neck joint. Chin to chest reactions are possible.
2. Head accelerations aft about neck joint. Sudden flexion-extension of the neck if free space is available or impact reactions if a head rest is provided.
3. Upper torso belt and/or lap belt inflicted injuries.
4. Spinal column loadings resulting from restraint system applied forces under a flexed body posture.
5. Dynamic response of internal organs due to externally applied accelerations.
6. Arm and hand impacts with vehicle interior.
7. Upper leg, lower leg, knee and foot impacts with vehicle interior.
8. Human tolerance to lateral accelerations due to side impacts.
9. Human tolerance to angular accelerations and body attitudes typical of rollover accidents.

Each of the above categories will be reviewed briefly to describe the nature and scope of the data available to assess the effectiveness (or hazard) of various integrated seat restraint configurations. Much of the controlled experimentation with human tolerance has originated in connection with aerospace applications. The acceptable level of injury has been taken as undebilitated or freedom from abnormal weakness, lanquor or feebleness. This level was selected because the personnel were expected to perform a vehicle escape subsequent to the exposure to the acceleration loadings. We may assume that a higher threshold of injury is acceptable for single event automotive accidents.

2.6.1 Head Accelerations -- Forward Motion

Figure 2.6-1 is a summary of tests from the literature (Reference 20) for chest-to-back accelerations. Trapazoidal pulse shapes were applied to the test sled as shown in the inset. The solid line indicates the assigned limit for tolerance to meet the aerospace criteria. The dashed line indicates the moderate injury threshold. The dash-dot line is the acceleration-time tolerance curve for moderate concussion from forehead impact on a hard flat surface as developed by Wayne State University researchers. The time duration as defined by Patrick of Wayne State may vary slightly from the definition $t_2 - t_1$ as used hence the line should be a band when plotted on Figure 2.6-1. Since the plotted points were not exposed to impacts per se, it is reasonable to assume that head acceleration tolerance should fall closer to the dashed line than the hard surface impacts. Only one human point at 25 g and .93 seconds falls on the moderate to severe threshold line. While this volunteer was able to stand momentarily, he could neither see nor maintain a standing posture. He returned to normal duty in five days. Although this level of injury may be considered a tolerance level, it is unknown if the head had been unrestrained which would permit the chin to impact the chest, whether his injuries would be worse or alleviated.

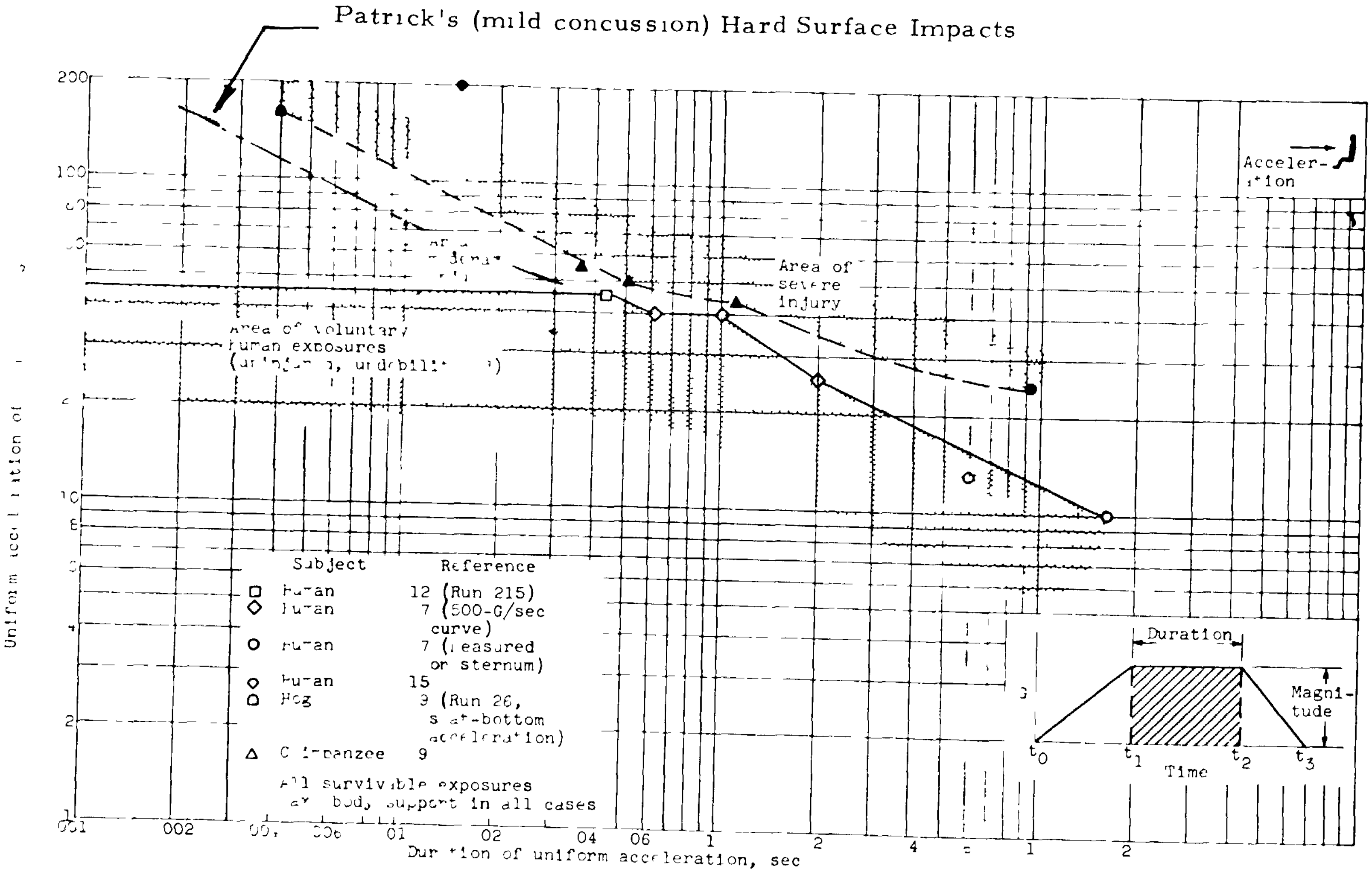


Figure 2.6-1 Duration and Magnitude of Spineward Acceleration Endured by Various Subjects

The onset of vehicle acceleration was found to be a contributing factor for the case of trapezoidal accelerations and with maximum body support as indicated by Figure 2.6-2. The shock limits fall within the 500 g/sec to 1060 g/sec range. Direct comparisons cannot be made with the rates of onset that occur in the irregular waveforms associated with automobile collisions, particularly in view of the differences in restraint systems. However, it is of interest to compare magnitudes. A typical barrier impact at 31.6 mph yields an onset of about 1470 g/sec, a car-to-car impact of 30 to 40 mph will produce a spike having a value of 1500 to 1700 g/sec when the large engine mass is suddenly stopped. Since the cause of shock, reported in Figure 2.6-2, is not known to be attributed to vehicle onset g alone, and also in view of the system differences, one cannot be certain that a head problem will exist under vehicle crash conditions. There is ample evidence that the vehicle rate of g onset is of concern, however, and its role in injury causation must be resolved as part of a future research program.

The preliminary computer simulations with their stated limitations have indicated peak values of head acceleration of 40 g to 50 g. These values are at least partially due to chin contacts on the chest and are of concern when compared to Figure 2.6-1. However, the force deflection characteristics of the necks as used in the simulation are best estimates" based on dummy tests. These values must be re-evaluated by examining high speed photographs of living volunteers. If our neck stop force deflection characteristics are reasonable, the head acceleration problem requires a future investigation. The solution may lie in the selection of harness yielding characteristics to alleviate the high peak g values.

In summarizing the potential forward head snap tolerance we recognize two problems, namely g rate and peak g magnitude. Peak g duration is also of concern but results thus far indicate that sustained high g is rarely over 20 milliseconds for the harness configurations computed thus far. The tolerance limits presented may be due to internal organ or brain response. Finally as an optimistic comment, there were

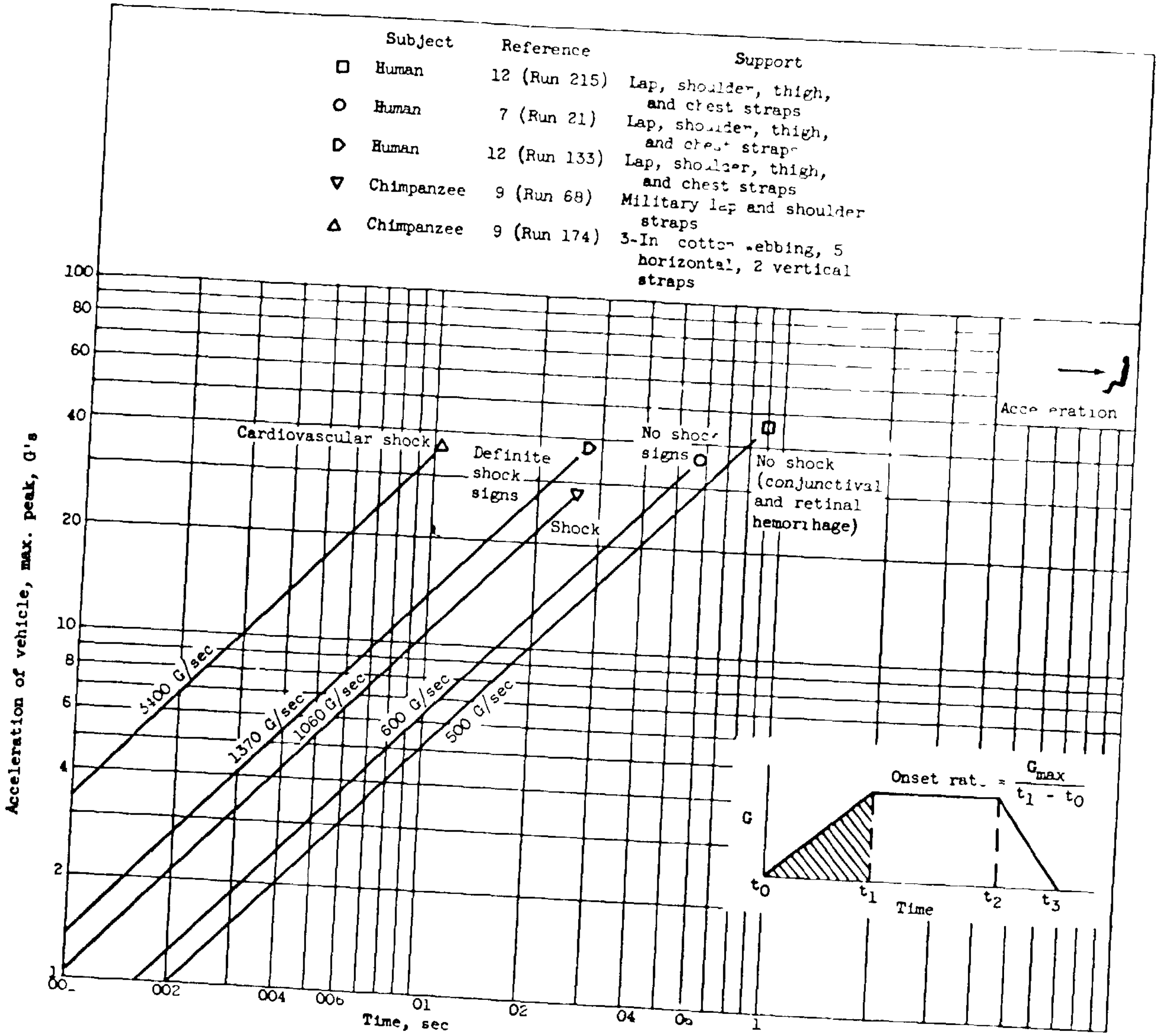


Figure 2.6-2 Initial Rate of Change of Spineward Acceleration Endured by Various Subjects

no non-impact head injuries reported for three point harness cases in the Adelaide, South Australia study by Ryan and McLean.

2.6.2 Head Accelerations - Aft Motion

Injuries resulting from these loadings are commonly called whiplash by the non-medical population. These injuries occur in rear end collisions which constitute about 19% of reported rural accident vehicles and about 28% of reported urban accident vehicles. A definition of the detailed causation mechanism is not universally accepted. There are some researchers who theorize that the injury occurs early in the force-motion results. These proponents argue that a head rest must be adjusted close to the head to be effective. Other researchers do not share this theory and contend that the injury occurs at a large backward angular displacement. While the latter group are in the majority, the conflict is expected to be resolved since Tulane University and the NIH group at Bethesda, Maryland are actively pursuing the mechanism of flexion-extension injuries of the neck.

Figure 2.6-3 presents a compendium of tests for back-to-chest accelerations (reproduced from Reference 20). The subjects were restrained in full length seats with head support from the seat back proper. The acceptable g levels are slightly less than the forward head motion cases. The g rate (onset of g) tolerance has been found to be slightly higher than the chest-to-spine acceleration case. Since the rear end collisions are usually much less severe it is tentatively felt that no serious problem exists if a head rest is provided with satisfactory adjustment.

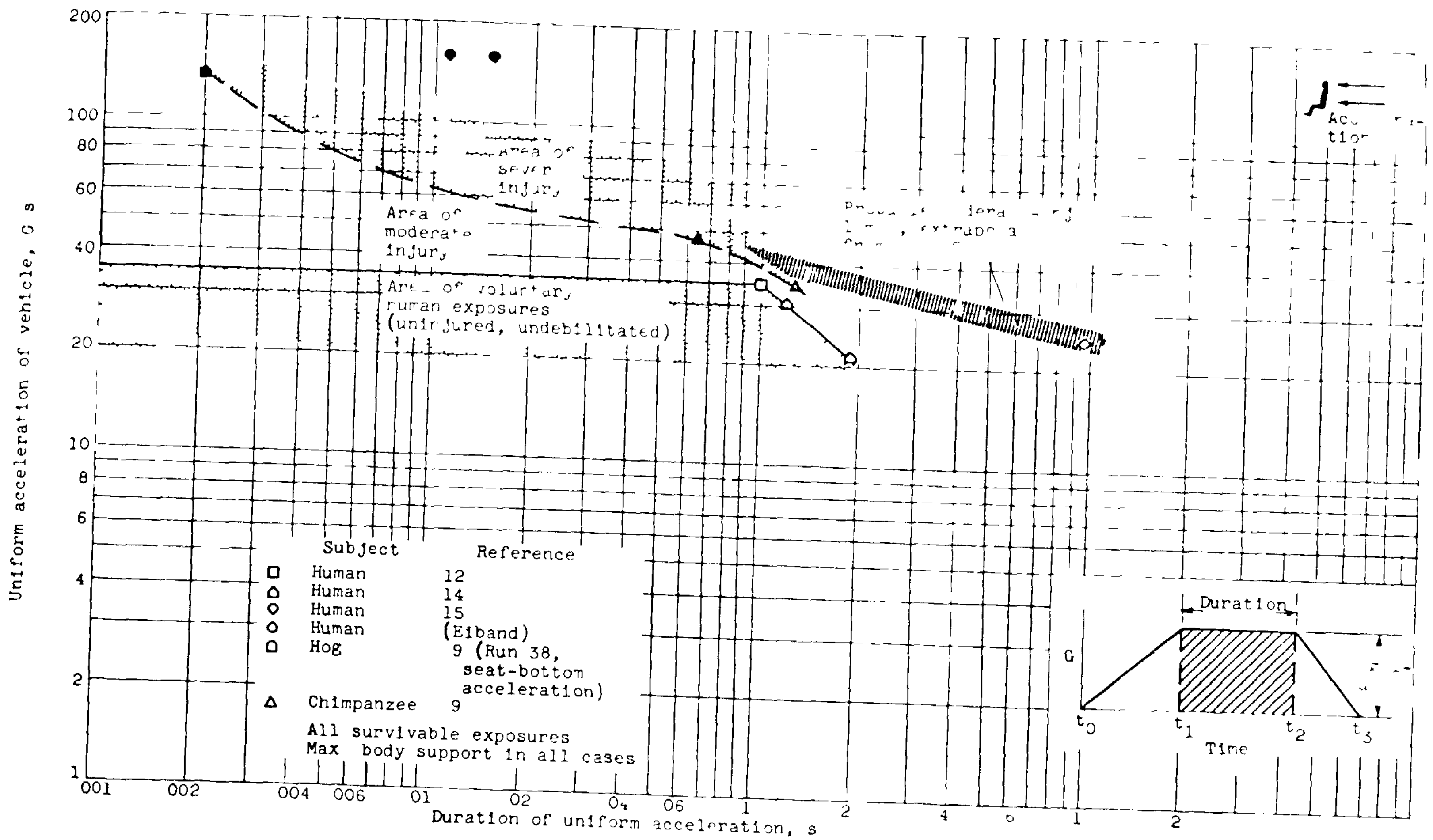


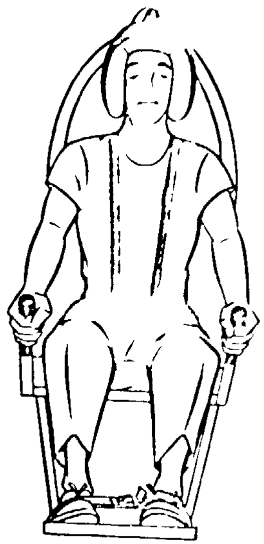
Figure 2. 6-3 Duration and Magnitude of Sternumward Acceleration Endured by Various Subjects

2.6.3 Restraint System Inflicted Injuries

The Automotive Crash Injury Research (ACIR) project has assembled data from 30 cases wherein abdominal injury was attributed to the seat belt buckle. The injuries were described as bruises, abrasions, contusions, etc., and were considered mild or minor. A future task of interest is an attempt to estimate and compare the probable injuries which would have resulted had the seat belts not been worn.

The National Bureau of Standards and Holloman Air Force personnel have conducted restraint system tests using volunteers with a maximum vehicle velocity of 14 mph. This data is not yet published since the data analysis is incomplete. The maximum loop loads (approximately two times the belt load) for the case of lap belt only was 1550 pounds. The maximum belt loop when used in combination with 3 point harness was 1350 lbs and the maximum upper torso portion was measured at about 1300 pounds loop load. Some volunteers felt a pain in the stomach but were willing to participate in other tests.

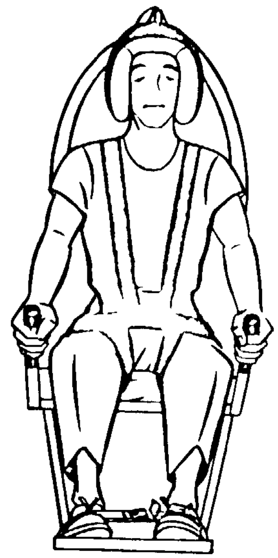
The 45 g endurance level shown in Figure 2.6-1 was achieved with an efficient full harness including leg straps as described by Group H, Figure 2.6-4. These harness configurations are not practical for the motoring public since 70% of the public do not now use simple and available lap belts. A more tenable solution is illustrated by Figure 2.6-5. However, no subject would volunteer for exposure above 11.3 g and 280 milliseconds. The corresponding levels of voluntary human tolerance are shown in Figure 2.6-6. The upper line presents acceptable g levels for the full harness with leg straps and the lower line for the standard harness. The volunteers comments for the standard harness (Group D) are repeated from Reference 21 as follows:



GROUP L

(a) Seat belt, #9 nylon, 3" wide
(b) Shoulder straps, #10 nylon, 1-3/4" wide, two straps
(c) Leg strap, #9 nylon, 3" wide (inverted "V")
(d) B-8 Parachute back-pack type

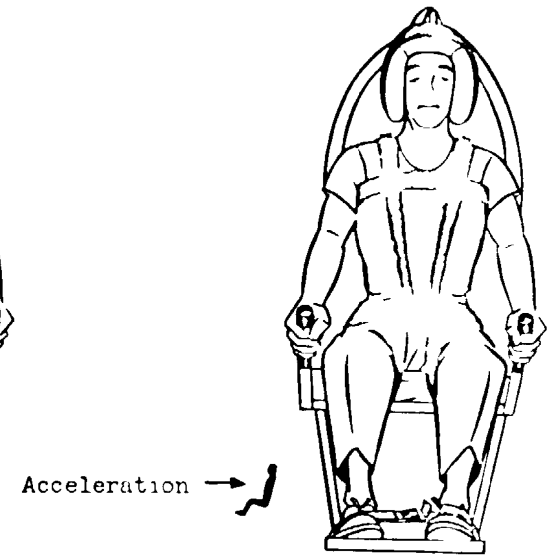
Area = 186 sq. in.



GROUP H

(a) Seat belt, #9 nylon, 3" wide
(b) Shoulder strap, #9 nylon, 3" wide
(c) Leg strap, #9 nylon, 3" wide, two straps

Area = 208 to 280 sq. in.

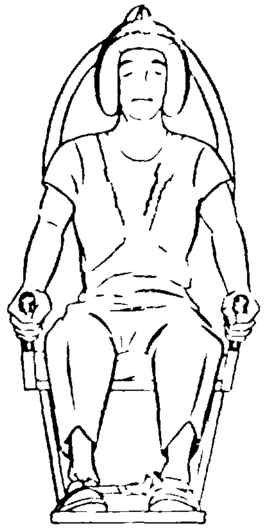


GROUP C

(a) Seat belt, #9 nylon, 3" wide
(b) Shoulder strap, #9 nylon, 3" wide, two straps
(c) Leg strap, #9 nylon, 3" wide, two straps
(d) Chest belt, #9 nylon, 3" wide

Area = 218 to 245 sq. in.

Figure 2.6-4 Harness Configurations for High G Capability



GROUP D

(a) Seat belt, #9 nylon, 3" wide
(b) Shoulder strap, M-16 #8 nylon
1-3/4" wide
Area = 138 sq. in.

Figure 2.6-5 Standard Military Lap and Shoulder Harness

1. Impact to abdomen and shoulders was quite marked.

2. Seat belt was brought up against the upper abdomen, lower rib margins very forcefully, followed by sharp pains to the ribs.

The special harness configurations (Figure 3-4) was reported to have pinched the legs and thighs but totally acceptable.

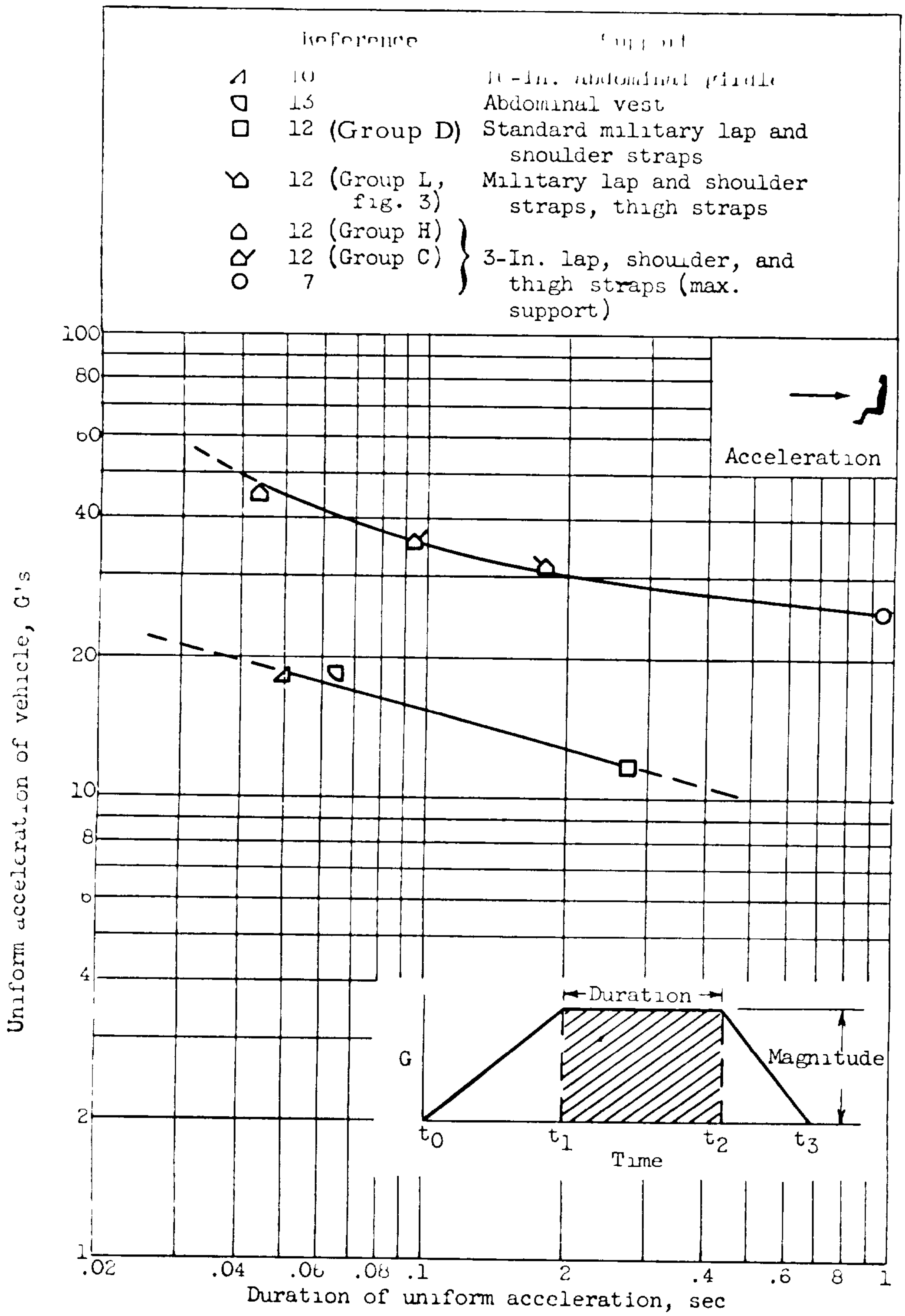


Figure 2.6-6 Variation of Voluntary Human Tolerance to Spineward Acceleration with Method of Total Body Support

1. Impact to abdomen and shoulders was quite marked.

2. Seat belt was brought up against the upper abdomen, lower rib margins very forcefully, followed by sharp pains to the ribs.

The special harness configurations (Figure 2.6-4) were reported to have pinched the legs and thighs but were totally acceptable.

In summarizing restraint tolerance we may conclude that the design of an effective and acceptable harness for forward impacts poses a challenging problem. The acceptable levels (for minor injury only) as shown by the lower curve of Figure 2.6-6 are slightly less than the peak vehicle g's expected in barrier crashes of about 30 mph or car-to-car crashes of about 35 mph. A great deal of effort in the design of a passive mechanical restraint appears justified as a follow-on effort.

2.6.4 Spinal Column Loadings from Restraint System Loadings

The phenomenon known as "submarining" has created apprehensions regarding a possible hazard in 3 point restraint systems. For certain combinations of geometric anchorage point locations and seat cushion stiffness, anthropometric dummy tests have shown a tendency to slide below the lap belt and an ensuing downward load from the shoulder diagonal has stressed the dummy's back. This phenomenon was first discovered by Ford (Reference 22). Crash tests conducted with pelvic and upper torso restraints resulted in broken backs of one type of anthropometric dummy. Aldman (Reference 23), on the other hand, conducted tests and did not experience this type of dummy damage. ACIR has recorded two cases of spinal fractures for some high speed police car crashes with 3 point restraints. The combined concern of the Public Health Service and CAL has been responsible for initiating investigations. The results have been reported in Reference 3.

The conclusion to be drawn is that a potential hazard exists. The reason the sled test volunteers did not experience submarining may be due to relatively hard thin cushioned seats, leg straps or both. Obviously, this is a human tolerance problem which requires research as part of an integrated seat follow-on effort.

2.6.5 Dynamic Response of Internal Organs

The contents of the human body are subject to an amplification in peak loading similar to any higher order sprung mass system. There has been active research on the influence of acceleration pulse length on the loading of various internal organs. Deceleration injuries to the thoracic aorta has been of particular interest since the existence of tears and failures have been frequently reported as a result of post accident examinations. The amplification factor of a linear undamped, single degree-of-freedom system can reach a maximum of about 1.76 for a one-half sine pulse shape, i.e., the sprung mass can experience an acceleration of 1.76 times the input acceleration to the supporting mass. Since the restraint system itself may act as a spring, the belt-torso-internal-organ system becomes a higher order system and amplification factors may exceed the 1.76 value of the simpler system. The sensitive parameters are the ratio of pulse length to natural period of the suspended organ, the damping ratio of the responding system, and the input pulse shape.

Figure 2.6-7 presents the amplification factor for the seat-to-chest system through the harness system. The maximum chest g was measured at the chest and the maximum seat g was measured on the seat pan. The numbered points are test runs from Reference 21, the curve is a half sine pulse period to approximate the data. The value of 1.6 suggests that a damping ratio of about .02 was achieved (1.76 is the value for zero damping). Of greater interest is the amplification factor of the internal organs, e.g., the heart-aorta suspension, which effectively responds to the acceleration of the chest. The higher order system is more complex and estimates are not readily available for the present study.

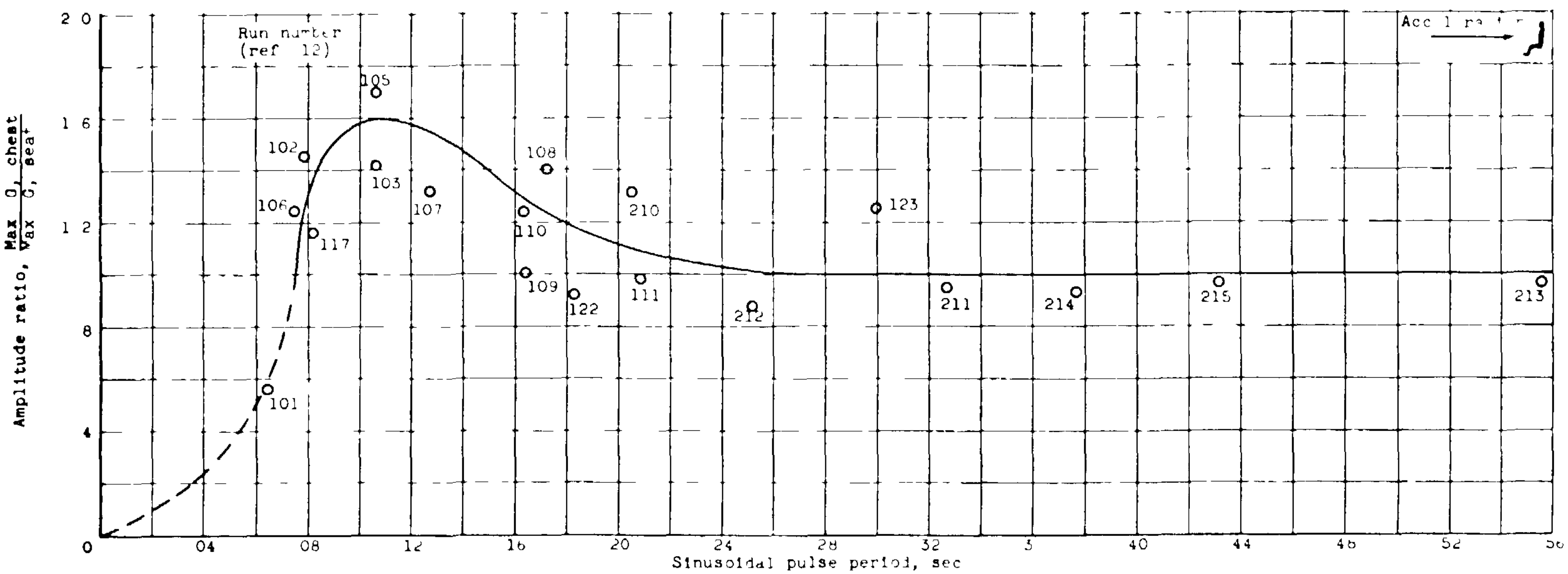


Figure 2.6-7 Spineward Acceleration of Human Subjects: Frequency Response as Function of Amplitude Ratio Period Corrected to Standard Subject Weight of 172 Pounds (Seat and Subject = 232 Lb.)

Goldman and Von Gierke (References 24 and 25) have reviewed available data on human response to shock and vibration. Table 2.6-1 presents the peak resonance measurements on the human body. The one-fourth period durations are listed whose g rate (jolt = g/sec) values will attain peaks of 20, 30, 40, 50, 100 and 200 g respectively.

In summary the dynamic response problem requires careful consideration to assure human protection from internal injuries. An integrated seat which is properly designed to shape the applied pulse to the body can do much to avoid the consequences of a "tuned" system which may exist under certain crash conditions.

2.6.6 Arm and Hand Impacts

Frontal impacts of automotive vehicles are of very short duration. Aldman (Reference 23) has shown that the effects of human muscular restraint are quite limited, except for low energy impacts. As a result the arms are likely to flail around and be exposed to injury. This problem is not considered serious, however, since ACIR data indicates that only 8 dangerous injuries to the arms exist in a sample of 34,700 injuries. Even those injuries were very likely to have occurred to unbelted occupants who were exposed to glass cuts or were ejected from the vehicle.

2.6.7 Upper Leg, Lower Leg, Knee and Foot Impacts

The lower extremities are currently the third most vulnerable body area for injury to the driver and front right occupant. The major cause of injury is the instrument panel. Since the large majority of ACIR cases involve unbelted occupants, an integrated seat which does not rupture its anchorages should significantly reduce the severity of this type of injury. However, the lower extremities will still be subjected to forward and upward motions, and injury alleviation will remain as an interior design problem.

	Peak Resonance cps	Period T Seconds T/4	Jolt G per second at T/4 for peak G of					
			20	30	40	50	100	200
Transverse, supine	1	.25	80	120	160	200	400	800
Whole body, unit mass	2	.125	160	240	320	400	800	1,600
Longitudinal, supine	3-3.5	.082	240	360	480	600	1,200	2,400
Vertical, sitting	4	.0625	320	480	640	800	1,600	3,200
Vertical, standing	5	.05	400	600	800	1,000	2,000	4,000
Longitudinal, abdomen	6	.041	480	720	960	1,200	2,400	4,800
Longitudinal, anterior chest	7	.035	560	840	1,120	1,400	2,800	5,600
Longitudinal, abdomen	8	.031	640	960	1,280	1,600	3,200	6,400
Longitudinal, anterior chest	9	.027	720	1,080	1,440	1,800	3,600	7,200
Longitudinal, anterior chest	10	.025	800	1,200	1,600	2,000	4,000	8,000
Longitudinal, anterior chest	11	.0225	880	1,320	1,760	2,200	4,400	8,800
Vertical, standing	12	.0207	960	1,440	1,920	2,400	4,800	9,600
Vertical, seated, head	18	.014	1,440	2,160	2,880	3,600	7,200	14,400
Vertical, standing, head	20	.0125	1,600	2,400	3,200	4,000	8,000	16,000
Vertical, standing, head	30	.081	2,400	3,600	4,800	6,000	12,000	24,000
Vertical, seated, eyeballs	60	.0041	4,800	7,200	9,600	12,000	24,000	48,000
Vertical, seated, eyeballs	90	.0027	7,200	10,800	14,400	18,000	36,000	72,000
Jaw versus head	100	.0025	8,000	12,000	16,000	20,000	40,000	80,000
Skull	300	.0008	24,000	36,000	48,000	60,000	120,000	240,000
Skull	400	.0006	32,000	48,000	64,000	80,000	160,000	320,000
Skull	600	.0004	48,000	72,000	96,000	120,000	240,000	480,000
Skull	900	.00027	72,000	108,000	144,000	180,000	360,000	720,000

Table 2.6-1 Peak Resonance Measurements
(Goldman and Von Gierke, Reference 25)

2.6.8 Human Tolerance to Lateral Accelerations

Lateral acceleration exposure is an important problem in automobile accidents. The frequency of occurrence of side impacts in urban accidents is about 17%, hence, research is warranted to establish related human tolerances.

The Air Force has conducted 87 tests on lateral acceleration (Reference 26) effects on the Bopper sled. The results have indicated that at a peak sled deceleration of 11.6 g one subject was exposed to possible cardiovascular involvement. Peak head acceleration was measured at 24.7 g. Human tolerance to lateral impact while restrained with a lap belt and over-the-shoulder harness has been demonstrated in a limited sense.

a. No permanent physiological changes were reported for healthy young male volunteers while exposed to impacts of 11.59 G's average and durations of approximately 0.1 seconds.

b. Minor physical complaints, such as muscle stiffness (neck musculation), occurred in greater than 60% of the exposures after the 8 G series (average exposure 8.8 G's).

c. The combination lap belt and over-the-shoulder harness was effective in restraining the torso at all levels tested (maximum average 11.47 G) as shown by a stabilized average torso deflection of approximately 5 degrees from the vertical in the direction of travel.

d. Head angular deflection should be considered as a possible problem area while the torso is restrained. Subjective complaints indicate a predominance of neck musculature discomfort.

e. The chest/sled average amplification factor increased with increasing vehicle decelerations, reaching an average of 1.75 for the 10 G series (average 10.56 G).

f. The head-chest average amplification factor fluctuated throughout the series between 1.15 and 1.20.

g. Exposure of volunteers to decelerations greater than approximately 12 G s laterally and time durations of approximately 0.1 seconds should be investigated with biological specimens other than man to investigate possible cardiovascular responses to impact.

Additional research is required on the head injury mechanism associated with lateral acceleration of the human with varying degrees of torso restraint. The head is known to be vulnerable to side impacts as reviewed by McHugh (Reference 27) in discussing Head Injury and Temporal Bone Fractures. In closed head injury, fractures of the temporal bone may be longitudinal, transverse, or a combination of both. Clinical experience of many (and experiments of Proctor, Gurdjian and Lissner) confirm that longitudinal fractures of the temporal bone occurs more commonly from blows to the temporal and parietal regions than from blows to the occupital or frontal areas. The medical effects (severity of injury) while complicated are generally known. The energy required to produce the fractures and resulting internal brain injuries are not completely documented.

In summary there is a need for much research to establish human tolerance to side impacts. Since human skull anatomy differs substantially from animal skulls it is expected that reconstructed accident techniques involving humans will be necessary to supply the needed data.

2.6.9 Human Tolerance to Angular Accelerations

During rollover type accidents the restrained occupant will be subjected to combined linear and angular accelerations. There are data on human tolerance to linear spinewise accelerations and to transverse (chest-to-back) accelerations. The added angular motions are not easily evaluated. It is expected that some experimental programs will be necessary to evaluate human tolerance in rollover accidents. Some appropriate preliminary research programs will be suggested in a forthcoming CAL report[†] which could provide some gross human tolerance information to angular accelerations.

† "Occupant Protection", FHA Contract No. FH-11-6574.

2.7 Industry Progress on Safety Seats

2.7.1 General Comments

Members of this study team visited General Motors on September 13, and Ford Motor Company on September 14, 1967. Both companies' representatives were responsive, cooperative, and courteous. Some detailed design features and long range conceptual designs were withheld as being proprietary, discussion was limited to generalities regarding the nature of their research. No judgments were made on potential effectiveness or the level of effort on the long range items. Both companies are supporting biodynamic research projects.

2.7.2 Current Seat Technology

Design emphasis and importance is directed to meeting current Federal Standards with regard to anchorage loadings, rear occupant protection requirements and seat back energy absorption and strength. Design practice is based on consideration of the interior as a system. Seat adjustments, control access, and interior impact points are studied as they are influenced by vehicle control requirements as well as occupant kinematics during an accident. Engineering compromises are made necessary by the fact that both the 95th percentile male and 5th percentile females must be accommodated as occupants.

2.7.3 Future Seat Research -- General Motors

This manufacturer has made preliminary studies of a variety of seat types. General Motors designers have studied proposed designs which have emerged such as the Cox of Watford seat, and Irving Airchute's seat design to name two. Also, some proprietary work is progressing on plastically yielding seats. Seat design is a continuing effort and no configurations have yet been sufficiently evaluated from the view-points of comfort and crash aspects. Computerized simulations have been used in the study of occupant kinematics in impacts. Some prototype designs have been built and tested on the acceleration sled. No firm trends were expressed regarding the rationale used in seat design.

General Motors have also "acceptance tested" some seat designs and restraint systems for comfort and convenience. Employees have been widely used to critique ideas. Retractors have been widely used, some are mounted to the seat. Three point harnesses have been installed, some complaints of discomfort have been expressed due to harness and buckle weight. Unused hanging belts have been found to be a complaint item since their motion poses a psychological hazard. Belt storage is considered to be very important.

Head rests have been offered on GM cars as optional equipment. A GM consideration is the assurance that mounting sockets are non-hazardous when head rests are removed.

GM is continuing studies regarding the appropriate width of a head rest. Men drivers have been found to sit toward the door whereas women drivers tend to sit toward the center of the seat. A width to suit the extremes may interfere with vision.

Professor Patrick of Wayne State University is performing some "whiplash" tolerance studies. Dr. I. McNab is also studying flexion injuries.

Some lateral impact protection improvements are being sought by means of arm rest design. Surface curvature(s) and energy absorbing characteristics are being examined with a view toward provision of improved lateral restraint and alleviation of injury. The air bag type of restraint system is considered to be impractical for side restraint.

2.7.4 Future Seat Research -- Ford

Ford Motor Company is working toward the same objectives as those reported for General Motors. Emphasis has been given to detailed features in order to progressively develop better seat designs. The inertia reel is such a device. Tests at Ford have indicated a 30%-35% reliability on existing available types. This performance is deemed unacceptable. Also, their tests reveal that an added variable amount of restraint slack is introduced before the reel locks. This increase in slack is detrimental to the performance of an upper torso harness. Ford designers have attempted to provide a reel which is actuated by vehicle deceleration rather than occupant motion relative to the vehicle. The acceleration component of gravity on an incline tends to defeat the principle unless sensitivity limits are adjusted to preclude the problem. Other crash generated effects are being examined as possible means of engaging the reel in hopes of circumventing the requirement for slow occupant movement to preclude unwanted locking. Ford engineers feel convenience is a primary objective, neat storage is a part of convenience.

Head rest installations have been made for evaluation purposes. Head and eye motion studies indicate that drivers turn their heads to confirm that a lane is free of traffic before turning. Small drivers have expressed annoyance about the visual obstruction produced by a passenger head rest.

Biomechanics engineers at Ford have expressed concern regarding the added injury potential of a rear end impact in which whiplash type loads are applied while a person's head is turned sideways. An instinctive response when tires squeal is a head turning movement. Neck vertebra are more vulnerable to injury when the head is turned sideways.

Side impact protection is considered to be a very difficult problem. Fixed lateral restraint poses ingress and egress problems. A swivel seat type design appears to be required, Chrysler's swivel seat, offered as optional equipment in the past, was not popularly accepted.

Finally, both GM and Ford have been working on child restraint systems. Ford expects to offer a child restraint shield in the near future.

2.8 The Application of Cost Benefit Analysis to Integrated Seat and Occupant Restraint Performance

Introduction

The objective of the analysis is to provide the decision maker with the cost and benefits of alternative seat concepts. More specifically, the incremental protection provided by the seats beyond that provided by present seats must be developed together with the associated costs.

Cost-benefit comparisons appear relevant at two levels. One is concerned with the incremental protection achieved on a per unit basis. In this case, the analysis is focused on one or several types of passenger vehicles equipped with alternate seat configurations in the most prevalent impact collision situations causing injury to the passenger. The other deals with the overall protection afforded by the candidate seats as may be reflected in national statistics. This analysis involves selection of a time period as a basis of comparison, and also requires estimations of the number of vehicles which will be equipped with the candidate seats during the time period, the usage rate of restraints associated with the candidate seats, the likelihood (frequency) of occurrence of various types of accidents, the relative number of different types of passenger-vehicles in the population where protection afforded by the seats may be related to vehicle size and weight, and the influence of other protection improvements internal and external to the cars which may be developed.

Although the second cost-benefit comparison may be more meaningful, it will require a greater number of initial assumptions and estimations than the first and as a result will be less precise. A number of sensitivity studies will be required in the second type of comparison to ascertain the effect of the various assumptions on the final results.

Cost Measure

The pertinent cost is the difference between the cost of existing or projected future standard seats and that of the candidate seat concepts. Current vehicles are equipped with two types of seats -- bench or bucket which are either manually or electrically adjustable. In order to determine the incremental cost of installing the new seat concepts we must initially determine the difference in cost between the new seat concepts and the types of seats they replace. The determination of the cost as related to the impact of the new seat concepts on national statistics will require projection of the number and kinds of standard seats which may be incorporated in new cars within the stipulated time frame, estimating the costs of these seats and then determining the additional cost incurred by introducing the new seat concepts.

Benefit Measures

Benefits represent the added protection offered by the new seat concepts. Four benefit measures are suggested here:

1. Increased usage of restraints, by means of improved convenience

2. Reduction in the physical forces acting on the vehicle occupants.

3. Reduction in the number of fatalities and number and severity of injuries.

4. Dollar savings resulting from Item 3.

The particular measure employed depends on the intended use of the data. Brief discussions of the applications of each measure are presented below.

The first measure may well be the most significant benefit. However, it will be a difficult item to predict.

The second measure applies where the protection afforded by the integrated seat is evaluated in combination with other protective features such as a change in the vehicle structure. The reduction in the physical forces serves as the common denominator for basically different approaches to protecting the occupants. It should be noted, however, that this measure implies knowledge of the relationship between the physical forces acting on the occupants and the resultant injuries.

The third measure is useful for comparing different integrated seat concepts or seat concepts vs other means designed to protect the occupants.

The fourth measure which expresses the benefits and costs in the same units can be employed for break-even analyses. For example, it can serve to answer the question: Given the incremental cost of an integrated seat, what reduction in injuries or fatalities is required for the seat to pay for itself?

Care must be exercised in interpreting the benefits when expressed in dollars, because the translation into dollars will obscure some significant qualitative differences. To illustrate, if the dollar cost of three light injuries are the same as for one serious injury, the benefit measure will not distinguish between them. Similarly, if the cost of a fatality is less than for a severe injury, the study results may become misleading.

Presentation of Results

Using the foregoing measures of cost and benefits the results can be presented in a number of ways. A single value of costs and benefits can be obtained by computing cost-benefit ratios either for specific collision situations or using a weighted average of different collision situations. A point to be noted, however, is that the largest ratio does not necessarily indicate the desired course of action, because even a large ratio may not mean a significant increase in passenger protection. Also equal ratios may not indicate equal benefits.

Example:

(1) $$\frac{\text{Incremental Benefit}}{\text{Incremental Cost}} = \frac{.1}{.01} = 10$$

(2) $$\frac{\text{Incremental Benefit}}{\text{Incremental Cost}} = \frac{2}{1} = 2$$

(3) $$\frac{\text{Incremental Benefit}}{\text{Incremental Cost}} = \frac{10}{5} = 2$$

Alternate methods of presenting results can include the grouping of data by specified levels of incremental costs and/or benefits. The specific method used to best present the results of the analysis cannot be determined apriori.

State-of-the-Art of Applicable Measures

The application of cost benefit analysis to integrated seats is presently limited by a lack of available measures of benefits.

For the case of an existing restraint device, such as the lap belt, an evaluation of benefits can be based on injury statistics related to ejection. That is, the prevention of ejection has been shown to reduce fatalities. However, a comparison of the benefits to be derived from new forms of restraint systems cannot be based on existing injury statistics. Rather, it will be necessary (1) to perform experimental research to measure performance benefits, and (2) to interpret the findings in terms of accident statistics (i.e., the distribution of accident vehicles among the various accident types, and their associated speed ranges).

A particular difficulty is introduced by the fact that the use of new forms of restraint can be expected to result in different kinds of injuries. If the same form of injury were associated with two types of restraint that are to be compared, it might be possible to compare the accident severities at which a given injury severity will occur. However, since this is not the case, it will be necessary to define "equivalent" injuries of different types.

Another difficulty is that of predicting the magnitude of potential benefits in the form of increases in the extent of restraint usage.

3.0 AREAS OF NEEDED RESEARCH

3.1 Restraint System Environment

The ability to describe the environment in which an integrated seat is to function is essential (1) to its conceptual and detailed design and, (2) to the performance of meaningful tests and experimental evaluations. Since the primary source of the environment description is accident statistics, the process of derivation should be an adaptive one whereby new data, or a reinterpretation of existing data can be effectively assimilated. Because of the statistical nature of many environmental parameters, the concept of sampling from them is proposed. The most accurate procedure would be to input data from all sufficiently defined accidents. This is obviously not practical, but it is possible to randomly sample from the data so that common and rare occurrences are correctly weighted. The following four items indicate specific data that must be assembled.

3.1.1 Occupant Variables

One class of variables is that necessary to describe a kinematic human model. This would include: weights, centers-of-gravity, dimensions, and inertial properties of the various body parts used in the kinematic model. For the general population, most of the required data are available (References 28, 29) or can be developed with sufficient accuracy. Relatively speaking, occupant mass property data may be described as "clean" in the sense that it is collected under controlled conditions from a large sample and not expected to be influenced by the introduction of an integrated seat.

A second class of data describes occupant position in the vehicle and exposure. Occupant position data are required because of the correlation between size and seating position (e.g., children occupying the rear seat). Exposure data would describe the frequency that various seating positions are occupied, which may be significant if there is a positional variation in protection afforded by the integrated seat.

3.1.2 Interior Geometry of Vehicles

Because any restraint system deforms under load, it is necessary to have sufficient information available to define a minimum clearance envelope for all intended vehicles. The minimum distance between the occupant and the vehicle structure is also needed to predict the probable injury due to penetration and crushing of the vehicle. The nature and details of the vehicle/occupant impact points will be important in arriving at the level of protection to be provided.

3.1.3 Restraint System Variables

Restraint system variables determine the loading and the total movement of the occupant due to a given deceleration time history of the compartment and the inertial load of the system itself. Because of anticipated nonlinearities and since the load is multi-directional, a considerable research effort will be necessary to determine the protection provided for various-sized occupants.

Other factors in evaluating the performance of a restraint system are:

(1) Comfort and safety during normal operation, and

(2) Ease of release after an accident has occurred.

3.1.4 Accident Variables

These can be grouped into two categories:

(1) Vehicle properties - of importance are the test or analytical data necessary to define the direction and waveform (time history) of the compartment deceleration. The concept of sampling accident statistics will be required to establish distribution of speeds and directions of impacts. Also of necessity in relation to vehicle properties, will be sufficient information concerning the restraint system/vehicle interface

to insure that loads can be successfully transmitted to the vehicle structure.

(2) Object properties - the behavior of a vehicle in a collision is dependent on the properties of the impacted object, and it is therefore necessary to take into account the deformation characteristics of obstacles. The frequency with which various objects are struck (e.g., barrier, car-to-car, etc.) must be predicted by sampling from available accident statistics.

3.2 Human Tolerance Research

The interpretation of available human tolerance data, for the case of pelvic plus upper torso restraint, in terms of the automobile collision environment is a dubious procedure at best. Much of the related aerospace research (see Section 2.6) has made use of trapezoidal deceleration waveforms, as measured on relatively rigid vehicles in linear decelerations. In the automobile, highly variable, combinations of linear and angular accelerations are encountered, and measurements of these accelerations indicate irregular waveforms containing "spikes". It is obvious that human tolerance experiments are required in the restraint system environment of automobiles (see Section 3.1). When that environment has been adequately defined and appropriate experimental facilities are available, the following items should be included in an experimental program.

3.2.1 Forward Head Acceleration

In Section 2.6, it is indicated that the rate of onset and the peak value of vehicle deceleration are considered to be the more significant parameters for this type of exposure. In the case of an irregular vehicle deceleration waveform, including "spikes", a direct interpretation of these items is not possible. However, it may be possible to relate human tolerance results to a specific frequency range, by means of a harmonic analysis of the vehicle deceleration waveform.

3.2.2 "Submarining" Responses

A "submarining" response may be defined as a combination of kinematics and loading that results in the occupant partially sliding under the lap belt portion of the restraint harness. References 11 and 3 discuss this problem as related to anthropometric dummies. While this type of response has not been demonstrated to occur with living humans, research should be performed to answer the questions that exist regarding "submarining".

3.2.3 Dynamic Response of Internal Organs

The exposure limits in the automobile collision environment, at which internal injuries will be encountered, are not currently defined. Yet this information is essential for a rational specification of upper torso restraint characteristics. That is, the responses of the internal organs will be strongly influenced by the filtering, or pulse shaping, effects of the upper torso restraint. Also, it has been frequently proposed that an upper torso restraint should yield at a constant load, or "saturate", at some loading condition below the injury threshold.

3.2.4 Side Impact Tolerance

Research is necessary to generate human tolerance data under conditions of the automobile collision environment in side or oblique, impacts. This information is required to establish performance criteria for the lateral restraint features of integrated seats.

3.3 Principles of Occupant Protection

From the review of existing integrated seat and restraint system concepts and of the relatively sparse substantiating data associated with many of them, it becomes apparent that a serious gap exists in current programs aimed at improved crash protection of automobile occupants. There is presently no organized evaluation and development activity for new or existing concepts, with the exception of limited proprietary activities within the automobile industry.

In view of both the complexity of the restraint system environment (Section 3.2) and the dearth of applicable and definitive human tolerance data (Section 3.1), the tasks of (1) evaluation of a specific concept, or principle, and (2) development of applicable performance criteria are beyond the means of individual inventors and small companies. Also, such an activity tends to be highly speculative, since the systems nature of occupant protection will, in most cases, require the marketing of a novel concept through the automobile manufacturers rather than by direct sales to the public. Another risk factor to be considered is the possibility that a technically successful concept may not meet with public acceptance.

For these reasons, the development and evaluation of new concepts, or principles, is not being pursued in as vigorous a fashion as the national problem warrants. A key problem in the improvement of this situation is definition of the proper role of the Federal Government in the development and evaluation of concepts and principles that may be embodied in patented devices. If the related policy questions can be resolved, the support of such an activity by NHSB would appear to be one of the more fruitful future programs.

Examples of concepts and principles that could be included in a program of combined experimental and analytical research are the following:

1. Energy absorbing seat structures and/or seat anchorages (i.e., by means of design for plastic deformation).
2. Tilting seats - both powered and inertial.
3. Yielding restraint belt anchorages and/or devices in series with belts.
4. Automatic belt tighteners.
5. Inertia reels actuated by vehicle deceleration as well as belt motion.
6. Head rests with yielding supports.
7. Swivel seats with structural "wings" for side impact protection.
8. Moveable sections of the instrument panel to provide occupant restraint.
9. Air bags.

In view of the fact that the described research program would require improved definition of human tolerances (Section 3.1) and of the restraint system environment (Section 3.2) it could serve to provide guidance and priorities for separate research activities related to those topics

4.0 CONCLUSIONS AND RECOMMENDATIONS

The integrated seat concept has been found to show promise as a safety device for both improving the performance of and increasing the usage of occupant restraint in automobiles. Although the most appropriate configuration for torso restraint is still open to question, it appears likely that lap and shoulder belts incorporated into the seat structure will prove to be a first step toward integrated occupant restraint. The incorporation of lateral restraint, as in the "winged" Liberty Mutual integrated seat will constitute a step toward providing the occupant protection needed in side impact and other accident types that produce side acceleration components.

Evaluation of integrated seats, or any other safety device, requires performance criteria. At present, the only restraint system criteria are belt strength and locations and loads for attachment points. These are inadequate. Occupant restraint performs as a system, criteria must be based on system performance rather than on individual components. Compliance tests should also be established on a systems basis. With data on human tolerance and the accident environment, system performance criteria and requirements for occupant restraint can be formulated.

The following recommendations are aimed at the design of a program that will meet the determined needs and that will be consistent with the role of NHSB, i.e., to promulgate effective and reliable vehicle safety standards and to conduct and stimulate research and development for the necessary backup and evaluation.

4.1 Short Term Development

The following theoretical and experimental research could begin immediately with the short term objective of defining improved occupant restraint concepts and preliminary (estimated) performance characteristics within one year.

4.1.1 Evaluation of Existing Design Concepts

4.1.1.1 Yielding Seat Structures and/or Seat Anchorages

The preliminary analytical exploration of potential benefits of integrated seats (Section 2.2) has indicated that seat structures designed for plastic deformation and headrests are the more promising of the design features included in the study, for improved occupant protection in purely longitudinal (i.e., fore and aft) impacts. In view of this finding and also in view of the predominance of frontal impacts as a source of fatalities and serious injuries (see Section 2.1), seat structures that yield under impact loading should receive first attention in a program of research and development of integrated seats. This feature is, of course, present in the Cox seat (Reference 4). The Cox seat would therefore appear to be a logical starting point for future developments.

The proposed program should include both analyses and experiments aimed at evaluation of the effects of occupant sizes, impact conditions, loading by rear seat occupants, rear impacts, etc. An attempt should be made, on the basis of available tolerance information, to establish the levels of yield forces that will achieve a balance between the hazards of interior contact and those of internal injuries.

4.1.1.2 Investigation of "Submarining" Responses

For the case of purely frontal collisions, the results of the analytical study indicate another potential benefit from integrated seats, in the form of a reduced tendency toward "submarining" (see Reference 3 for a discussion of the "submarining" phenomenon). It should be noted, however, that "submarining" has not yet been demonstrated to occur with living humans. It may constitute only a reflection of deficiencies in the design of anthropometric dummies. Research should therefore be performed to answer the questions that exist regarding "submarining".

This research should include low severity experiments using living subjects who are wearing upper torso restraints, in order that detailed comparisons can be made between the responses of the living subjects and those of dummies with this type of restraint. An analytical study of the type reported in Reference 3, but with a greater scope and with experimental verification of findings, should be performed.

4.1.1.3 Tilting Seats

Among the concepts reviewed in this study, one novel principle that may offer benefits in fore-and-aft collisions is that of tilting the seat (e.g., Protect-O-Matic, pendulum seat, pedestal seat, etc.). Unfortunately, none of the several forms of the tilt seat principle is known to have been subjected either to detailed analytical study or to appropriately instrumented crash tests. They also involve some potential systems problems (e.g., possible interference with other occupants, loss of driver control functions, etc.). However, at least one form of the principle (i.e., Protect-O-Matic), on the basis of documentary films of tests, is considered to merit further investigation.

It is proposed that the tilting seat concept be first evaluated by means of an analytical investigation. The analysis, by means of the CAL simulation of the crash victim (Reference 1), would include such items as tilt angle, tilt rate, location of seat pivot, time increment between triggering and seat action, use or non-use of seat belt, etc. Emphasis would be placed on determination of trends in spinal compression and bending forces and in neck flexure effects within the limitations of the digital simulation. The effects of varying such parameters on passenger acceleration and trajectory would be studied for various simulated vehicle impact velocities with representative deceleration magnitudes and waveforms. The existing CAL simulation would require modification to include seat tilt as well as more detail on the representation of spinal compression and bending forces. The proposed research would provide understanding of the 'protective" effects of various configurations of tilting seats and of the sensitivities of installation dimensions in relation to performance.

Following the analytical study, prototype hardware should be designed and fabricated. The prototypes should be subjected to experimental testing to verify the preceding analytical findings.

4.1.1.4 Lateral Restraint Features

The preceding items of discussion have been concerned with benefits in the form of improved performance of the restraint functions that can be currently provided by available belt systems. However, integrated seats can also provide restraint functions that are not present in existing restraint systems. For example, most actual "frontal" impacts include lateral and angular acceleration components. Therefore, there are likely to be substantial benefits from the lateral support that can be provided by an integrated seat in "frontal" collisions which are not indicated by the planar simulation study. Experimental research should be performed to evaluate concepts and to establish performance criteria for lateral restraint.

4.1.1.5 Inertia Reels

A program of experimentation should be initiated to measure the performance, reliability, and the sensitivity of currently available inertia reels.

4.1.1.6 Belt Tighteners

An investigation should be made of the feasibility of using automatic belt tighteners in automobile restraints, as a means of improving both performance and convenience. Ryan (Reference 19) has demonstrated prototype hardware for this purpose, using his proposed hydraulic bumper as a source of both the signal and the required energy. Military belt tighteners should be reviewed in detail as a part of this research task.

4.1.2 Preliminary Design Studies

Much of the success of the integrated safety seat concept depends on its convenience and practical utility as installed in typical automobiles. It is desirable therefore to initiate several creative preliminary design studies which will generate new ideas and work out dimensional and material characteristics of various types of integrated safety seats.

One such design study would be on the passive (occupant) restraint systems.

The rationale for this study is presented in Reference 33. It is presented here as recommended research as it relates directly to the subject of integrated seats.

An exploratory engineering study to generate fully automatic (or semi automatic) restraint system preliminary designs should be conducted to determine the feasibility of passive (occupant) restraint systems. If practical means for restraining all occupants automatically can be achieved, then a major step in improving overall occupant protection will be achieved. (Approximately 70% of occupants do not use available seat belts.)

It is recommended that a study be conducted (1) to provide mockups of passive restraint seats, (2) to conduct surveys regarding comfort and acceptance and (3) engineering evaluation of protection provided. Seat designs would take into consideration distribution of occupant sizes, vehicle control locations, and applied loads.

Outputs of such studies would be evaluated by FHA to determine promising new concepts for further exploration in the long range program.

4.1.3 ACIR Study of Neck Flexure Effects

An ACIR study of neck injuries should be performed to determine whether differences occur as a function of seat back configuration and occupant height. In Figure 4.1-1, a relationship between δ and injury would be sought with a view toward determining the influence of potentially different "stop" effects in the shape of the upper seat back.

Sample Requirements of Study

1. Cars with good rear seat shelf
2. Rear impact
3. Front and rear occupants present (in same car)?

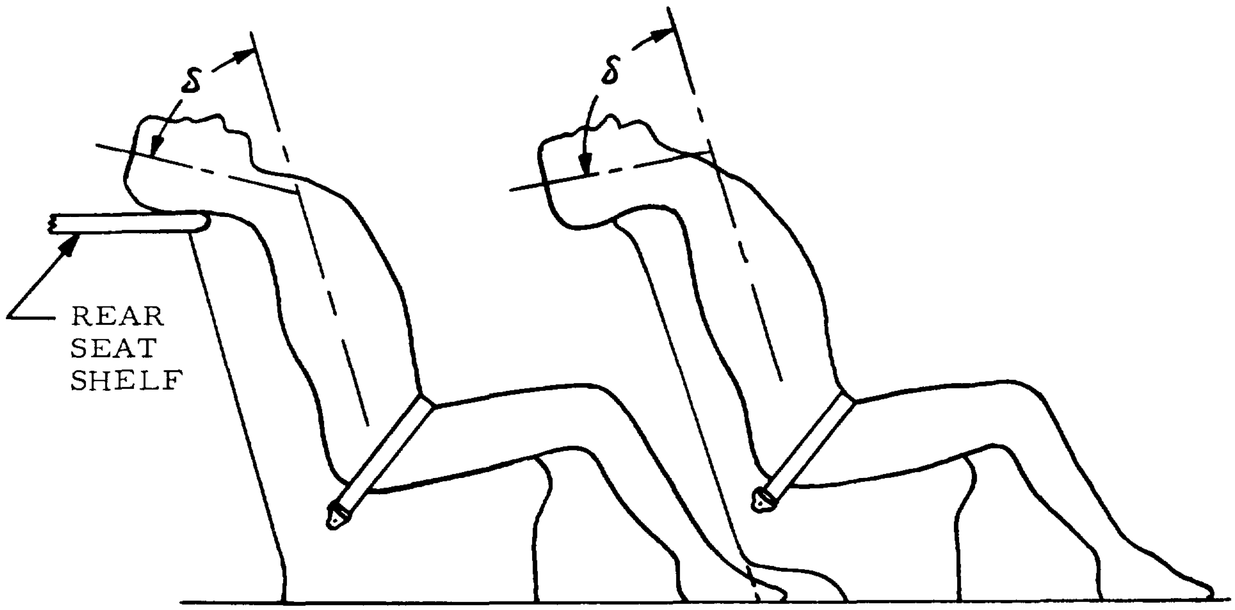


Figure 4.1-1 Head Stopping Action

4.1.4 Preliminary Performance Requirements

A study should be performed to define preliminary performance requirements based on results of the presently proposed short range program and on existing research.

Pertinent questions to be studied would include:

- How would an Integrated Seat be evaluated?
- What are appropriate performance measures?
- Define a compliance test.

4.1.5 Formulation of Methods for Estimating Effectiveness of Passenger Car Restraint Systems

The discussion of Cost/Benefit analysis, Section 2.8, points out that the basic problem in estimating cost/benefit ratios of restraint devices is in determination of the Expected Benefits of new types of devices in a world where even the existing standard device (seat belt) is not fully evaluated. The Dollar Cost of present and future types of restraint devices is relatively simple to estimate with reasonable confidence. The Expected Benefits of new types of devices such as three-point systems, integrated seats, etc. is, at present, fraught with great uncertainty in a quantitative sense.

The follow-on analytical and experimental research program outlined in this report seeks to provide some of the data which will be useful in estimating Effectiveness of various forms of integrated seats and other types of restraint devices. Even when such data is obtained, it will still require formulation of some form of pseudo-arbitrary method (evaluation model) of combining the benefit factors in some quantitative and convincing fashion to yield an Expected Measure of Safety Effectiveness for a particular type of device.

It is recommended that, rather than wait out the experimental program, a study be undertaken now to formulate several different restraint system evaluation models capable of expressing safety effectiveness of various types of restraint systems, both on an individual device level and or a national level. Such models would serve several purposes:

- They would identify the important factors to be considered.

For preliminary discussion of an Effectiveness Measure see, "The Discovery and Control of Ejection in Automobile Accidents", by Robert A. Wolf, Journal of American Medical Association, April 21, 1962.

- They would provide preliminary estimates of effectiveness in a rational framework.

- They would guide experimental research in gathering the type of data needed for evaluation.

There are many possible approaches to formulation of evaluation models and it would seem logical to start with a representation of an existing device (the seat belt*) and then move to an estimate of the effectiveness of a relatively new device (3-point system**) and finally compare this with a variety of yet untried concepts (integrated seats). The U. S. Public Health Service (in its internal planning) has formulated a crude approach to evaluation of the seat belt and this could be used as a starting point.

Use and effectiveness data is available from highway surveys and ACIR accident research as well engineering crash tests and sled tests.

** Use and effectiveness data not generally available but should become so in the near future.

4.2 Long Range Development

To improve techniques for evaluation, obtain information on the accident environment, increase knowledge on human tolerance, and continue to generate new concepts and designs, a long range program of research is recommended. Specific tasks for such a program are outlined in the following paragraphs.

4.2.1 An Acceleration Sled for Combined Angular and Linear Accelerations

Existing acceleration sled facilities do not adequately simulate the collision environment in car-to-car side impacts, single vehicle side impacts, and rollovers. That is, the effects of angular accelerations are not included in existing sled test facilities. Since increased lateral restraint and rollover protection of the occupant are major objectives in many proposed forms of integrated seats, it follows that improved test facilities will be necessary for related programs of development and evaluation.

It is recommended that a program of research and development be initiated with the objective of producing an acceleration device that will provide a more realistic physical simulation of car-to-car impacts, single vehicle side impacts, and rollovers. A test facility is envisioned, in the form of a modified acceleration sled, in which adjustable combinations of time-varying linear and angular accelerations can be programmed, and in which the axis of rotation for the angular motion is an adjustable time-varying parameter. The exact physical configuration of such a facility is not yet defined. It is therefore suggested that a conceptualization and design competition be sponsored by the Department of Transportation to establish performance requirements, possible configurations, and cost estimates for such a facility.

4.2.2 Human Tolerance Research

Human tolerance information for the restrained occupant in the automobile collision environment is, of course, the key item in any research aimed at improvement of occupant protection in automobile collisions. Yet, applicable data are currently very limited. This aspect of the recommended long range research is therefore considered to be an item that should receive priority attention.

4.2.2.1 A Program of Experiments

Using a facility such as that described in 4.2.1, a series of tests should be performed with volunteer subjects at low severity levels and with trauma-indicating dummies and cadavers at higher severity levels. The acceleration environments applied to the occupants should be based on engineering and statistical studies of actual automobile accidents and should cover the spectrum of accident types and severities. In this manner, human tolerance information could be generated that would apply specifically to automobile collisions.

4.2.2.2 Accident Reconstruction

A major difficulty that hampers progress in the development of human tolerance information applicable to the collision environment of an automobile is the inability to use living volunteers in tests that approach injury thresholds. Existing restraints in automobiles permit relatively large changes in the position and orientation of an occupant, and impact forces on the vehicle interior tend to predominate in the production of injuries. (Note that yielding upper torso restraints will continue to permit interior contact at high severities.) The interpretation of results obtained with cadavers, dummies, and animals in terms of the tolerances of living subjects leaves much to be desired.

Human tolerance as related to the integrated seat, with its assumption of more-or-less total restraint must be concerned primarily with (1) forces generated by belts and other restraints on the occupant, (2) internal organ response to acceleration, (3) whole body accelerations, and (4) body component response (e.g., whiplash). The Bureau of Standards has obtained low speed data with human subjects on item (1), the U. S. Air Force has been conducting research on item (2). However, this work has necessarily been in low severity situations and has made use of linear acceleration devices.

It is proposed that, as a supplement to experimental research programs, a major effort should be applied to the development of analytical means of accident reconstruction, with the objective of deriving detailed human tolerance information from actual highway accidents. The technical and economic feasibility of analytically predicting three-dimensional vehicle responses in certain types of single vehicle accidents has recently been established (Reference 30), and the CAL crash victim simulation (Reference 1) has been shown to accurately predict occupant kinematics in longitudinal collisions. With the crash victim simulation extended to treat three-dimensional motions (see Section 4.2.3), it should be feasible to develop iterative techniques with which the external physical evidence (e.g., skid marks, vehicle damage, etc.) and the internal physical evidence (e.g., dents in interior, fracture patterns on glass, etc.) can be used to reconstruct the event. From a reconstructed accident, supplemented by laboratory experiments, it should be possible to accurately relate injuries to specific conditions of deceleration and loading.

The application of the proposed reconstruction techniques only to accidents with 3 point restraint systems, as a means of generating data applicable to integrated seats, is obviously not feasible from the viewpoint of the limited total number of such cases within range of a special investigation team. Rather, the proposed reconstruction techniques should be applied to all available accidents. The general tolerance information thus generated can serve as a basis for "trade-off" decisions related to occupant protection (e.g., yielding upper torso restraints which will permit interior contact in high severity collisions).

4.2.3 Analytical Simulation of the Crash Victim

The high degree of variability of the restraint system environment in automobile collisions (see Section 3.2) makes it necessary to select specific test conditions and procedures in restraint system testing to represent wide distributions of accident situations, occupant sizes, etc. The total number of tests must be limited, in view of the costs associated with full-scale testing, and the interpretation and extrapolation of test results is made difficult, if not impossible, by the overall complexity of the system and by the prevalence of nonlinearities. From a scientific viewpoint, an exclusively experimental approach to the problem of improving the performance of a complex physical system is neither sufficient nor efficient.

It is recommended that a long range program of research be performed to develop analytical means to supplement experiments related to the development and evaluation of integrated seats. One task in this approach should consist of an extension of the existing CAL planar simulation of the crash victim (Reference 1) to the three-dimensional case.

With the proposed analytical simulation, the results of a limited number of experiments could be extrapolated to cover the spectrum of accident types and severities, and a representative sample of occupant sizes and conditions could be exposed. By this means, a proper balance could be struck between protection levels provided by specific concepts and their costs.

4.2.4 Evaluation and Development of New Concepts

New integrated seat concepts that evolve should continue to be evaluated. Some will come from the research discussed above, others will come from manufacturers and inventors. A contract mechanism for conducting a continuing program of engineering studies of new concepts, constructing prototypes and conducting performance evaluations should be provided. Sled and crash test facilities and appropriate personnel are required for evaluations of actual hardware. Engineering evaluations could be conducted using to-be-developed mathematical simulations not only to supplement experimental tests, but also to provide parameter studies aimed at "optimizing" particular concepts.

4.2.5 Passive (Occupant) Restraint

Select the best design(s) evolved under the short term program and extend the feasibility research to practical prototype solutions having structural integrity, functional mechanisms and demonstratable experimental units.

Preliminary designs developed in the short range program should be incorporated into computer simulations for studies to determine final design parameters. Prototype seats (2) should be constructed for accelerator sled and full-scale vehicle experiments. Findings should be translated into performance requirements.

5.0 SUMMARY OF RESEARCH AND DEVELOPMENT TASKS

5.1 Short Range Program

The recommended short range research program, requiring a total performance period of approximately one year, would be comprised of four separate tasks, namely: (1) evaluation of existing concepts, (2) preliminary design studies, (3) an ACIR neck flexure study, and (4) definition of preliminary performance requirements. A greater percentage of the manpower would be oriented toward evaluation of existing integrated seat concepts. Both theoretical and experimental studies are included in the recommended short range research program. This program consists of the tasks summarized in the following paragraphs.

5.1.1 Evaluation of Existing Concepts

5.1.1.1 Yielding Seat and/or Seat Anchorages

Experimental and analytical studies should be conducted to evaluate this concept. The studies should include both front and rear impacts, ranges of impact conditions and occupant sizes, etc. The manpower requirement is estimated at 24 man-months with a cost of $90,000.

5.1.1.2 "Submarining" Response Investigation

Experimental and analytical studies should be conducted to better define the submarining phenomenon and to determine whether or not living humans are susceptible to this type of response. Required manpower is estimated at 18 man-months with a cost of $60,000.

5.1.1.3 Tilting Seats

First, an analytical study is proposed to explore the potential benefits of this concept. The study should include ranges of impact velocities and conditions, variation of seat tilt rates, etc. Second, an experimental study should be conducted to verify the analytical findings Manpower is estimated at 18 man-months with a cost of $70,000.

5.1.1.4 Lateral Restraint Features

Experimental studies should be performed to evaluate side restraint concepts for integrated seats and to establish performance criteria for this type of restraint. Manpower is estimated at 24 man-months with a cost of $90,000.

5.1.1.5 Inertia Reels

An experimental program should be conducted to test the performance and reliability of currently available inertia reels. Manpower is estimated at 6 man-months. with a cost of $25,000.

5.1.1.6 Belt Tighteners

The feasibility of using automatic belt tighteners in automobile restraint systems to improve performance and convenience should be investigated, including a review of military types. Manpower is estimated at 6 man-months with a cost of $25,000.

5.1.2 Preliminary Design Studies

Several preliminary creative design studies should be conducted on integrated seats, including studies of dimensional and material characteristics, in order to explore means of making them more convenient and appealing to the motoring public. Manpower is estimated at 18 man-months with a cost of $50,000.

A special design study should be conducted to generate fully automatic (or semi automatic) restraint system preliminary designs. Manpower is estimated at 18 man-months with a cost of $50,000.

5.1.3 ACIR Neck Flexure Study

An ACIR study of neck injuries should be performed to indicate the effects of seat back geometry and occupant height (size) in rear impacts. Front and rear occupants in the same accident vehicle may show relationship between the amount of neck flexure and injury, since the occupants have different neck "stops". Manpower is estimated at 6 man-months with a cost of $20,000.

5.1.4 Preliminary Performance Requirements

A study should be conducted to define preliminary performance requirements for integrated seats, based on results of the presently proposed short range research program and on existing data. Manpower is estimated at 9 man-months with a cost of $30,000.

5.1.5 Formulation of Methods for Estimating Effectiveness of Passenger Car Restraint Systems

Several evaluation models should be formulated, capable of expressing safety effectiveness of various types of restraint systems. It is estimated that 24 man-months of effort would be required at a cost of $75,000.

5.2 Long Range Program

The recommended long range research program of automobile safety seats, to be conducted over a period of five years, is divided into four main tasks, namely: (1) development of a modified acceleration sled, (2) human tolerance research, (3) analytical simulation of the crash victim, and (4) evaluation and development of new concepts. The purpose of this program is to increase human tolerance knowledge, to more fully define the accident environment, and to continue to generate new safety seat concepts and designs. The proposed tasks are summarized in the following paragraphs.

5.2.1 A Modified Acceleration Sled

Development and application of an acceleration sled facility is proposed in which both angular and linear accelerations can be imposed on an occupant and test seat. The objective is to simulate more closely actual crash conditions, especially those produced in automobile side collisions. This task would entail design, fabrication, and application of an acceleration facility. Manpower is estimated to be 42 man-months with a cost of $250,000.

5.2.2 Human Tolerance Research

5.2.2.1 A Program of Experiments

Experimental tests should be conducted with volunteers, dummies and cadavers in a facility such as described in Section 5.2.1. The acceleration environment would simulate actual automobile collisions and thus would produce human tolerance data that apply directly to automobile impacts. Manpower is estimated to be approximately 48 man-months with a cost of $200,000.

Where possible, test conditions and environmental data for these proposed tests should be correlated with similar research conducted at other facilities such as Holloman Air Force Base and the National Bureau of Standards.

5.2.2.2 Accident Reconstruction

It is proposed that an analytical method be developed with which actual automobile accidents can be reconstructed on the basis of physical "on-the-scene" evidence. With the known accident environment and human injury data from the accident, it would be possible to accurately relate injury to specific conditions of deceleration and loading. The reconstruction technique should be applied to all available accidents (i.e., both restrained and unrestrained occupants). Manpower is estimated to be approximately 60 man-months with a cost of $200,000.

5.2.3 Analytical Simulation of the Crash Victim

An analytical simulation of an automobile crash victim should be developed for the case of 3-dimensional motions, similar to the existing CAL planar model (Reference 1). The simulation should be applied to supplement experimental tests in the development and evaluation of integrated seats. Manpower for this task is estimated to be 54 man-months with a cost of $180,000.

5.2.4 Evaluation and Development of New Concepts

A program of continuing research and evaluation of integrated seat concepts, as they evolve from the proposed programs and from industry, is proposed. Evaluation of hardware should be conducted on sled and crash test facilities. Engineering evaluations and parameter studies should also be made by means of the analytical simulation described in Section 5.2.3, above. Manpower is estimated to be 72 man-months with a cost of $250,000.

5.2.5 Passive (Occupant) Restraint

Construct prototype passive restraint seats (2) for accelerator sled and full-scale vehicle requirements and determine performance requirements. Manpower required is estimated to be 72 man-months with a cost of $250,000.

5.3 Schedule of Proposed Research

Please see chart on the following page.

5.4 Task Priorities

5.4.1 Short Term Program

The order of the tasks proposed for the short range research program reflects a priority ranking that is based on anticipated early payoffs in the reduction of injuries and fatalities. The proposed tasks are listed in Table 5.4-1. The selected order of the four main tasks places the evaluation of existing concepts first. This priority ranking is based on the fact that several promising concepts exist which have not yet been subjected to a comprehensive program of evaluation and testing. Existing concepts would of course, produce the earliest payoff in reduced occupant injury, if they proved to be successful in tests.

The preliminary design studies of integrated seats, would be expected to produce a somewhat longer range payoff in view of the fact that an unpredictable creative process is involved.

Within the task of evaluating existing seat concepts, the sub-programs are also ordered according to a judgement of desirable priority. Here, the yielding seat evaluation program is ranked first in view of the potential benefits in fore-aft collisions indicated by the analysis reported in Section 2.2.

SCHEDULE OF PROPOSED RESEARCH

5.1 SHORT RANGE PROGRAM	1ST. YEAR	2ND.	3RD.	4TH.	5TH.	MAN MONTHS	TOTAL COST
5.1.1 EVALUATION OF EXISTING CONCEPTS							
.1 YIELDING SEAT						24	$90,000
ANALYSIS							
EXPERIMENTAL							
.2 SUBMARINING						18	60,000
ANALYSIS							
EXPERIMENTAL							
.3 TILTING SEATS						18	70,000
ANALYSIS							
EXPERIMENTAL							
.4 LATERAL RESTRAINT						24	90,000
.5 INERTIA REELS						6	25,000
.6 BELT TIGHTENERS						6	25,000
LITERATURE SEARCH							
EXPERIMENTAL							
5.1.2 PRELIMINARY DESIGN STUDIES						18	50,000
PASSIVE (OCCUPANT) RESTRAINT						18	50,000
5.1.3 ACIR NECK FLEXURE						6	20,000
5.1.4 PREL. PERFORMANCE REQUIREMENTS						9	30,000
5.1.5 EFFECTIVENESS METHOD						24	75,000
TOTALS - SHORT RANGE PROGRAM						171	$585,000
5.2 LONG RANGE PROGRAM							
5.2.1 MODIFIED ACCEL. SLED.						42	$250,000
.1 DESIGN							
.2 FABRICATION							
.3 APPLICATION							
5.2.2 HUMAN TOLERANCE RESEARCH							
.1 EXPERIMENTAL TESTS						48	200,000
.2 ACCIDENT RECONSTRUCTION						60	200,000
5.2.3 ANALYTICAL SIM. OF CRASH VICTIM						54	180,000
5.2.4 EVALUATION & DEVELOPMENT OF NEW CONCEPTS						72	250,000
5.2.5 PASSIVE (OCCUPANT) RESTRAINT						72	250,000
TOTALS - LONG RANGE PROGRAM						348	1,330,000

Table 5.4-1 Short Term Program Priorities

Specific Tasks, in Order of Priorities	Program Magnitude 1 = Largest
1. Evaluation of Existing Concepts	1
(1) Yielding Seat	(1)
(2) Submarining Response	(3)
(3) Tilting Seat	(2)
(4) Lateral Restraint	(1)
(5) Inertia Reels	(4)
(6) Belt Tighteners	(4)
(7) Effectiveness Models	(2)
2. Preliminary Design Studies	2
3. ACIR Neck Flexure Study	3
4. Preliminary Performance Requirements	3

The column at the right side of the table indicates the estimated relative magnitudes of the proposed programs.

5.4.2 Long Term Program

The proposed long range research tasks are ordered in Table 5.4-2 according to a judgement of desirable priority ranking. The modified acceleration sled research is ranked first in view of the need for such a device in each of the other tasks.

Human tolerance research is ranked second (i.e., after the development of needed equipment) because it is the key item in research aimed at improving occupant protection. It is also ranked first in program magnitude.

Long range payoff would be expected to occur somewhat later in the proposed analytical simulation research. The estimated magnitude of each of these tasks is approximately equal.

The task of evaluating and developing new integrated seat concepts was ranked last in long-range priority, however, the proposed task must parallel analytical and experimental developments, since a continual evaluation of new concepts is required to insure progress.

Table 5.4-2 Long Term Program Priorities

Specific Tasks, in Order of Priorities		Program Magnitude 1 = Largest
1.	Modified Acceleration Sled	2
2.	Human Tolerance Research	1
3.	Analytical Simulation (3-D)	2
4.	Evaluation & Development of New Concepts	3

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