REPORT NO. FRA/ORD-77/73, I

# RAIL SAFETY/EQUIPMENT CRASHWORTHINESS

## Volume I: A Systems Analysis of Injury Minimization in Rail Systems

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JULY 1978
INTERIM REPORT

Prepared by

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington DC 20590

**Technical Report Documentation Page**

1. Report No.
FRA/ORD-77/73, I

2. Government Accession No.
PB289147

3. Recipient's Catalog No.

4. Title and Subtitle
RAIL SAFETY/EQUIPMENT CRASHWORTHINESS

Volume I: A Systems Analysis of Injury Minimization in Rail Systems

5. Report Date
July 1978

6. Performing Organization Code

7. Author(s)
M. J. Reilly, R. H. Jines, A. E. Tanner

8. Performing Organization Report No.
D339-10047-1
DOT-TSC-FRA-77-15, I

9. Performing Organization Name and Address
Boeing Vertol Company*
Philadelphia PA 19142
P.O. Box 16858

10. Work Unit No. (TRAIS)
RR728/R8327

11. Contract or Grant No.
DOT-TSC-821-1

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Railroad Administration
Office of Research and Development
Washington DC 20590

13. Type of Report and Period Covered
Interim Report
6/74 - 9/76

14. Sponsoring Agency Code
DTS-744

15. Supplementary Notes
*Under contract to:
U.S Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge MA 02142

16. Abstract

The Department of Transportation, Transportation Systems Center (TSC), is providing technical assistance to the Federal Railroad Administration (FRA) in a program to improve railroad safety and efficiency by providing a technological basis for improvement and possible regulation in rail vehicle crashworthiness, inspection and surveillance of equipment, and other areas. As part of this program, TSC is conducting technical analyses of passenger railcar collisions, derailments, and other accidents, directed towards minimizing occupant injuries.

This document, the first of four volumes, reports on the collection of data for a representative accident sample, the analysis of the data to identify injury types, locations, and, when possible, injury causal factors. Vehicle interior design details are also considered in conjunction with the accident data to compile a list of potential improvements in occupant protection.

Volume II is a design guide to assist engineers in understanding the problems associated with the development of crashworthy interiors of locomotives, cabooses, and passenger railcars. Volume III proposes engineering standards in the format of the <u>Code of Federal Regulations</u> (Title 49, Transportation, Parts 200). Volume IV is an executive summary.

17. Key Words

Railway Accidents
Injury Data
Collision
Human Tolerance
Injury Minimization
Crashworthiness
Crash Simulation
Delethalization
Locomotive
Caboose
Passenger Railcar

18. Distribution Statement
DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages

22. Price
PC A12 / MF A01

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

# PREFACE

The author would like to acknowledge the assistance received from the Federal Railroad Administration (FRA), National Transportation Safety Board and the railroad industry, including Electromotive Division of General Motors and the Penn Central Transportation Company. In addition, the author would like to acknowledge the advice on presentation techniques provided by J. H. Wiggins Company of Redondo Beach, California.

# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

### LENGTH

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| in | inches | 2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |

### AREA

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
|  | acres | 0.4 | hectares | ha |

### MASS (weight)

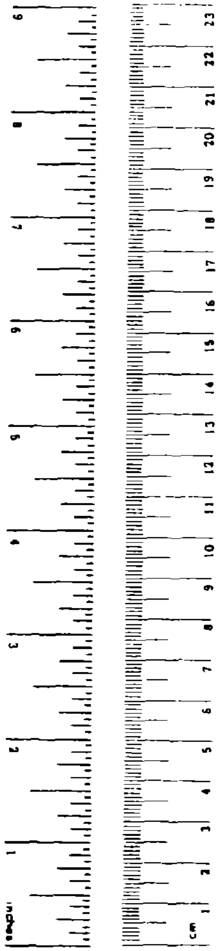
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
|  | short tons (2000 lb) | 0.9 | tonnes | t |

### VOLUME

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |

### TEMPERATURE (exact)

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |



## Approximate Conversions from Metric Measures

### LENGTH

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |

### AREA

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres |  |

### MASS (weight)

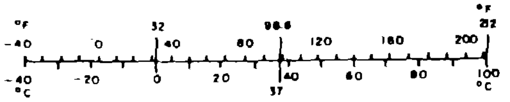
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons |  |

### VOLUME

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |

### TEMPERATURE (exact)

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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# 1. INTRODUCTION

Much effort has been expended in developing and testing safety features for highway vehicles for the protection of occupants during a collision. Federal regulations have been issued for the incorporation of these safety features in the design of current highway vehicles. Little consideration has been given in the past for the protection of rail vehicle occupants during a collision. The Transportation Systems Center (TSC) is presently engaged in providing technical assistance to the Federal Railroad Administration (FRA) in a program directed at improving railroad safety and efficiency by providing a technological basis for improvement and possible regulation in rail vehicle crashworthiness, inspection of equipment, surveillance of equipment, and other areas. As part of this program, TSC is conducting technical analyses of passenger railcar collisions, derailments, and other accidents, directed towards minimizing occupant injuries.

In support of the TSC efforts in the improved crashworthiness of rail vehicles, the Boeing Vertol Company has been contracted to investigate "Rail Safety - Equipment Crashworthiness," under Contract DOT-TSC-821.

This contract, which concerns itself with the interior environment of rail vehicles during a crash, has been divided into three distinct phases:

Phase 1. Railcar Safety Environment: A Systematic Analysis of Injury Minimization in Rail Systems

Phase 2. Railcar Occupant Protection and Injury Minimization Design Guide

Phase 3. Proposed Engineering Standards, Evaluation and Conformance Test Methods

Phase 1 consists of the collection of data for a representative accident sample, the analysis of the data to identify injury types, locations, and when possible, injury causal factors. Vehicle interior design details are also considered in conjunction with the accident data to compile a listing of potential improvements to develop occupant protection guidelines.

The accident sample consists of accidents which occurred within the time frame 1967-1973, and warranted detailed investigation and the issuance of a formal report either by the National Transportation Safety Board (NTSB) or the Federal

Railroad Administration (FRA). This sample was selected because all reports were readily available and precluded excessive data searching into archive files.

Potential interior design improvements are presented in this report based on accident data, current state-of-the-art design concepts used in other vehicles such as automobiles and aircraft, and the results of mathematical simulations of the dynamic response of occupants which impact vehicle interiors for typical accident scenarios.

This report covers Phase 1 of Contract DOT-TSC-821, and addresses the problem of secondary impact effects on the occupants of locomotives, cabooses, and passenger railcars.

The Phase II effort involved the utilization of the above data in the preparation of a crashworthiness design guide which is covered in Report No. DOT-TSC-821-2.

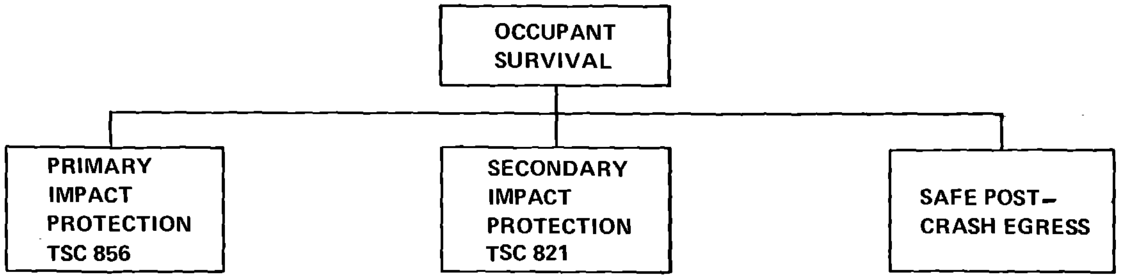
In the phase III effort a set of proposed engineering standards has been prepared which establishes design requirements based on the findings of the first two phases. The proposed standards are documented in Report No. DOT-TSC-821-3.

Primary impact effects, due to primary structural failure and the associated unacceptable reduction in occupied volume, are addressed in another TSC contract currently being performed by the Boeing Vertol Company, DOT-TSC-856.

Secondary impact effects, which is the impact of the rail vehicle occupants with their interior environment, is the subject of this investigation. It is however only a portion of the overall problem when the crashworthiness of rail vehicles is considered.

Figure 1-1 shows the "Basic Requirements for Occupant Survival in a Crash Environment" as a function of three basic problems: primary impact protection, secondary impact protection, and safe post-crash egress. Contracts TSC-856 and TSC-821 deal with primary and secondary impact protection, respectively; and it is emphasized at this time that safe post-crash egress is an important element of the crashworthiness problem not addressed in either of these contract studies.

In the final assessment of potential design improvements, each of the three categories cannot be considered exclusively; each one interacts with the other in some fashion and an optimum crashworthiness assessment must consider all parameters.



**PRIMARY IMPACT PROTECTION TSC 856**

- STRUCTURAL INTEGRITY OF OCCUPIED AREA OF VEHICLE TO PRECLUDE OCCUPANT INJURY DUE TO COLLAPSED STRUCTURE
- LOCATION OF OCCUPANTS IN AREAS OF VEHICLE WHERE THE REDUCTION IN OCCUPIED VOLUME IS COMPATIBLE WITH OCCUPANT SURVIVAL AND INJURY MINIMIZATION
- STRUCTURAL DESIGN TO PRECLUDE OVERRIDING OF IMPACTING VEHICLES AND INGRESS OF ONE VEHICLE INTO THE OCCUPIED AREA OF ANOTHER
- STRUCTURAL ATTACHMENTS OF SEATS, ETC., COMPATIBLE WITH g LOADS ASSOCIATED WITH CRASH ENVIRONMENTS

**SECONDARY IMPACT PROTECTION TSC 821**

- OCCUPANT LOCATION, INTERIOR LAYOUT OF SEATS, DIVIDERS, BULKHEADS, STANCHIONS, ETC., TO BE OPTIMIZED TO MINIMIZE TRAJECTORY DISTANCES AND PROBABILITIES OF POTENTIALLY DANGEROUS IMPACTS
- SEAT DESIGN AND INSTALLATION
- RESTRAINT OF OCCUPANTS, CARGO, BAGGAGE AND INTERIOR EQUIPMENT AND FITTINGS
- INTERIOR MATERIALS AND DESIGN OPTIMIZATION TO REDUCE IMPACT g LOADS TO ACCEPTABLE LEVELS FOR OCCUPANTS PROJECTED WITHIN THE VEHICLE DURING A CRASH
- DESIGN AND LOCATION OF WINDOWS TO MINIMIZE INVOLUNTARY OCCUPANT EGRESS

**SAFE POST-CRASH EGRESS**

- STRUCTURAL INTEGRITY TO PRECLUDE JAMMING OF EMERGENCY EXITS
- EMERGENCY EXIT LOCATIONS AND EQUIPMENT ACCESS TO ENSURE OCCUPANT EVACUATION IN A GIVEN TIME WITH THE VEHICLE IN ANY POST-CRASH POSITION:
  - UPRIGHT
  - ON SIDE
  - UPSIDE DOWN
- INTERIOR DESIGN TO ENSURE OCCUPANTS CAN REACH EMERGENCY EXITS
- INTERIOR DESIGN TO ENSURE TIMELY EVACUATION OF INJURED
- FIRE-RESISTANT DESIGN TO PRECLUDE OR LIMIT TO A TOLERABLE LEVEL:
  - POST-CRASH FIRE
  - SMOKE GENERATION
  - TOXIC FUMES GENERATION
  - FIRE, SMOKE AND FUMES, GENERATED BY CARGO AND OCCUPANT'S BAGGAGE
- EMERGENCY LIGHTING

*Figure 1—1. Basic Requirements for Occupant Survival in a Crash Environment*

## 1.1 SCOPE OF THE INVESTIGATION

This investigation is aimed at determining the causes of injury to rail vehicle occupants in a collision or derailment and studying ways of eliminating or reducing the severity of these injuries. The investigation is limited to occupants of locomotives, cabooses and passenger cars used in inter-city operations. Not covered are urban transit or commuter rail vehicles, switcher locomotives or rail vehicles not normally occupied.

To aid in the determination of causes of rail vehicle occupant injuries, data surveys of accidents were made. The data was analyzed using the fault tree methodology in an attempt to isolate the major injury causing factors. Typical rail vehicle configurations were investigated in the areas of the occupant's normal seated and standing environment for injury producing potential during an accident. Crash impulses are simulated mathematically for various types of rail vehicles and at different collision velocities. A computer program is used to simulate on occupants impact within a railcar. Graphs were developed for a simplified determination of impact forces of occupants impacting various interior furnishings.

To prevent and minimize injuries, the crashworthiness state-of-the-art for aircraft and highway vehicles was investigated for application to rail vehicle use. New protective devices are proposed and delethalization procedures discussed. Costs for incorporation of improved crashworthy features in rail vehicles on a new build and retrofit basis are presented.

## 1.2 OBJECTIVES

The purpose of this investigation is to determine the causes of occupant injury and fatalities in rail vehicle accidents as a result of secondary collision (the occupant striking objects within the rail vehicle) and to propose improvements within the rail vehicles to minimize the injury potential. The results of this investigation are to be presented in the form of a crashworthiness design guide to aid designers in improving the crashworthiness of rail vehicle interior designs. In addition a set of proposed design standards is to be prepared which will establish regulations to which the rail vehicle interiors are to be designed. Each of these documents are under separate cover report nos. DOT-TSC-821-2 and DOT-TSC-821-3 respectively.

## 1.3 SUMMARY OF KEY FINDINGS

### 1.3.1 Accident Data

The primary source of data, the FRA T-forms, in general presented the type of accident which occurred, the nature of the injury to the occupant and the type of rail vehicle in which the occupant was riding. The data that was lacking in most of the cases was the injury mechanism or the object that the occupant struck. Of all the fatal injuries reported, the injury mechanism was not specified for any of these cases. The great majority of the fatalities were attributed to rail vehicle crushing, after reviewing the few NTSB reports and photographs of the accidents. The more minor injuries and those not attributed to collision recieved more detailed writeup presumably to justify payment or time off for the injury.

### 1.3.2 Crash Impulse Simulation

Mathematical simulation of occupants striking typical interior surfaces and furnishings within the rail vehicle did not show forces or accelerations generally high enough to produce fatal injury. Although fatal injury can be incurred from a simple fall, the idealized cases analyzed did not show a general trend toward exceeding human tolerance limits.

### 1.3.3 Injury Mechanisms

Of the 1400 injury cases investigated only 288 presented data on the mechanism producing the injury. Only 10 percent of the passenger car injury cases reported the injury mechanism none of which were due to collisions. The mechanism was reported in 18 percent of locomotive accident injuries and 64 percent of caboose injuries. Of the mechanisms reported in the various type rail vehicles, no single one stood out as a chief producer of injury. The 288 injury cases which had the mechanism reported were distributed over 56 items of rail vehicle equipment and structure.

### 1.3.4 Rail Accidents Contributing to Injury

The initiating accident circumstances contributing to occupant injury is thought to be principally due to collision of two trains. However, there are more incidents of hard coupling and slack action, in which injury occurs, than any other factor. Derailment is the third most frequent occurrence. Rear-end collisions occur at a rate three times as frequently as head-on collisions. Injury due to braking has a high frequency of occurrence while train motion accidents and grade crossing collisions occur at an average frequency.

Derailment accidents produce the greatest number of injuries but rarely cause fatalities. Rear-end collisions produce the next greatest number of injuries and when structural crushing occurs there are a high number of fatalities.

## 2. TYPICAL RAIL VEHICLES INVESTIGATED

Interior arrangements, equipments, furnishings and structures of typical rail vehicles were investigated for their potential to cause injury due to acceleration of occupants within them. A locomotive and several types of passenger cars and cabooses were included in the investigation.

### 2.1 LOCOMOTIVE

The EMD GP-40 locomotive was selected as the typical general purpose locomotive in large quantity usage on railroads throughout the United States. The above-deck structure consists of a short and a long hood with a control compartment or cab and an electrical cabinet between the two hoods. The hoods and electrical cabinet are mounted directly to the top of the underframe while the cab is raised 27 inches off the top of the underframe on a sub-base. The hoods and electrical cabinet are 6 feet wide while the subbase and cab are ten feet wide.

The locomotive cab, as a working environment, provides work space for the engineman and one or two helpers. Swiveling seats are provided so that the locomotive may be operated in either the forward or rearward directions using the same controls. The crew seats have both padded seat and back cushions and are adjustable vartically and longitudinally. The seat details such as shape of the cushion and arm rest are quite varied depending upon the particular railroad.

Generally, the cab is arranged with the engineman on the right side and the short hood forward. From the right-hand position the engineman has optimum visibility straight ahead through a vertical windshield approximately 36 inches directly in front of him. Left or straight ahead he has visibility through two horizontal windshields over the short hood and to his far left a windshield in the left forward cab door. Behind the engineman is another vertical window in the right rear cab door which affords visibility to the rear along the long hood and train. All of these windows are located with the top edge approximately 60 inches above the cab floor and are glazed with 9/16-inch thick safety plateglass. Alongside the engineman and symmetrically on the opposite side of the cab are two side windows with horizontal sliding sash that can be opened with a protruding latch. The sliding sash are normally glazed with 1/4-inch laminated sheet glass.

The engineman's control stand is located to his left and is slightly canted in front of him to be convenient and comfortable for his normal position facing forward, but also accessible when he is facing rearward or leaning out the side window facing in either direction.

The control stand is a sheetmetal box-like structure which is welded to the top deck frame. The stand contains air gauges, electrical meters, electrical control devices, and lever-operated pneumatic controls for the locomotive and train air brake systems. The heater is also in front of the engineman (Figure 2-1).

The helper's position (Figure 2-2), has a clear space ahead, but has a glazed door 21 inches in front of the seat.

A number of appurtenances are installed inside the cab and vary with each railroad. These devices are usually mounted on the walls and include form holders, flag and fusee holders, first aid kits, fire extinguishers, etc. One major variable in the cab is the water cooler which is floor-mounted in about the center of the cab. These units vary from small refrigerators or inverted bottle units to large combinations of refrigerators and bottle coolers.

The electrical cabinet is located in the rear wall of the cab. This structure is a lightweight angle and channel frame covered with either bolted-on or hinged covers and doors. Many of the small items of equipment are attached to the rear wall (Figure 2-3).

The area of the locomotive of particular interest for collision safety is the crew-occupied cab. This assumes that the structural integrity of the cab is maintained during the collision.

The engineer is particularly vulnerable to injury in a collision due to the equipment directly in front of him into which he could be thrown (Figure 2-1). As shown in this figure, the principal object which presents a hazard to the engineer is the control console with its sharp edges, glass instrument faces and protruding handles. The heater, although less of a threat, is also in front of the engineer. Sharp edges on the window handle to the right of the engineer are a potential source of injury.

The engineer's seat (Figure 2-4) is not securely anchored and would be subject to disengagement from the adjusting holes during a collision. In rearward accelerations the seat back would not restrain the head and the engineer would be subject to whiplash.

The fireman's position (Figure 2-2), presents a cleaner

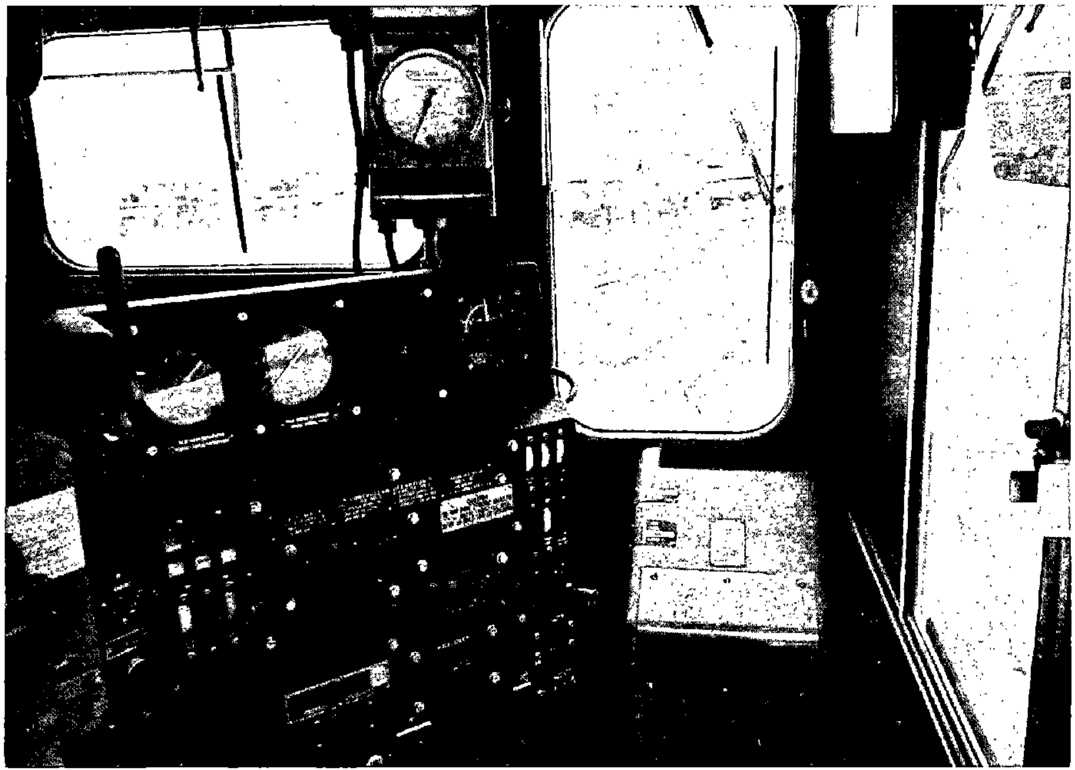


Figure 2–1. Engineman's Position in a General Purpose Locomotive

Figure 2–2. Helper's Position in a General Purpose Locomotive

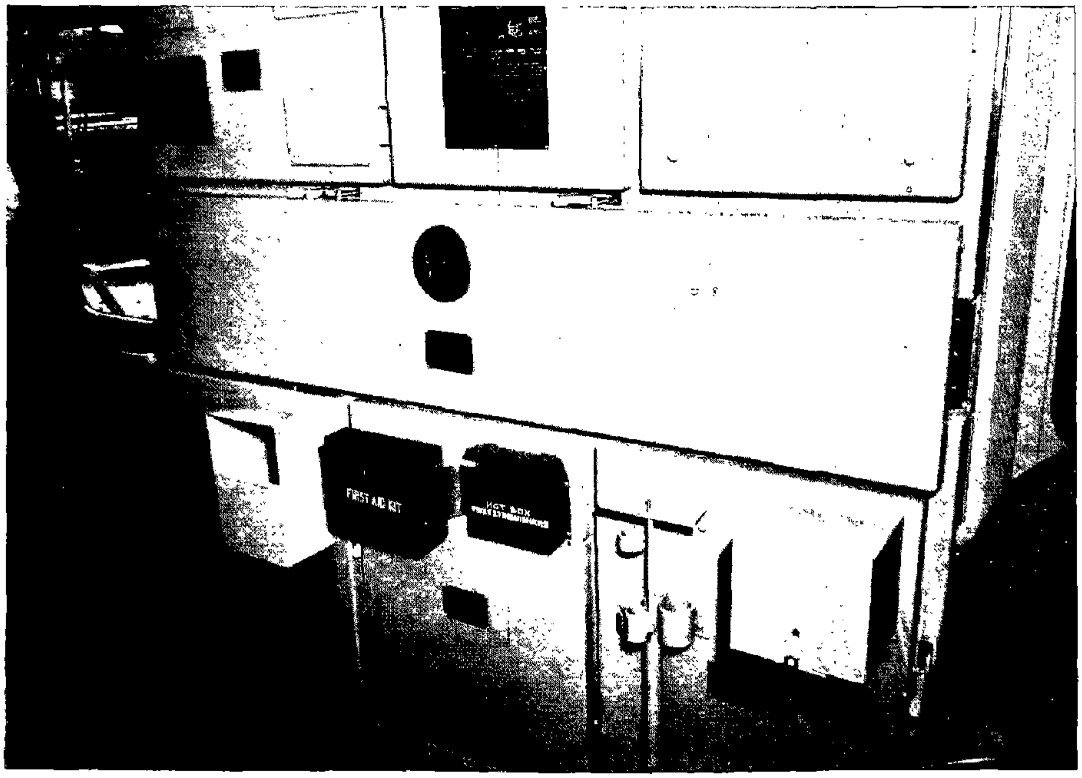


*Figure 2–3. Equipment Attached to Rear Wall of Cab*

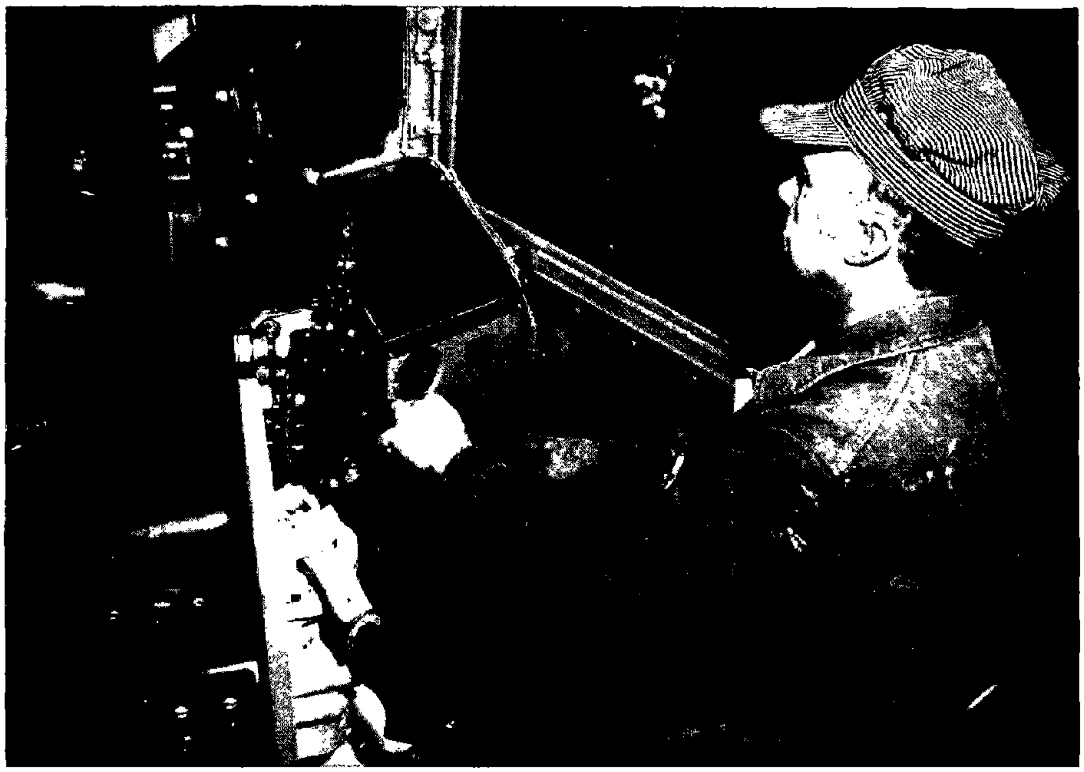


*Figure 2–4. Engineer's Seat in a General Purpose Locomotive*

surface into which he could be thrown in a collision. The main hazard for the fireman is the potential for him to be projected through the glass in the door. Whiplash is also a potential hazard for the fireman in rear-end collisions and hard coupling due to his low seat back. Sharp edges at the back end of the armrest and on the seat back would be a hazard to the occupant of the rear seat.

## 2.2 PASSENGER RAIL CARS

Three basic type passenger rail cars were reviewed as representing typical passenger environments: coach, parlor car, and snack bar coach. Each car was analyzed for seating arrangement, inherent containment provisions, and surfaces or equipment with potential to cause injury if impacted.

### 2.2.1 Coach

Coach-type passenger railcars are the type which are in the most general use on passenger runs in the United States. The interiors of this type car was investigated for areas which are subject to impact by occupants who may be thrown about during an accident.

In general, coach-type passenger railcars have similar interior arrangements. Double seats are located on each side of the aisle throughout most of the car and rest rooms for men and women are located in the remaining area at each end of the car (Figure 2-5). Luggage racks are provided on each side of the car above the seats along the full length of the passenger area (Figure 2-6).

Three basic types of seat installations are provided: double seats which can be reversed in direction by pushing on the seat back (Figure 2-6); double seats which can be reversed in direction by pulling inward and rotating the seat 180 degrees about its swivel base (Figure 2-7); and single seats which are free to swivel 360 degrees on a pedestal (Figure 2-8). A fixed back seat would provide more restraint for a passenger thrown into the back of the seat than seat backs which are free to move. Seat backs vary in height from shoulder-height to head-height. Those seats which have head-height backs provide head support minimizing whiplash due to rear-end collisions.

Bulkheads at the end of the passenger area are constructed with light-gauge sheet metal covering a structural frame. In one case, illustrated in Figure 2-7, a glass mirror is mounted on the bulkhead and could increase the probability of injury if impacted by a passenger.

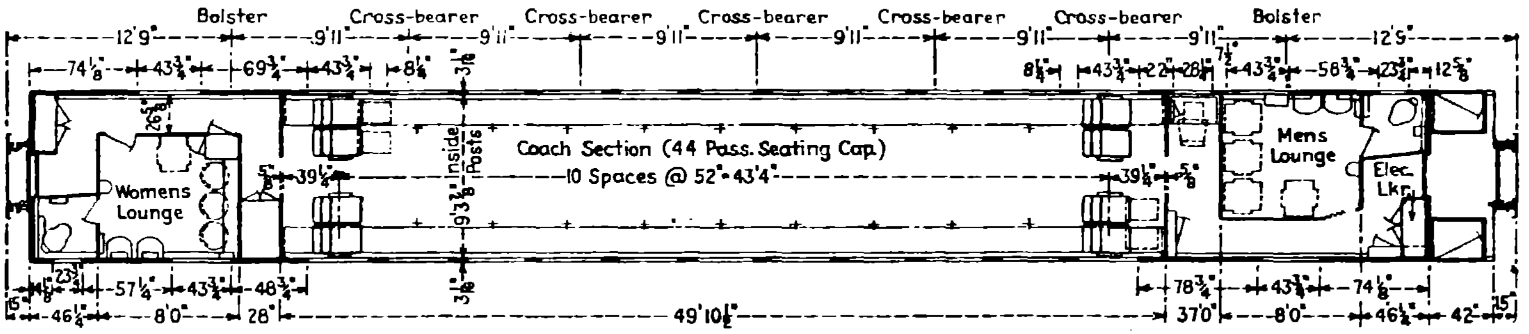


Figure 2—5. Floor Plan of Typical Passenger Railcar Coach

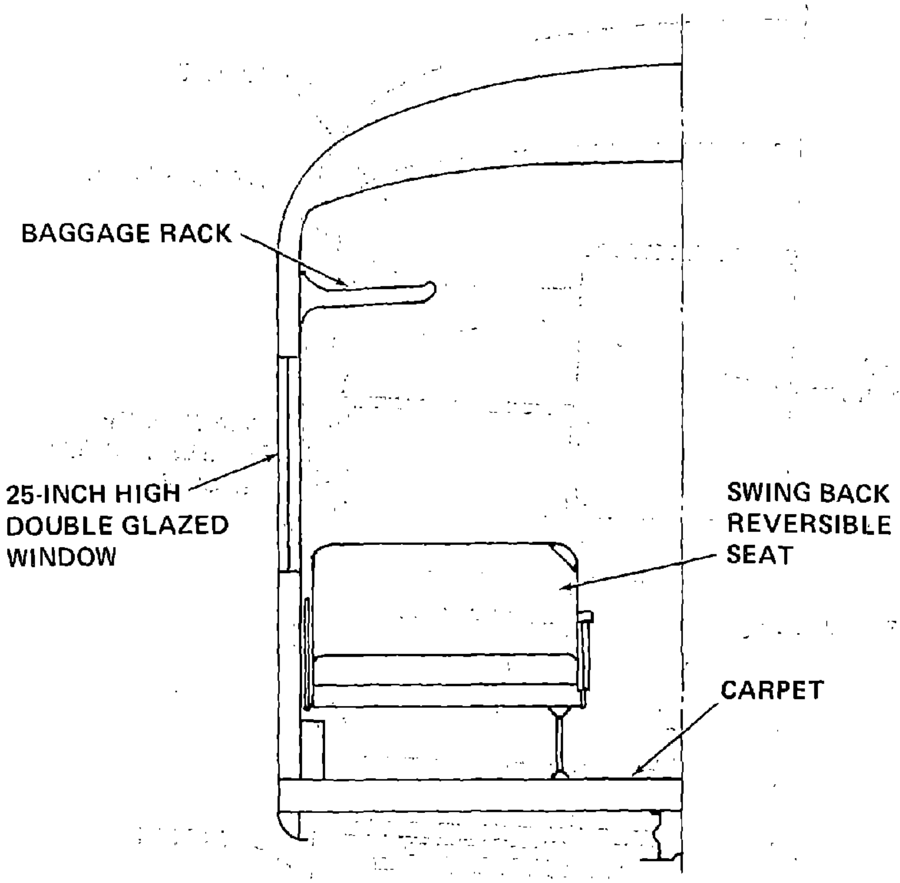


*Figure 2–6. Budd Passenger Car Cross Section*

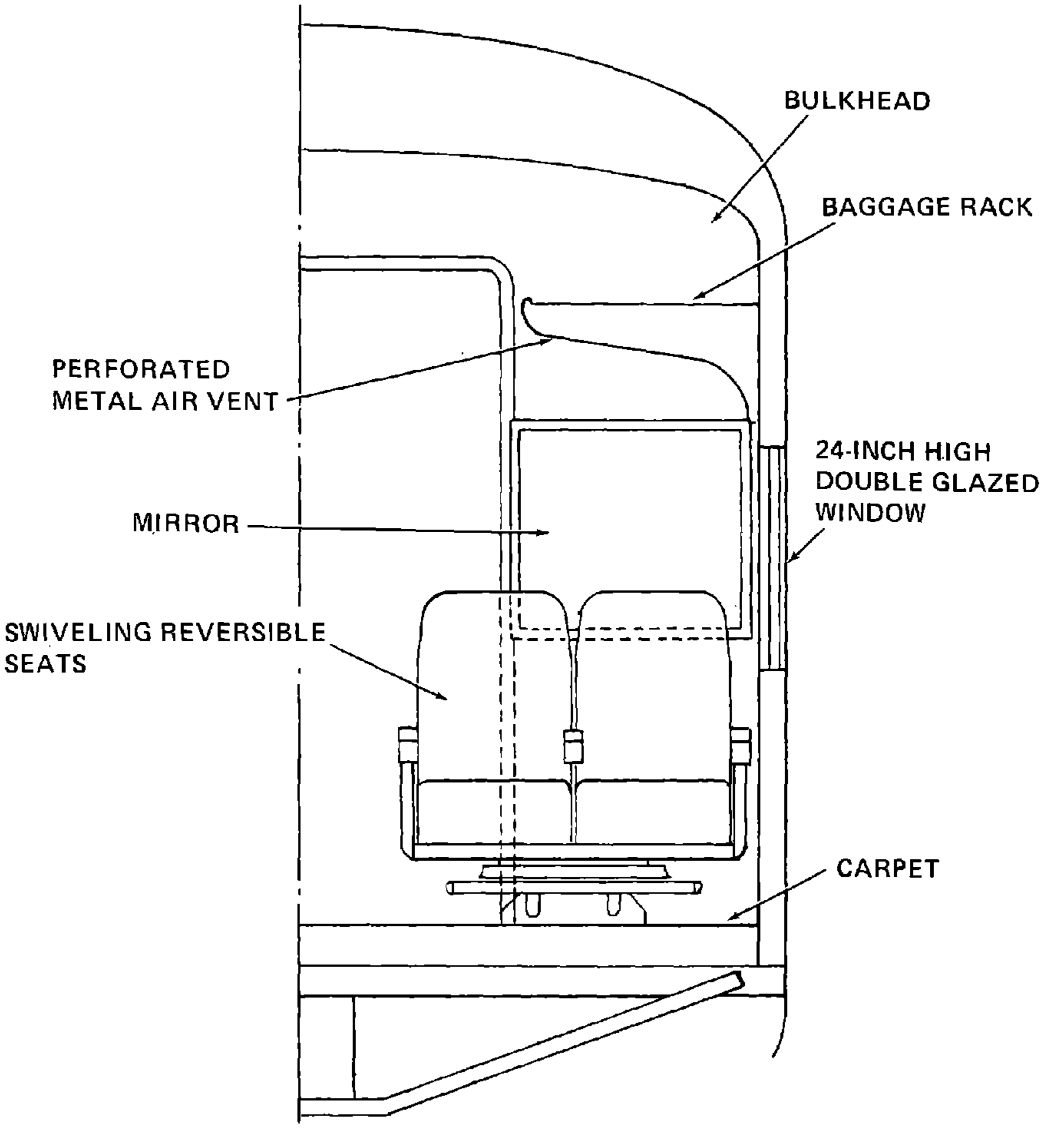
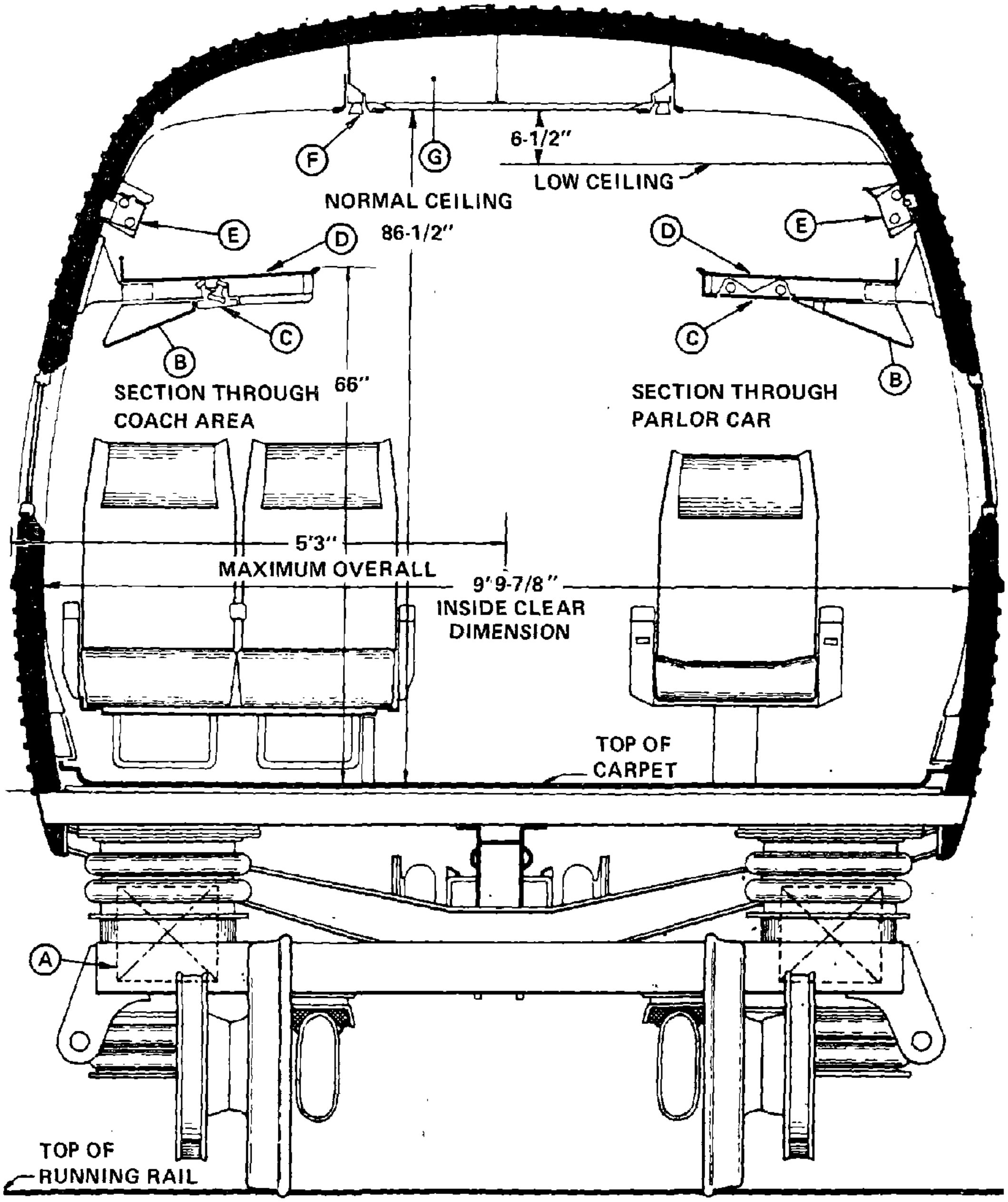


*Figure 2–7. Penn Central Passenger Car Cross Section*



KEY:

| | |
|---|---|
| A – SUPPLEMENTARY SPRINGS | E – CONTINUOUS LIGHTING FIXTURE |
| B – EXHAUST AIR DUCT | F – AIR DISTRIBUTOR |
| C – READING LIGHTS | G – MAIN AIR DUCT |
| D – PARCEL RACK | |

*Figure 2–8. Metroliner Passenger Car*

Luggage racks are constructed so that the upper surface will withstand a 250-pound load concentrated midway between supports without the deflection exceeding 0.25 inch. The lower surface of the luggage rack is generally covered with more readily yielding materials. A perforated material is shown in Figure 2-7, and a light gauge sheet metal exhaust air duct is shown in Figure 2-8. No provisions are made to restrain the luggage under lateral accelerations.

Side windows are generally 24 inches high; however, on the Metroliner the windows are only 14 inches high (Figure 2-8). Passengers are less likely to be thrown through the smaller windows. AMTRAK specifies a safety glass bonded with "Plexigum" or plasticized polyvinyle butynal resin membrane at least 0.045-inch thick.

In the coach car, passengers can be contained during rearward or forward accelerations by their seat back and the seat back or bulkhead ahead of them. Injuries due to impact with these surfaces could occur if these surfaces lacked sufficient energy absorbing characteristics or if there were nonyielding projections or areas causing entrapment and bending of limbs. Typical areas of impact into an upright seat back under forward acceleration are the head, face, legs, and arms. Sliding of the leg under the seat can produce concentrated bending loads applied to the tibia as the legs become jammed under the seat due to a forward acceleration. With the coach seat in the reclined position, additional injuries may be imparted to the chin, neck, and possibly the thorax, particularly if a rigid hand grab is included on the seat back.

Injuries may be produced in the upper torso, knee-thigh-complex, the back, or the head from being pitched into an unyielding bulkhead several feet from the seated passenger. Additional localized head and facial injuries could be imposed by the presence of a nonyielding magazine or display rack. Rotation of seats to a face-to-face position produces a potential for injury when the rear passengers are hurled into the forward passengers.

A seated passenger may suffer hyperextension of the neck in a rear-end collision if a low seat back is used or when the body is not completely in the seat during the collision and becomes skewed. Side flexion and possible rib cage damage can occur from the seat armrest due to a severe side thrust or rollover of the car. Rollover can throw the occupant up from the seat causing the head to contact the baggage rack and the shoulder the upper window sill. Derailment or jackknifing can exert lateral accelerations to cause impact of the shoulder against the car side and the head against the window. Lateral sway, derailment or rollover would pitch a standee about the armrest with possible impact of the head against the window.

### 2.2.2 Parlor Car

The Metroliner parlor car (Figure 2-8) is typical of such type cars. It contains 38 seats in a low-density arrangement with a single row of seats on either side of the aisle. Adjacent to each seat is a folddown desk cantilevered from the side wall. Each seat has thickly padded armrests and a reclining high seat back with a concave cushioned head rest. The seat also has a full swiveling feature which permits omnidirectional use during transit.

Containment is less likely in the parlor car than in the coach. Seats may be oriented in any position of their 360-degree rotational capability. The problem associated with face-to-face seating is present. Leg entrapment in face-to-back positions will also occur. One mitigating circumstance which may eliminate some of these problems, for seats positioned in a direction other than the direction of impact, is the seats capability to rotate. The center of gravity of the occupant is behind the swivel point and a collision acceleration will tend to rotate the seat back in the direction of the acceleration. Provided the seat back will withstand the collision forces, this is the best direction for the occupant to be facing.

Foldout tables or desks are provided along the side of the car. An occupant leaning over the desk is subject to injury in a collision. A lateral load would cause abdominal impact with the desk, and head impact with the window. A seat facing rearward in a rear-end collision could cause an occupant to be thrust into the desk to the rear.

The larger aisle and smaller number of seats permits the standee to be closer to the baggage rack and more liable to impact due to lateral accelerations. The rack edge, if unpadded, could produce head injury.

### 2.2.3 Snack Bar

The Metroliner snack bar car presents conditions typical of snack bar and club cars or cars where food is prepared. In the Metroliner snack bar coach, the same density of seating is used as in the coach. However, only 60 seats are available. The balance of the car space is devoted to a snack bar. This is a partitioned section in the center of the car with two smooth metal edged counters, one for food preparation and the other for standup eating.

Potential injury-producing circumstances would be the same in the coach portion as in a standard coach car. The snack bar is the only new area of consideration and this is confined to standee passengers. In lateral accelerations during derailment, jackknifing, or rollover, passengers standing at the bar could be thrown backwards over the counter or head first over the bar.

A partial partition with a transparent plastic panel insert is located at each end of the snack bar area. Longitudinal or lateral accelerations causing impact with the rigid partition or with its sharp corners could produce injury. The partition would, however, limit the distance a standee at the counter would be thrown in a longitudinal collision.

The food preparation area of the snack bar presents many sharp edges and much protruding hardware, which could produce injury upon impact.

## 2.3 CABOOSES

Caboose cars, normally the last car of a freight train, house the train crew, usually consisting of brakeman, flagman, and conductor. A desk is provided for the conductor for making out and keeping his records. Toilet facilities are provided as well as facilities for food preparation and sleeping.

Four versions of the ICC cabooses were investigated for interior arrangements, equipments furnishings and structures. The versions fall into two basic types in general use, the cupola and bay window types. The cupola type has a projection above the roof in which the crewmen sit to observe the condition of the train as it proceeds. The bay window type has a projection through the side of the car for the purpose of observation (Figure 2-9). There are several variations of the cupola type: centrally located cupola (Figure 2-10), forward displaced cupola (Figure 2-11), and wide vision cupola which extends over the side of the car (Figure 2-12). Ladders are provided with the cupola types for the crew to climb up into the cupola. Such ladders could be a source of injury or falls which would not be experienced with the bay window types.

There are other potential sources for injury in the typical cabooses. Many cabooses have space heaters or stoves placed out in the open area (Figures 2-9 through 2-12). A pipe guard rail is usually placed around the heater, but the rail itself could be a source of injury if one falls or is thrown against it. Other items having sharp corners or projections such as ice chests, desks, sinks, chairs, tables, water coolers, etc., are potential sources for injury.

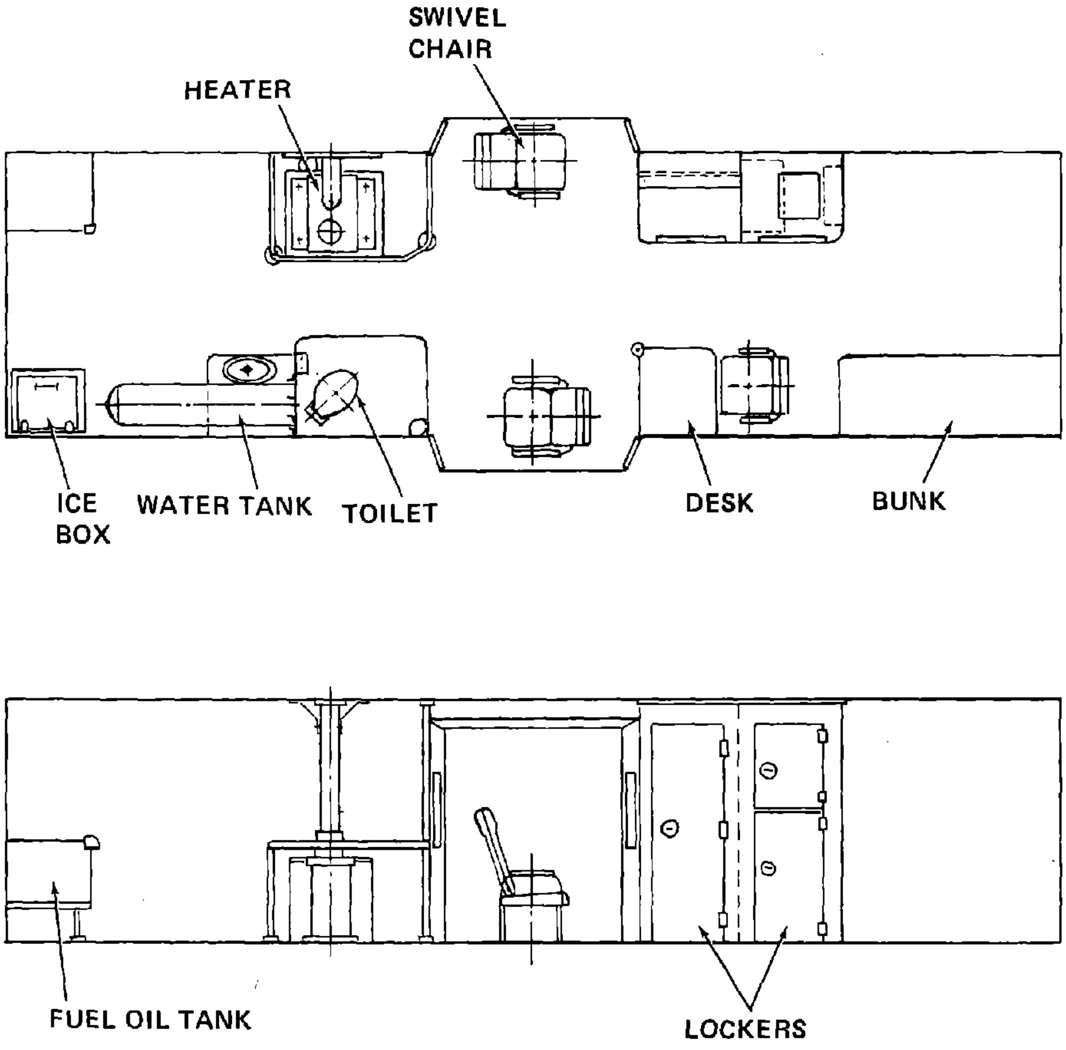


*Figure 2–9. Bay Window Type Caboose*

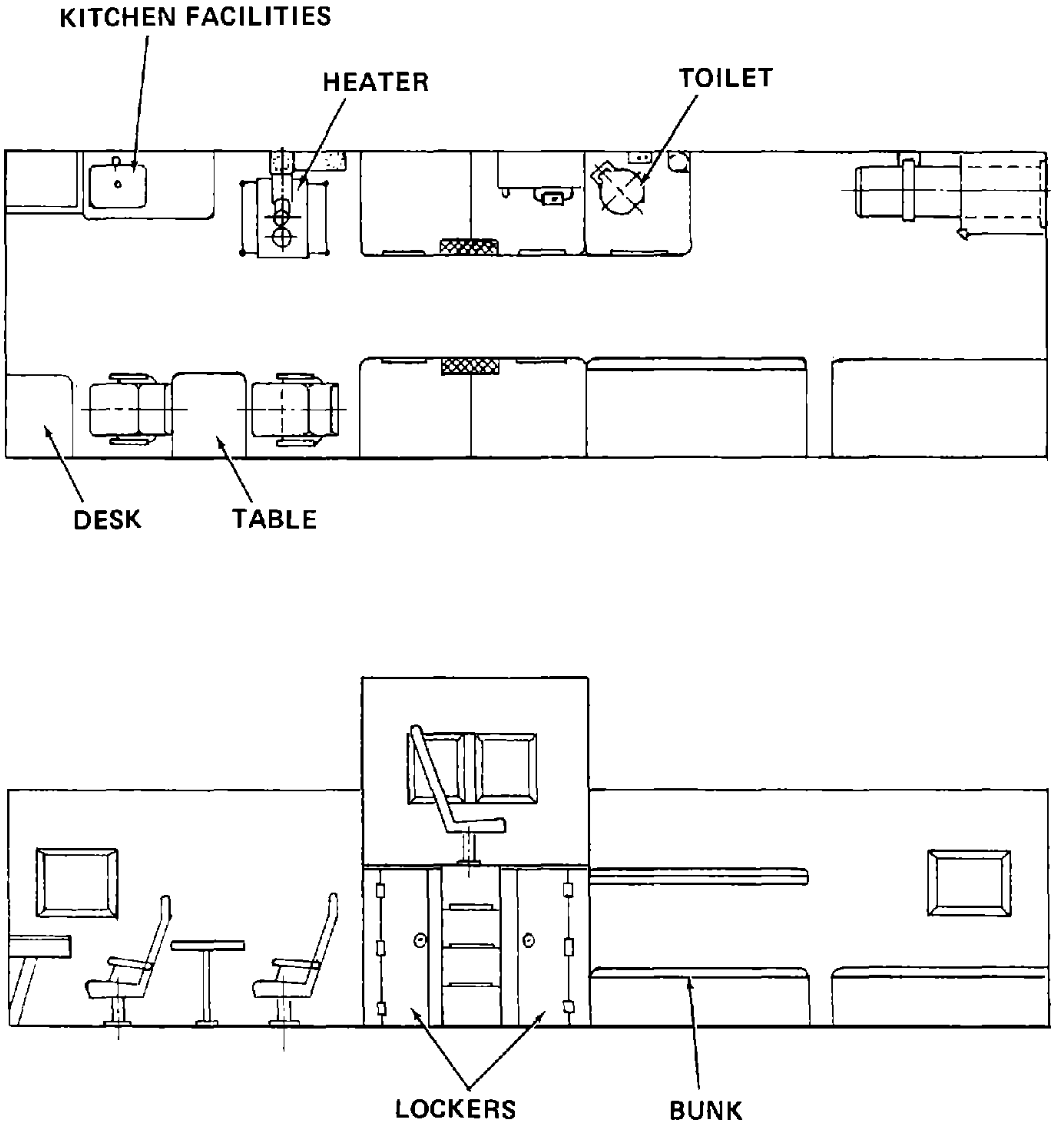


*Figure 2–10. Center Cupola Type Caboose*

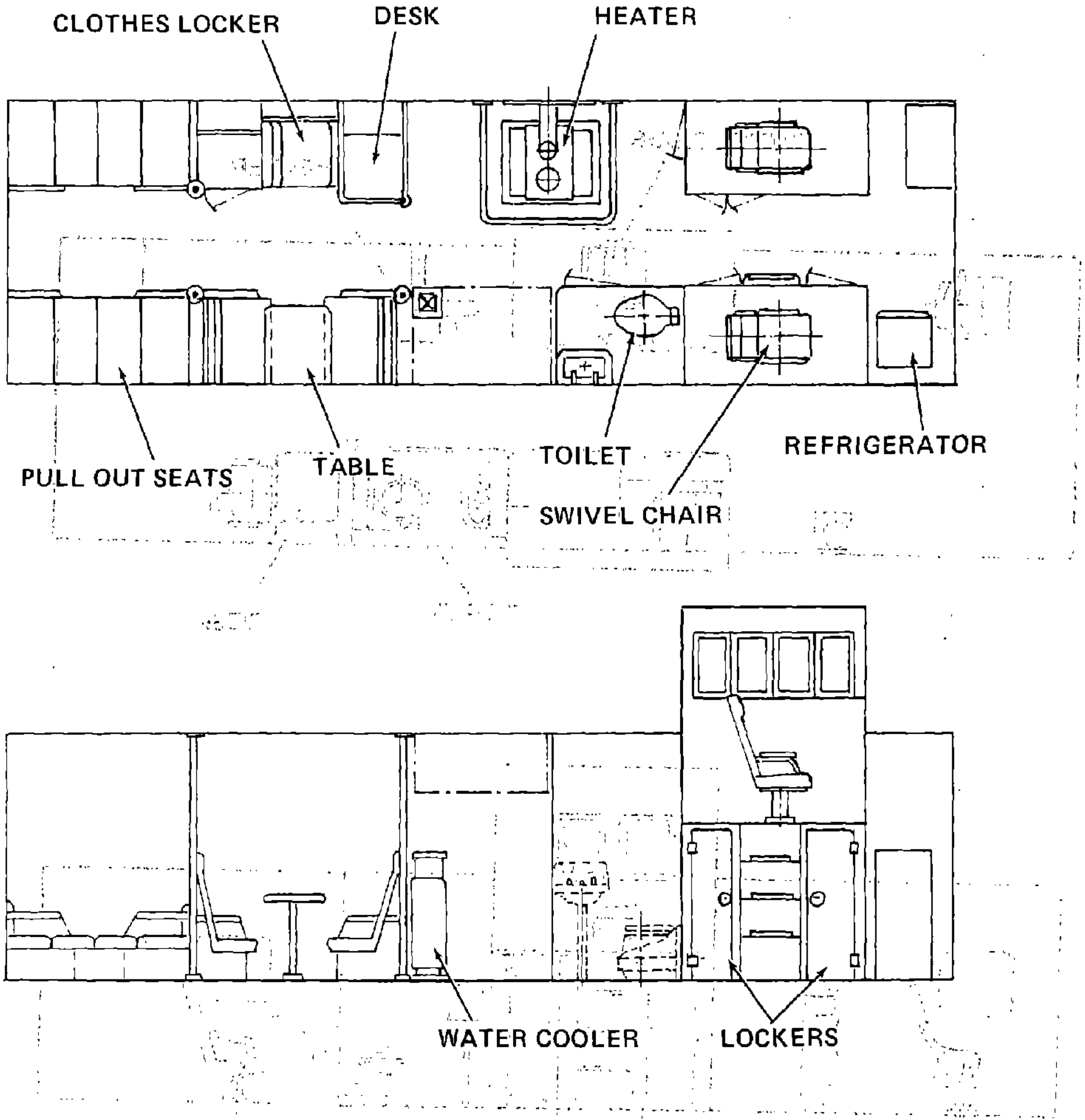


*Figure 2–11. Forward Displaced Cupola Caboose*

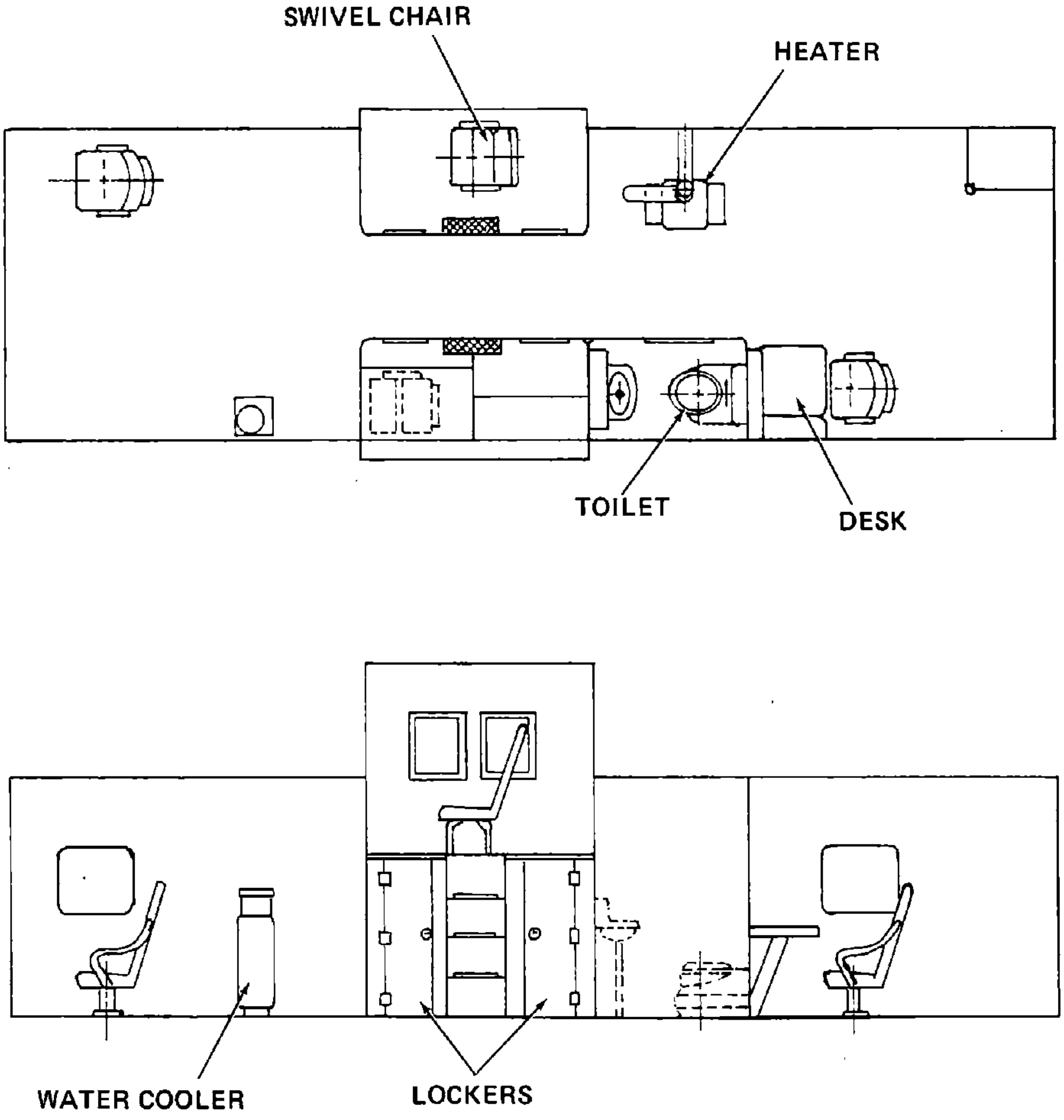


*Figure 2—12. Wide Vision Cupola Caboose*

# 3. EVALUATION OF SYSTEM SAFETY TECHNIQUES

The formal systematic approach for considering the safety aspects of a design was developed first in the aerospace industry to aid the design engineer and assure that the ever increasingly complex systems being developed were safe for use. Many system safety techniques have evolved and each has its limitations. This section discusses some of the most important techniques and their applicability. These techniques have only emerged in the last decade as viable methods for dealing with complex systems.

## 3.1 COMPARISON OF TECHNIQUES

Various state-of-the-art system safety analysis techniques employed in such fields as aerospace and nuclear power were investigated for their appropriateness to rail safety analysis. This investigation was conducted concurrently with the requirement of this program to analyze engineering data on vehicle crashworthiness and occupant injury minimization for intercity passenger railcars, locomotives and cabooses.

Table 3-1 is a summary of the analysis techniques that were investigated. Generally speaking, the objective of any safety analysis is to identify hazardous conditions and provide for their elimination or control. Therefore one would expect that a technique used in the aerospace field could very well be applied to the railroad transportation field. What is needed is an experienced system safety specialist to properly evaluate and define what would be the most effective analytical approach on any given product program. Obviously, the hazardous conditions that are considered in an analysis vary with the nature of the product. For example, a system hazard analysis (SHA) dealing with railcar transportation has specific types of environmental hazardous conditions unique to that product. Examples are . . .

- Emergency evacuation from passenger cars stranded in a tunnel when fire has erupted.
- Flooding of subways.
- Missiles such as rocks thrown from overpasses at passing trains.
- Collision of the railcar with a fuel truck at a crossing.

TABLE 3-1. SUMMARY OF SYSTEM SAFETY TECHNIQUES

| ANALYSIS TECHNIQUE | DESCRIPTION | COMMENTS |
|---|---|---|
| FAULT TREE ANALYSIS | ● A logic arrangement of the combination of events and failures which produce a stated undesired event.<br>● Because the fault tree is a logic arrangement, it is ideally suited to the use of probability theory to predict frequency of occurrence of the undesired event. | Appropriate for rail safety analysis. Applicable at any phase of a program. Can be qualitative and quantitative.<br>References A & B |
| HAZARDS ANALYSIS (General) | ● Primarily a safety tool directed toward all material failures/ malfunctions and human errors that could cause an accident.<br>● A design evaluation technique to identify hazards, determine their effects, and provide for the elimination or control of hazards.<br>● A top down analysis that is compatible with any level of design effort.<br>● Matrix type format is used. | Appropriate for rail safety analysis. See comments below on the various types of hazards analysis.<br>References C & D |

TABLE 3-1 - Continued

| ANALYSIS TECHNIQUE | DESCRIPTION | COMMENTS |
|---|---|---|
| PRELIMINARY HAZARD ANALYSIS (PHA) | ● Provides the overall visibility of identified hazards, risk areas, and safety assessments for the defined boundaries of a system.<br>● Identifies gross hazardous conditions in the early design phase.<br>● Identifies the established compensating design features for controlling the hazardous conditions.<br>● Identifies risk areas and provides guidance for the performance of subsequent in-depth analyses such as Subsystem Hazard Analyses (SSHA), System Hazard Analyses (SHA), and Operating Hazard Analyses (OHA). | Appropriate for rail safety analysis. The PHA is normally performed as the initial system safety on any system, operation or product.<br>References C, E & F<br>PHA is basicly qualitative. Quantitative accident experience has been used with PHA to show perspective. |
| SUBSYSTEM HAZARD ANALYSIS (SSHA) | ● SHA are performed to the level necessary to identify hazards for components and equipments whose performance degradation or functional failure could result in hazardous conditions. Subsystem analysis starts when the subsystem functions are defined and progresses downward as each subassembly and component is defined and detail functions are outlined. | Appropriate for rail safety analysis. Use at the safety analyst's discretion or if the PHA indicates that further in-depth subsystem hazard analysis is required.<br>References C, E & F<br>SSHA is basicly qualitative. Quantification may be used for specific hazards. |

TABLE 3-1 - Continued

| ANALYSIS TECHNIQUE | DESCRIPTION | COMMENTS |
|---|---|---|
| SYSTEM HAZARD ANALYSIS (SHA) | • The SHA is basically an extension of the PHA. The SSHA and OHA are generally limited in scope and may not bridge all the interfaces between subsystems, especially where redundancy is spread across two or more subsystems. In this regard, the SHA is performed on the total system. The technique for performing the SHA considers the common causal factors as well as the spatial relationships between parts and subsystems. | Appropriate for rail safety analysis. Use at the safety analyst's discretion or if the PHA indicates that further in-depth system hazard analysis is required.<br>References C, E & F<br>SHA can be qualitative and quantitative. |
| OPERATING HAZARD ANALYSIS (OHA) | • OHAs are performed to identify hazardous conditions related to the performance of tasks involving vehicle use. Control of operating hazards is generally attained by implementing appropriate procedures, instructions and training. | Appropriate for rail safety analysis. Use at the safety analyst's discretion or if the PHA indicates that further in-depth operating hazard analysis is required.<br>References C, E & F<br>OHA is qualitative. |
| MAINTENANCE HAZARD ANALYSIS (MHA) | • MHAs are performed to identify the hazards which could result from faulty maintenance and provide a means of initiating action to eliminate or control the hazards. Maintenance tasks are reviewed for safety-related problem areas and corrective action recommendations are made to change maintenance procedures and/or design. | Appropriate for rail safety analysis. Use at the safety analyst's discretion or if the PHA indicates that further in-depth maintenance hazard analysis is required.<br>References C, E & F<br>MHA is qualitative |

TABLE 3-1 - Continued

| ANALYSIS TECHNIQUE | DESCRIPTION | COMMENTS |
|---|---|---|
| FAILURE MODE AND EFFECT ANALYSIS (FMEA) | ● Primarily a reliability tool directed toward material malfunctions/failures effecting mission, maintenance, reliability and flight safety.<br>● A study of a single independent component failures in a system.<br>● Analysis is generally conducted from the selected lowest level upward. | If these analyses are available, the information contained within may be used to help expedite the performance of hazard analyses.<br>Reference G<br>FMEA is qualitative. Individual failure modes may be quantified. |
| MANAGEMENT OVERSIGHT AND RISK TREE (MORT) | ● MORT is a predefined logic or decision tree which may be used to conduct a systematic investigation of occupational accidents and safety programs. The top event of this predefined tree is broad in scope "injuries, damage, other costs, performance lost, degraded" so that it can be applied to any occupational accident. The analyst uses this tree as a guide or screening devide to determine those areas which require detail analysis or investigation. | May be used as a guide to establish safety program deficiencies and corresponding corrective actions.<br>Reference H<br>MORT is qualitative. |

TABLE 3-1 - Continued

| ANALYSIS TECHNIQUE | DESCRIPTION | COMMENTS |
|---|---|---|
| USAAMRDL TECHNICAL REPORT 71-22 "CRASH SURVIVAL DESIGN GUIDE" | ● Provides design guidance to improve the crashworthiness of U.S. Army aircraft. The following areas are covered:<br>● Aircraft crash kinematic and survival envelopes<br>● Airframe crashworthiness design criteria<br>● Aircraft seat design<br>● Restraint system design criteria<br>● Occupant environment design criteria<br>● Ancillary equipment stowage design criteria<br>● Emergency escape provisions<br>● Post-crash fire design criteria | A similar document, "Rail Crash Survival/Injury Prevention Design Guide" would be beneficial in providing the analyst with insight to the different types of hazard controls which should be considered. Considered appropriate for rail safety analysis.<br>Reference I<br>Qualitative |

TABLE 3-1 - Continued

| ANALYSIS TECHNIQUE | DESCRIPTION | COMMENTS |
|---|---|---|
| ADS-11 (Aeronautical Design Standard, Survivability/Vulnerability Program) | ● Provides for a numerical evaluation of aircraft crashworthy characteristics. The evaulation considers six basic factors:<br>● Crew retention system<br>● Troop retention system<br>● Post-crash fire potential<br>● Basic airframe crashworthiness<br>● Evacuation<br>● Injurious environment<br>Weighted values are assigned to each of these factors based on their relative hazard potential. The basic factors in turn are broken down into subfactors against which a hazard potential percentage has been assigned and converted to an optimum numerical value. The evaluator selects that portion of the optimum value using the criteria/considerations presented in ADS-11. The optimum score is 725. | A similar document for rail safety would provide a quick first-cut evaluation (strong points and weak points) of established or new railcar designs. Considered appropriate for rail safety analysis.<br>Reference J<br>Quantitative |

The essential aspects of any formalized safety evaluation effort are that it be properly planned, comprehensive in nature (not concerned with only one hazard or program phase), and performed in a time frame that permits its findings to be effectively factored into the program.

Table 3-1 includes a brief description of each technique, comments on the appropriateness of the technique to rail safety analysis. References that may be consulted for more detailed information are listed in Table 3-2.

## 3.2 APPROACH SELECTED

The fault tree analysis and preliminary hazard analysis techniques were selected as the most appropriate for the rail injury minimization program. These analyses were selected because they cover the spectrum of those elements considered essential to a basic safety technique (see Figure 3-1) and provide the necessary analytical depth and visibility for this program. The initial analytical step (the fault tree) provides a pictorial display of the scope of the analysis; e.g., hazardous conditions derived from the accident data as well as potentially hazardous conditions (accidents which have not yet occurred). The preliminary hazard analysis matrix then permits the hazardous conditions to be analyzed for the necessary corrective action. Figure 3-2 displays the safety analysis procedure used for this program. The detail analysis is contained in Section 5.

### 3.2.1 Fault Tree Methodology

The fault tree technique provides a systematic top-down analysis approach to identify the possible hazardous events and their combinations which end ultimately in the "top, undesired event." The top event of the subject fault tree was established as "Occupant Death or Injury." The sub-events (hazardous conditions) necessary to cause the top event were then determined. This process was continued to the level necessary to define injury mechanisms and factors which could be related to the details of the data survey. These bottom level events were then transferred from the fault tree format to the columnar format for further evaluation.

Fault trees can be readily used to develop varied types of mathematical models for use in providing quantitative results. The type of results vary, accordingly. Predicted hazard or accident rates are most commonly developed. The math modeling methodology can involve simulation, Monte Carlo Technique, Boolean Reductions, Importance Sampling and Lambda-Tau Approximations. The analysis performed in this report simply used the fault tree logic as the framework for summarizing accident experience of the rail vehicles being studied.

TABLE 3-2. REFERENCES

A. Boeing Document D6-53604, "Fault Tree For Safety," dated November 1968.

B. Boeing Document D2-113072-2, "System Safety Analytical Technology Fault Tree Analysis," dated February 1970.

C. AFSC Design Handbook DHI-6, "System Safety," 4th ed., dated July 1974.

D. Paper "Product Assurance Through System Safety Techniques," General Electric Co., Aerospace Group.

E. MIL-STD-882, "System Safety Program for Systems and Associated Subsystems and Equipment: Requirements for," dated 15 July 1969.

F. USAAAVS Technical Report 72-8, "Preparation of a System Safety Program Plan for Aviation Systems Development," dated March 1972.

G. SAE ARP-926 "Design Analysis Procedure for Failure Mode, Effects and Criticality Analysis."

H. The Management Oversight and Risk Tree (MORT) including systems developed by the Idaho Operations Office and Aerojet Nuclear Company, Document SAN 821-2, dated 12 February 1973.

I. U.S. Army Air Mobility Research and Development Laboratory Technical Report 11-22, Crash Survival Design Guide.

J. U.S. Army Aviation System Command ADS-11, Aeronautical Design Standard Survivability/Vulnerability Program.

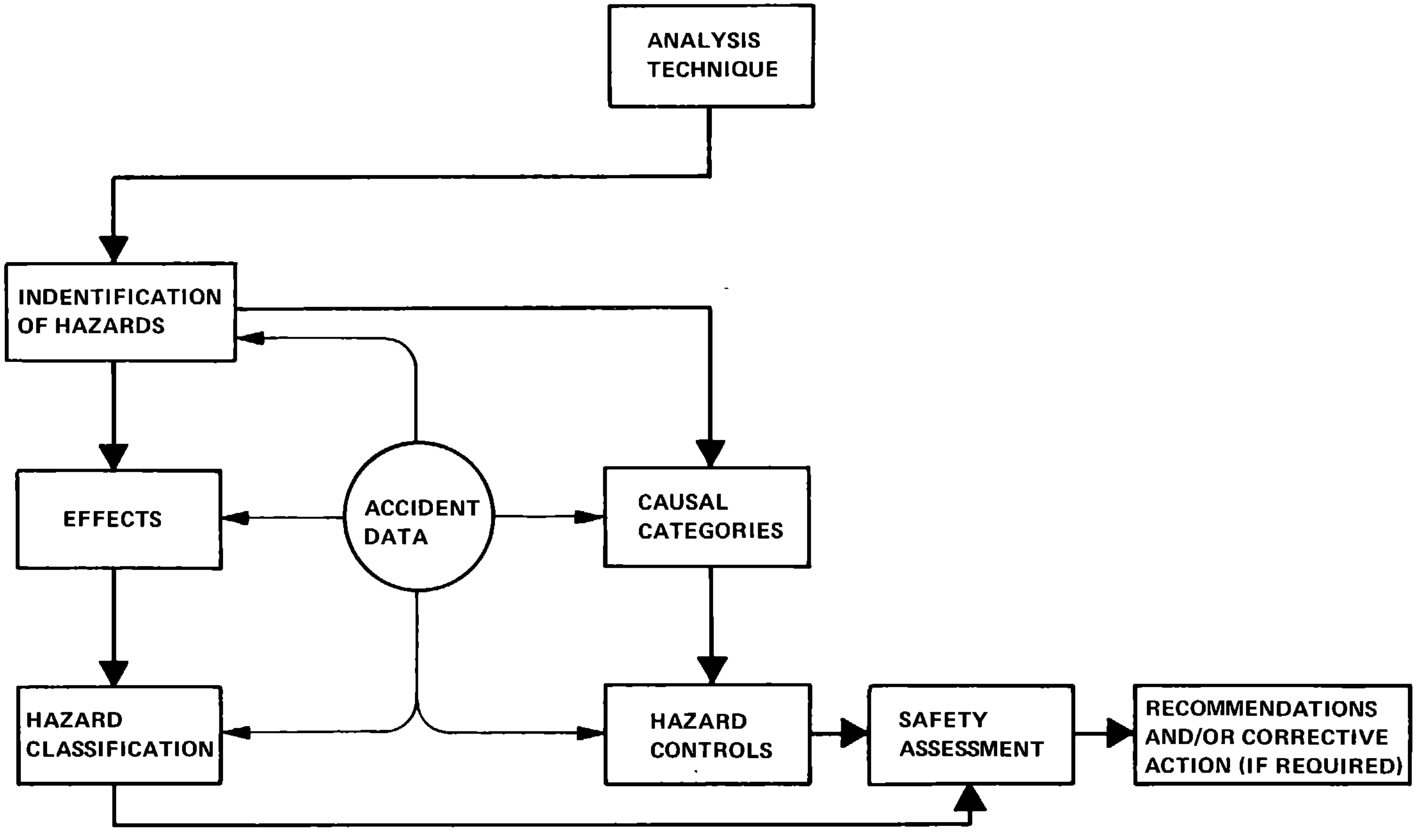


*Figure 3–1. Essential Elements of a System Safety Analysis*

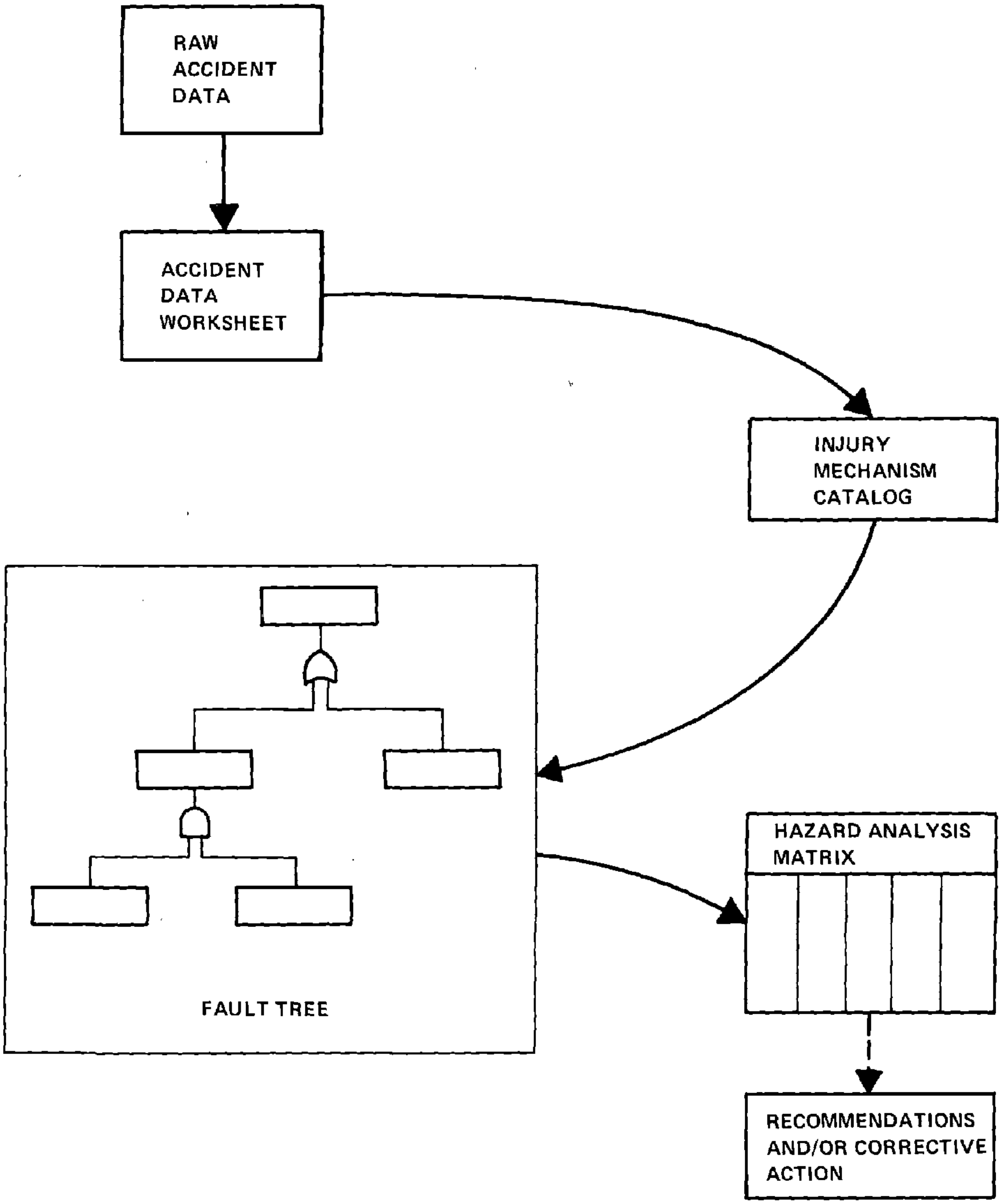


*Figure 3–2. Safety Analysis Procedure Used for the Rail Injury Minimization Program*

The following three steps were required in the fault tree analysis:

Step 1 - Define undesired event
Step 2 - Acquire understanding of the system
Step 3 - Construct fault tree

### Step 1 - Define Undesired Event

To begin the evaluation process, the most undesired event, i.e., the event to be avoided, was defined. Since it is single-event oriented, the fault tree must be constructed with only one "most undesired event." Usually, there are several events that lead to the "top" event and as such, they are analyzed in relationship to the top event. This situation makes it mandatory to establish terminology for the top event that will encompass the lesser events, individually or collectively. In this analysis "Occupant Death or Injury (ODI)" was selected as the top event. By this selection the analysis did not address, directly, injury to persons outside the train, damage to property, or damage to the train itself. Although some of these events may appear in the fault tree, they cannot be used for evaluation since the information presented may be only a fragment of that actually related to these events.

### Step 2 - Acquire Understanding of the System

The safety of any system must be analyzed for a specific time and type of activity; for this reason the system safety engineer must understand the nature of the system. For this analysis the system was an extremely generalized train system including locomotive, passenger car and caboose. There are many diverse versions of each of these types of vehicles and to detail each of these was considered prohibitive because of the lack of detail available and the extensive research required to obtain the data. Because of this restriction as to the definition of the system, the fault trees were terminated at levels appropriate to features associated with the vehicles, in general. The fault tree constructed in this study applies to rail vehicles in general and could easily be expanded to any specific model.

### Step 3 - Construct Fault Tree

A fault tree is constructed by properly relating the possible sequences of events that, upon occurrence, result in the undesired events. Beginning with the "most undesired event," the fault tree graphically depicts the paths that lead to each succeeding lower level of the display. These paths are developed through a series of logic gates which usually relate to an "and" or "or" statement. These gates generally define whether the upper event occurs when any one of the lower events occurs, or only when a combination of two or more of the lower events occurs.

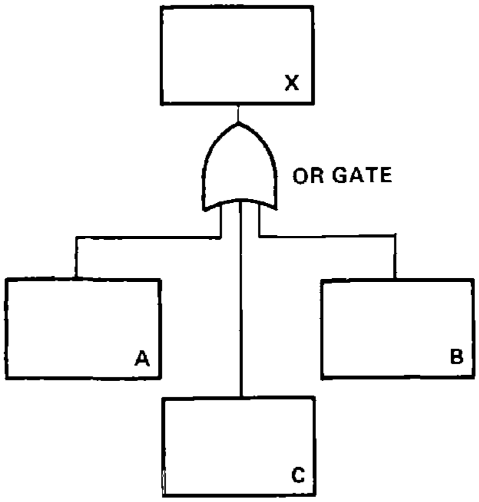
Basic Logic Gates: The basic logic gates used in constructing a fault tree are shown in Figure 3-3. These gates represent fundamental Boolean functions that form the basics for all logic analysis. The decision to use an "and" gate or an "or" gate can be explained by the following rule. If the event being considered will, by itself, cause the next higher even to occur, use an "or" gate. Otherwise, determine what is necessary and sufficient to cause the next higher event and use an "and" gate. The "inhibit" gate is a variation of the "and" gate. Its use lets the analyst apply conditional probabilities to a fault sequence. For example, smoke will be produced (output) if a fire exists (input) and the fire evolves smoke (conditional probability, inhibit).

Special Logic Gates: There are numerous, special logic gates used in fault tree analysis. Some of these special gates are used to depict special considerations and some are used to streamline or reduce the size of the presentation. A special "Matrix" gate was used in the fault tree developed for this study. The "Matrix" gate replaces a series of "and" gates inputting "Inhibit" gates, where the series input into a common "or" gate. This special gate simplified the presentation of the condition where the output event may be caused N percent of the time that A and B occur or M percent of the time that A and C occur or L percent of the time that B and C occur, etc. Figure 3-4 shows the matrix gate and its equivalent in basic logic gates.

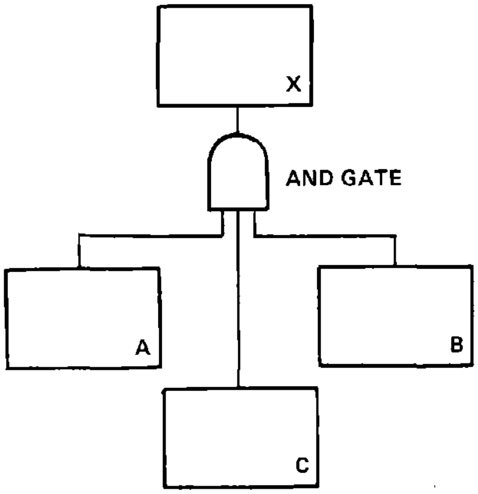
### 3.2.2 Preliminary Hazard Analysis Procedure

The preliminary hazard analysis technique was selected to depict the interrelationship of the injury hazards identified by the accident data survey. This technique was the most appropriate since the approach was adaptable to events, in this instance hazardous events or undesired events. The other types of analysis, in general, are directed more to preventing the crash which initiates an injury sequence. Table 3-3 briefly indicates the applicability of the various analysis techniques.

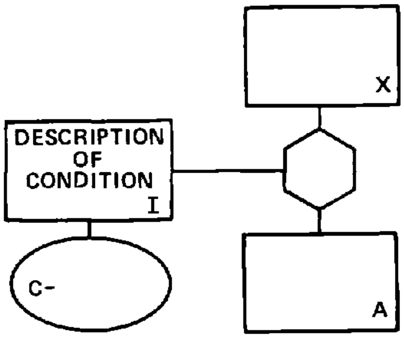
The preliminary hazard analysis technique consisted of three basic steps:



The "OR" gate performs the logic function that requires any one of the gate input (A, B, C) events in order to realize an output (X) event.

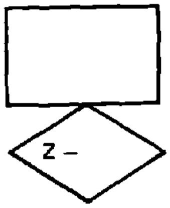


The "AND" gate performs the logic function that requires the coexistence of all gate inputs (A, B, C) events in order to realize an output (X) event.

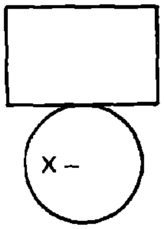


The "INHIBIT" gate provies a means of applying a conditional probability to the fault sequence. If the input event (A) occurs and the condition (I) is satisfied, an output event (X) will be generated.

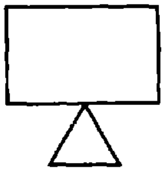
*Figure 3–3. Fault Tree Symbols and Their Use (Sheet 1 of 2)*



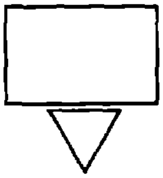
An input event below which the fault sequence is either terminated or referred to a detailed hazard analysis, such as SSHA, MHA, OHA or system hazard analysis detail sheet.



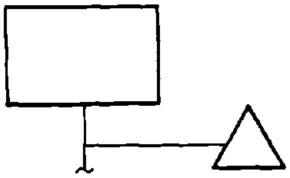
An input event described by a basic system component or part failure.



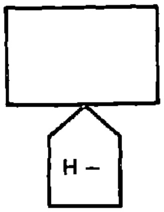
Transfer out symbol indicates where an identified branch of the fault tree is to be transferred.



Inverted transfer symbol indicates a transfer of a redundant or similar system composed of identical or functionally similar components and has the same mode or probability of failure.



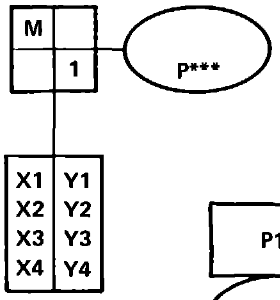
Indicates a branch of the fault tree.



House symbol indicates an event that can be expected normally to occur.

*Figure 3–3. Fault Tree Symbols and Their Use (Sheet 2 of 2)*

NOTE: "MATRIX" GATE = CONVENTIONAL PRESENTATION



| M1 | Y1 | Y2 | Y3 | Y4 |
|---|---|---|---|---|
| X1 | P11 | P12 | P13 | P14 |
| X2 | P21 | P22 | P23 | P24 |
| X3 | P31 | P32 | P33 | P34 |
| X4 | P41 | P42 | P43 | P44 |

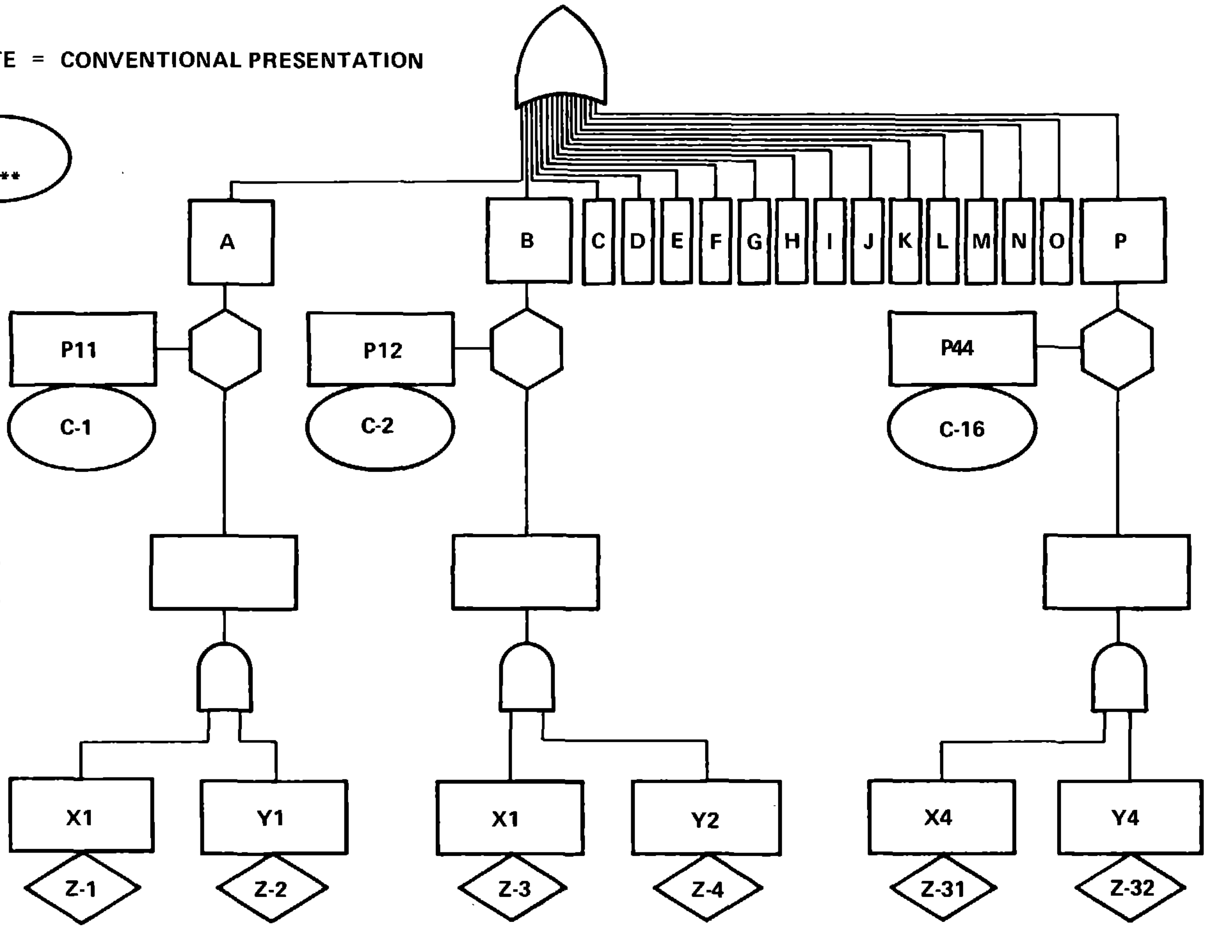


*Figure 3–4. Matrix Gate Equivalent*

TABLE 3-3. SYSTEM SAFETY TECHNIQUES

| ANALYSIS TECHNIQUE | PRIMARY APPLICATION |
|---|---|
| Subsystem hazard analysis and failure modes and effects analysis. | Hardware analysis, deals in loss of function of an item, the consequence and, if the consequence is bad, how is the sequence controlled. Most applicable to preventing a crash. |
| Operational hazard analysis and maintenance hazard analysis. | Task analysis, deals in failure of tasks to be properly done, the consequence and, if the consequence is bad, how is the sequence controlled. Can be used to evaluate operating procedures in order to prevent accidents. |
| System hazard analysis, fault tree, preliminary hazard analysis. | Event analysis, starts with an undesired event and through logic, determines the factors which cause the event. Both the system and the preliminary hazard analyses are based around a fault tree (undesired event tree). The system hazard analysis is more detailed and primarily is used to determine inter-relationships between subsystems which are hazardous and would ordinarily be overlooked in the subsystem hazard analysis. These techniques have usually been used for accident prevention but are adaptable to any type event. |

1. A fault tree (logic diagram) analysis to establish hazardous conditions.
2. A quantitative reduction of the data to correlate to events identified by the fault tree.
3. A columnar format to translate hazardous conditions to a cause and evaluation presentation.

The preliminary hazard analysis technique is demonstrated in Section 5.

# 4. RAIL VEHICLE ACCIDENT DATA

## 4.1 ACQUISITION OF DATA

A data file was compiled of major railroad accidents which have occurred since 1967, where personal injuries have been involved. Four primary data sources were used:

- NTSB Railroad Accident Reports
- FRA Railroad Accident Reports
  - Accident Reports
  - Accident Summary Reports
- FRA Accident Bulletins (Annual Summary)
- FRA T-Forms
  - Train Accidents
  - Train-Service Accidents

Whenever possible, supplementary data was obtained from NTSB Accident Dockets, FAA investigations in support of the NTSB, and FRA Accident Jackets.

Other agencies were consulted to determine the extent of information availability; and these, together with the major sources, are summarized in Table 4-1.

Figure 4-1 shows the types of information collected at the Boeing Vertol Company and the sources of these data.

### 4.1.1 National Transportation Safety Board (NTSB)

The NTSB has been investigating railroad accidents and publishing formal reports since 1967. All of their reports published up to 1973 were included in the Boeing Vertol data file and supplementary information was obtained from the NTSB Library File Railroad Accident Dockets, this representing a total of 26 reports.

A list of accidents investigated by the NTSB is given in Table 4-2.

### 4.1.2 Federal Railroad Administration (FRA)

The FRA has several methods of presenting accident data:

TABLE 4-1. DATA ACQUISITION: SOURCES OF RAILROAD ACCIDENT DATA

- FEDERAL RAILROAD ADMINISTRATION*
  - OFFICE OF SAFETY
  - OFFICE OF POLICY AND PLANS
- NATIONAL TRANSPORTATION SAFETY BOARD*
- NATIONAL RAILROAD PASSENGER CORPORATION
- ASSOCIATION OF AMERICAN RAILROADS
- PENN CENTRAL TRANSPORTATION COMPANY
- NORFOLK & WESTERN RAILWAY COMPANY
- ELECTROMOTIVE DIVISION OF GENERAL MOTORS
- INTERNATIONAL CAR COMPANY
- GENERAL ELECTRIC TRANSPORTATION SYSTEMS
- FAA CIVIL AEROMEDICAL INSTITUTE
- WAYNE STATE UNIVERSITY

*Major data source

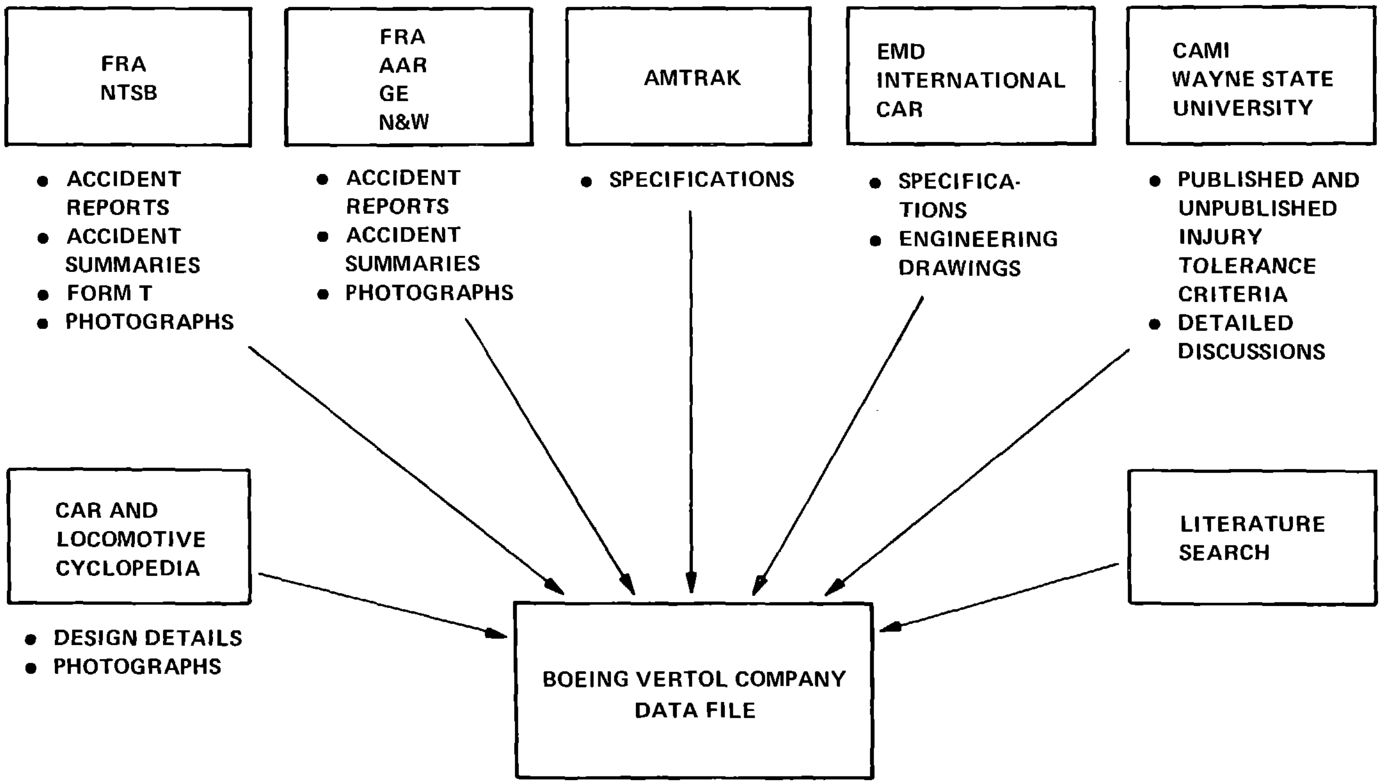


*Figure 4–1. Data Acquisition: Sources for Accident Details and Vehicle Design Features*

TABLE 4-2. ACCIDENTS INVESTIGATED BY THE NTSB, 1967-1973

| DATE OF ACCIDENT | LOCATION | TYPE OF ACCIDENT | REPORT NUMBER |
|---|---|---|---|
| 28 Dec 66 | Everett, MA | Derailment | RHAR, 2-29-68 |
| 22 May 67 | New York, NY | Head-on Collision | RAR, 12-29-67 |
| 2 Oct 67 | Waterloo, NE | Grade Crossing | HRAR, 9-18-68 |
| 1 Jan 68 | Dunreith, IN | Derailment | RHAR, 2-29-68 |
| 25 Jan 69 | Laurel, MS | Derailment | RAR, 10-6-69 |
| 18 Feb 69 | Crete, NE | Derailment | RAR 71-2 |
| 28 Jun 69 | Glenn Dale, MD | Derailment | RAR 70-1 |
| 20 Aug 69 | Darien, CT | Head-on Collision | RAR 70-3 |
| 11 Sep 69 | Glendora, MS | Derailment | RAR 70-2 |
| 24 Jan 70 | Loda, IL | Grade Crossing | RAR 71-1 |
| 27 Jan 70 | Franconia, VA | Derailment | RAR 71-1 |
| 21 Jun 70 | Crescent City, IL | Derailment | RAR 72-2 |
| 8 Sep 70 | Riverdale, IL | Derailment | RAR 71-3 |
| 8 Oct 70 | Sound View, CT | Derailment | RAR 72-1 |
| 28 Mar 71 | Sheridan, NY | Rear-end Collision | RAR 72-4 |
| 5 Apr 71 | Collinsville, OK | Derailment (G.C.) | RAR 72-1 |
| 10 Jun 71 | Salem, IL | Derailment | RAR 72-5 |
| 19 Oct 71 | Houston, TX | Derailment | RAR 72-6 |
| 12 Mar 72 | Herndon, PA | Head-on Collision | RAR 73-3 |
| 27 Apr 72 | Arlington, VA | Derailment | RAR 73-2 |
| 24 May 72 | Maquon, IL | Head-on Collision | RAR 73-4 |
| 30 Oct 72 | Chicago, IL | Rear-end Collision | RAR 73-5 |
| 21 Feb 73 | Taft, LA | Head-on Collision | RAR 73-6 |
| 25 Jun 73 | Indio, CA | Rear-end Collision | RAR 74-1 |
| 11 Aug 73 | Pueblo, CO | Rear-end Collision | RAR 74-2 |
| 1 Dec 73 | Cotulla, TX | Head-on Collision | RAR 74-3 |

- FRA Accident Bulletin: This consists of annual statistical data based on the data obtained from T-Forms.

- FRA Monthly Report of Railroad Accident (T-Form): T-Forms are required to be submitted by each railroad property to the FRA for all railroad accidents where the involved liability consisted of personal injury and/or equipment damage in excess of a specified minimum dollar value. (For the time period considered the dollar value was $750.)

- FRA Railroad Accident Investigation Report: This is a formal method of reporting the findings of an investigating committee where a major accident is involved. Individual reports are issued for each accident.

- FRA Railroad Accident Investigation Summary Report: This is a less detailed form of accident reporting for individual accidents.

### 4.1.3 Data Selection from the FRA

Accident information was selected for inclusion in the Boeing Vertol Data File based on the following criteria:

- Time frame: 1967-1973 for major accidents

- Accident reports on file at the FRA facility, Buzzard Point, Washington, D.C. (For both accident and accident summary reports.)

- T-Form data for 1972 and 1973 (only forms available at FRA). 100 percent review of forms and data selected which satisfied:
    - personal injury
    - equipment damage in excess of $5,000 (to ensure elimination of many minor accidents)

Where available, and as needed, additional information was obtained from FRA jackets for individual major accident investigations.

Lists of FRA Accident Reports and Accident Summary Reports used as data sources for this study are given in Tables 4-3 and 4-4, respectively, and are representative of 39 FRA Accident Reports and 31 FRA Accident Summary Reports.

### 4.1.4 Data Sources and Compilation Diagram

A summary of the data sources and compilation procedures employed is given in Figure 4-2.

TABLE 4-3. FRA ACCIDENT REPORTS INCLUDED IN DATA FILE

| DATE OF ACCIDENT | LOCATION | TYPE OF ACCIDENT | FRA REPORT NO. |
|---|---|---|---|
| 28 Dec 66 | Everett, MA | Derailment | 4107A |
| 5 Aug 68 | Winter Haven, FL | Head-on Collision | 4148 |
| 23 Sep 68 | Ashtabula, OH | Derailment | 4167 |
| 3 Mar 69 | Ama, LA | Grade Crossing | |
| 12 Apr 69 | Ridgeway, OH | Derailment | 4162 |
| 25 Apr 69 | Germantown, MD | Derailment | 4159 |
| 6 Jun 69 | Marysville, WA | Rear-end Collision | 4152 |
| 23 Jun 69 | New York, NY | Rear-end Collision | 4150 |
| 29 Jun 69 | Tobar, NV | Explosion | 4153 |
| 7 Jul 69 | McManus, LA | Head-on Collision | 4155 |
| 13 Aug 69 | New York, NY | Rear-end Collision | 4150 |
| 18 Aug 69 | Wellington, OH | Rear-end Collision | 4158 |
| 14 Sep 69 | Burtonville, IL | Rear-end Collision | 4156 |
| 21 Sep 69 | Colby, OH | Rear-end Collision | 4165 |
| 26 Sept 69 | Riverdale, IL | Rear-end Collision | 4163 |
| 12 Oct 69 | Conneautville, PA | Grade Crossing | 4151 |
| 26 Oct 69 | Leadvale Jct., TN | Rear-end Collision | 4160 |
| 3 Nov 69 | Walkerford, VA | Side Collision | 4157 |
| 11 Nov 69 | New Carlisle, IN | Rear-end Collision | 4154 |
| 9 Jan 70 | New York, NY | Rear-end Collision | 4164 |
| 17 Feb 70 | Fullerton, CA | Side Collision | 4173 |
| 25 Mar 70 | Union, MO | Rear-end Collision | 4168 |
| 28 Mar 70 | Floka, NV | Side Collision | 4166 |
| 6 Jun 70 | Newport, WA | Head-on Collision | 4169 |
| 14 Jun 70 | Masillon, OH | Rear-end Collision | 4170 |
| 19 Aug 70 | Pembroke, VA | Head-on Collision | 4171 |
| 25 Aug 70 | Finney, VA | Head-on Collision | 4175 |
| 23 Sep 70 | Zwolle, LA | Rear-end Collision | 4172 |
| 9 Oct 70 | Langhorne, PA | Rear-end Collision | 4176 |
| 24 Oct 70 | Kings Mtn., KY | Rear-end Collision and Derailment | 4174 |
| 30 Jan 71 | Duluth, MN | Rear-end Collision | 4177 |
| 22 Apr 71 | Truckee, CA | Derailment | 4179 |
| 11 May 71 | Sheffels, MT | Head-on Collision | 4178 |
| 7 Sep 71 | Pontiac, MI | Head-on Collision | 4182 |
| 18 Sep 71 | Belton, MT | Head-on Collision | 4180 |
| 18 Oct 71 | Kearny, NJ | Rear-end Collision | 4181 |
| 25 Dec 71 | Mt. Marion, NY | Head-on Collision | 4183 |
| 23 Feb 72 | S. Seattle, WA | Derailment | 4184 |
| 2 Mar 72 | Fall River, MA | Rear-end Collision | 4186 |
| 9 Jun 72 | Duncanville, TX | Rear-end Collision | 4185 |

TABLE 4-4. FRA ACCIDENT SUMMARY REPORTS INCLUDED IN DATA FILE

| DATE OF ACCIDENT | LOCATION | TYPE OF ACCIDENT | FRA REPORT NO. |
|---|---|---|---|
| 1 Jan 69 | Coon Rapids, IA | Rear-end Collision | SR #1 |
| 2 Jan 69 | Rocklin, CA | Derailment | SR #2 |
| 12 May 69 | Parrish, AL | Rear-end Collision | SR #3 |
| 14 Jul 69 | Neosha Rapids, KS | Derailment | SR #8 |
| 28 Oct 69 | Charleston, IL | Rear-end Collision | SR #5 |
| 6 May 70 | Otis Orchards, WA | Side Collision | SR #4 |
| 3 Jun 70 | Oluster, OK | Rear-end Collision | SR #10 |
| 6 Jul 70 | Scotland, IL | Grade Crossing | SR #7 |
| 21 Aug 70 | Ravenna, OH | Rear-end Collision | SR #11 |
| 25 Oct 70 | Green Mtn., NC | Head-on Collision | SR #9 |
| 3 Mar 71 | Shumla, TX | Rear-end Collision | SR #14 |
| 10 Mar 71 | Palmer, MN | Head-on Collision | SR #13 |
| 26 Mar 71 | N. Manchester, IN | Rear-end Collision | SR #12 |
| 3 Apr 71 | Saxton, KY | Rear-end Collision | SR #17 |
| 7 Jul 71 | New York, NY | Derailment | SR #16 |
| 9 Jul 71 | New York, NY | Rear-end Collision | SR #18 |
| 16 Jul 71 | Deschute, OR | Rear-end Collision | SR #15 |
| 23 Aug 71 | New York, NY | Rear-end Collision | SR #19 |
| 31 Oct 71 | E. Gary, IN | Grade Crossing | SR #20 |
| 23 Dec 71 | Cross Bayou, FL | Derailment | SR #21 |
| 28 Jan 72 | Cut Bank, MT | Derailment | SR #22 |
| 28 Mar 72 | Rocker, MT | Rear-end Collision | SR #23 |
| 14 Apr 72 | Ft. Morgan, CO | Derailment | SR #24 |
| 22 May 72 | Riverton, VA | Rear-end Collision | SR #31 |
| 29 Jun 72 | Lancaster, PA | Rear-end Collision | SR #26 |
| 4 Sep 72 | Inland, NE | Derailment | SR #25 |
| 17 Sep 72 | Derry, PA | Rear-end Collision | SR #30 |
| 20 Sep 72 | Arlington, IL | Grade Crossing | SR #27 |
| 25 Sep 72 | Newark, NJ | Rear-end Collision | SR #28 |
| 8 Dec 72 | Cornersville, TN | Derailment | SR #29 |
| 13 Mar 73 | Hortense, GA | Grade Crossing | SR #32 |

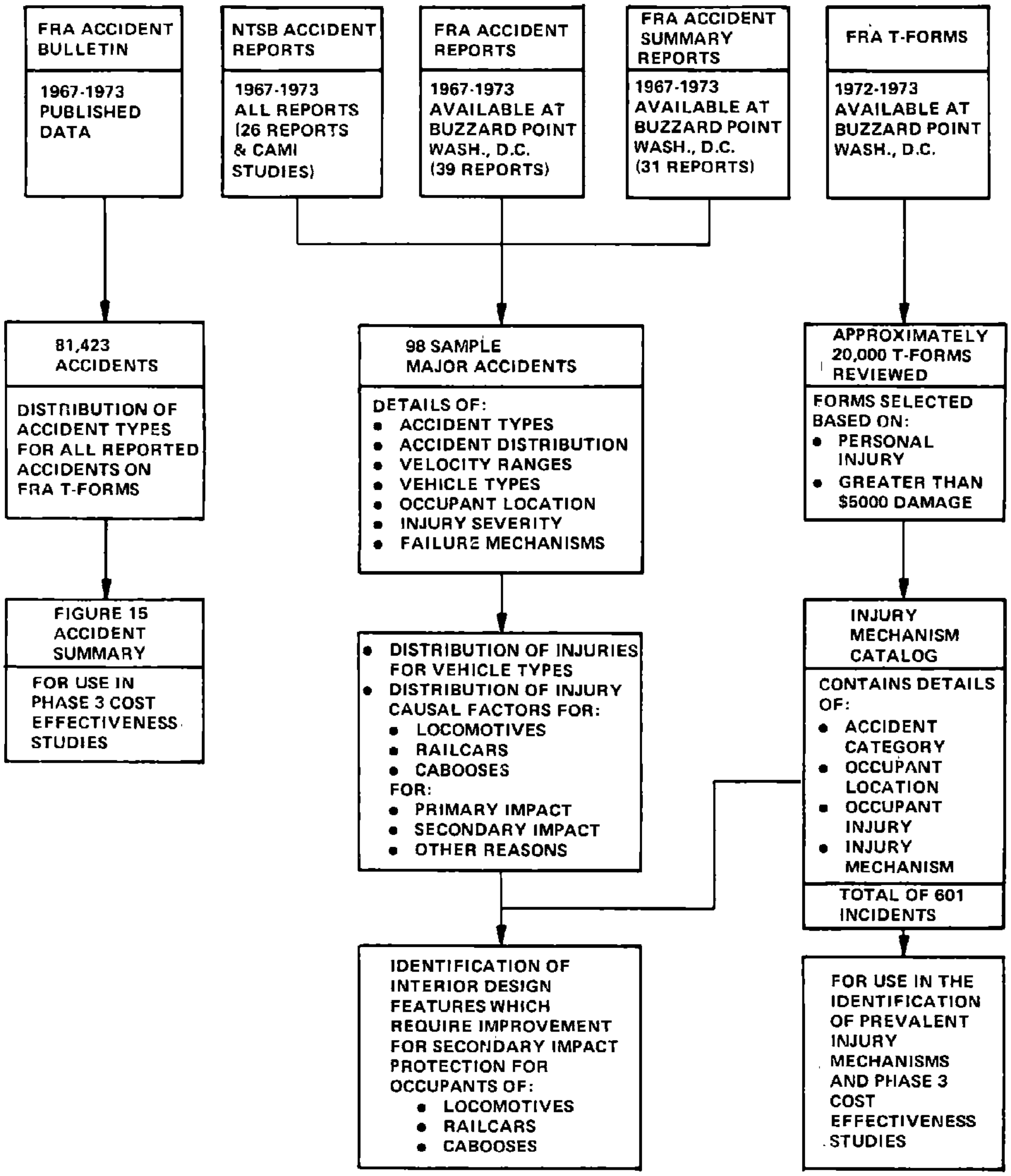


*Figure 4–2. Data Source and Compilation (1967 through 1973)*

A process is shown which indicates the sources of data samples, the types of data processed and published, and the potential usefulness in later phases of the contract.

### 4.1.5 Federal Aviation Administration, Civil Aeromedical Institute (CAMI)

NTSB requested CAMI to investigate the injury mechanisms for the occupants of passenger railcars in some major railroad accidents. Most of their observations were included in the formal NTSB reports; but in addition to these, one formal report was issued concerning the "Application of Commercial Aircraft Accident Investigation Techniques to a Railroad Derailment" (Illinois Central AMTRAK derailment near Salen, Illinois, which occurred June 10, 1971.) This report and the results of informal discussions with CAMI personnel concerning passenger injury mechanisms were used in the review of accident data.

### 4.1.6 Other Data Sources (See Table 4-1)

The data obtained from the primary sources was supplemented whenever possible with written, verbal, and photographic information. Some accident structural damage information was enhanced as a result of discussions with the personnel involved in the accident investigation; examples of such contacts are FRA inspectors, railroad personnel (Norfolk and Western), and NTSB investigators. In particular instances, photographs were obtained which provided good indications of the reduction in occupied volume of the vehicles involved, quite often the only way of defining whether primary or secondary impacts or failures contributed to occupant injuries.

## 4.2 CLASSIFICATION OF ACCIDENTS

The principal types of rail vehicle accidents in which occupants are injured are as follows:

- Head-on Collision
- Rear-end Collision
- Side or Cross Collision
- Grade Crossing Collision
- Derailment
- Hard Coupling

- Slack Action
- Braking

Collisions and derailments are the more serious type accident and are likely to cause serious or fatal injuries. Collision accidents include head-on, rear-end, and side-collisions. These type accidents are most relevant to the secondary impact situation. Design requirements for impact protection are established based on the impulses generated during these accidents. Grade crossing accidents can also be serious if the highway vehicle struck is a truck carrying hazardous material, however, secondary impact is not relevant. The remaining type accidents, although they occur more frequently than the more serious type, usually cause injuries that do not exceed the moderate injury level.

### 4.2.1 Head-On Collision

This type of accident involves impact between the lead locomotives of two trains operating on the same track. Collisions in a head-on direction can occur between freight and passenger trains or combinations of both. However, rarely are passenger trains involved in major head-on collisions. This is primarily because they run on dedicated tracks where traffic control systems exist. In addition, many more freight trains are in service at any given time, many running on tracks which do not possess automatic signalling systems.

### 4.2.2 Rear-End Collision

This type of accident involves the locomotive of one train impacting the rear of another train operating on the same track. The vehicle at the rear of the train is generally a caboose or a passenger car, although in less frequent occurrences it may be a freight car or a pusher locomotive.

### 4.2.3 Derailment

A single train consist can derail at any of the vehicle elements of the train: locomotive, car, or caboose. Generally, the train is moving in a forward direction, although derailment can occur when reverse motion is employed. Derailment can result from vehicle hardware failure, track failure, incorrect switch setting, or track obstruction.

### 4.2.4 Grade Crossing Accidents

Grade crossing accidents involve a collision between a highway vehicle and a rail vehicle. Generally the only collisions at grade crossings which pose a major threat to the occupants of rail vehicles are those where gravel, heavy mass objects, or flammable fluids are carried. FRA data shows that 24 percent of grade crossing accidents involve trucks and 10 percent of the trucks carry potentially hazardous cargo.

Grade crossing accidents are usually considered the most hazardous when derailment ensues or fire occurs. The effects on occupants of vehicles in a derailment environment are the same whether the initiating factors are due to railroad equipment failure or highway vehicle collision. This is because of the relatively low mass of the highway vehicle. Therefore, the interior design evaluation for regular derailments will suffice.

### 4.2.5 Collision and Derailment Velocity Data

Figure 4-3 shows the cumulative distribution as a function of velocity for the three major accident categories: head-on, rear-end, and derailment. Derailment data is given for freight trains and passenger trains since there is an obvious difference in normal operating speeds for each class of vehicles.

Median values for the relative velocities of which the respective types of accident occur are given in Table 4-5. These values are indicative of the normal operating speed ranges for the classes of vehicles considered and may be used for average design conditions.

TABLE 4-5. RELATIVE VELOCITIES FOR DIFFERENT TYPES OF ACCIDENTS

| Type of Accident | Class of Vehicle | Median Relative Velocity (mph) | Vehicle Operating Velocity (mph) |
|---|---|---|---|
| Head-On Collision | All* | 44 | 22 |
| Rear-End Collision | All* | 22 | 22 |
| Derailment | Freight | 42 | 42 |
| Derailment | Passenger | 62 | 62 |

*Freight and passenger

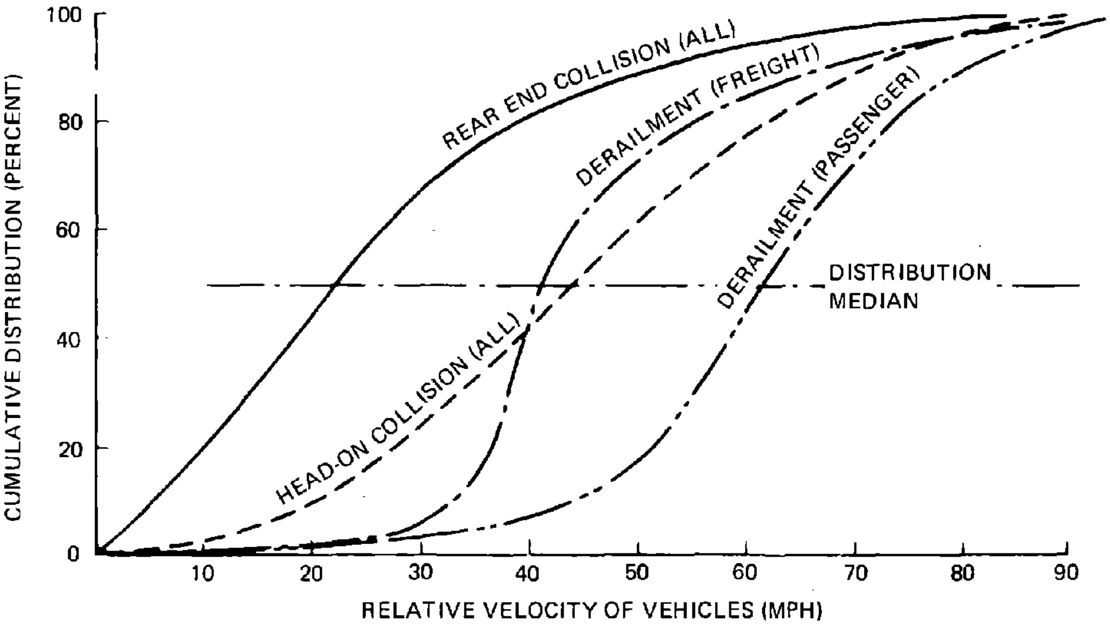


*Figure 4–3. Cumulative Accident Distribution as a Function of Relative Velocity*

## 4.3 QUALITY OF DATA

A detailed investigation was made to pinpoint the cause of injury in rail vehicles so that interior arrangements and equipment design requirements could be established. FRA T-forms for the years 1972 and 1973 were used as the basis of the investigation. Injury data on 1400 persons was reviewed. The extent of the injury, the type of railcar the injury occurred in, and the type of train accident which precipitated the injury were documented on the T-forms. A summary of the injuries and types of accident causing the injuries appears in Table 4-6.

T-form data on injury mechanisms was minimal. Of the 1400 cases investigated, only 288 reported the device, structure, or condition which caused the injury. Documentation as to the injury causing mechanism was not available for any of the occupants that received fatal or serious injury in a collision. Injury mechanisms for passenger car occupants were the least documented, amounting to less than 10 percent none of which occurred in a collision. The highest percentage (64 percent) of injury producing factors were documented in caboose accidents. For locomotive injuries, only 18 percent of injury causes were reported.

The degree of injury is generally extremely inadequately defined in all accident reports. The differentiation between serious and other injuries is seldom addressed and injury causal factors and occupant locations are also sadly neglected. The only exception to this is the CAMI investigations into passenger train accidents where they employ aircraft accidents investigation techniques and attempt to locate occupants and define injury causal factors.

As a result, certain assumptions were made when definitive information was not available. For example, if primary structural failure resulted in the reduction of occupied volume to an unacceptable level, it was assumed that all fatalities and serious injuries were the result of such primary failure. Additionally, if an occupant was reported as being partially ejected through a window or other opening and then crushed, the injury mechanism was assumed to be crushing external to the vehicle, that is in the "other" category. This decision process is based on the acceptance of the more likely cause of death or serious injury; impact with a window may have caused an injury, but absolute crushing would definitely have been the major cause of injury or death.

To gain further insight into injury producing circumstances, an investigation was made to determine the areas of the body most frequently injured. The types of injuries received by the particular occupant of a particular type of rail vehicle

TABLE 4-6. INJURY MECHANISM CATALOG SUMMARY

(T-Form Data for Years 1972 and 1973)

| ACCIDENT CATEGORY | NUMBER OF INCIDENTS | | | | NUMBER INJURED | | | | NUMBER KILLED | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LOCO | CAB. | P CAR | TOTAL | LOCO | CAB. | P CAR | TOTAL | LOCO | CAB. | P CAR | TOTAL |
| A. MISC, TRAIN NOT MOVING | 10 | 1 | 7 | 18 | 10 | 1 | 7 | 18 | — | — | — | — |
| B. MISC, TRAIN MOVING | 5 | 3 | 12 | 20 | 5 | 3 | 16 | 24 | — | — | — | — |
| C. TRIPPED/LOST BALANCE | 1 | 5 | 8 | 14 | 1 | 5 | 8 | 14 | — | — | — | — |
| D. HARD COUPLING | 53 | 33 | 1 | 87 | 60 | 35 | 1 | 96 | 4 | 2 | — | 6 |
| E. TRAIN MOTION | 1 | 4 | 29 | 34 | 1 | 4 | 29 | 34 | — | — | — | — |
| F. EQUIP. FAILURE | 11 | 2 | 5 | 18 | 11 | 2 | 5 | 18 | — | — | — | — |
| G. SLACK ACTION | 11 | 77 | 0 | 88 | 11 | 78 | 0 | 89 | — | — | — | — |
| H. BRAKING (INCL EMERGENCY) | 7 | 44 | 11 | 62 | 7 | 47 | 13 | 67 | — | — | — | — |
| I. SUDDEN LURCH (JERK) | 2 | 5 | 17 | 24 | 2 | 5 | 17 | 24 | — | — | — | — |
| J. GRADE CROSS. COLL. | 26 | 3 | 4 | 33 | 40 | 4 | 8 | 52 | 1 | — | — | 1 |
| K. HEAD-ON COLL. | 26 | 1 | 0 | 27 | 47 | 3 | 0 | 50 | 35 | 2 | 0 | 37 |
| L. CROSS COLLISION | 14 | 4 | 0 | 18 | 26 | 4 | 0 | 30 | 2 | 0 | 0 | 2 |
| M. REAR END COLL. | 38 | 31 | 7 | 76 | 64 | 42 | 271 | 377 | 12 | 6 | 47 | 65 |
| N. DERAILMENT | 30 | 36 | 16 | 82 | 46 | 42 | 381 | 469 | 8 | 0 | 2 | 10 |
| TOTAL | 235 | 249 | 117 | 601 | 331 | 275 | 756 | 1362 | 62 | 10 | 49 | 121 |

was compared with the seated environments of that occupant. In most cases an injury trend was evident and could be associated with a particular piece of equipment or structure peculiar to that occupants station. By this analysis the injury mechanism could be pinpointed and recommendations made for crashworthiness improvements.

# 5. ANALYSIS OF RAIL VEHICLE ACCIDENT DATA

The selection of 1967-1973 as the time frame for this study was predicated on the availability of formal reports and support data from the FRA and the complete set of NTSB railroad accident investigations.

It is considered that this sample, covering a time span of seven years, provides a reasonable distribution of the accident types encountered in service, and, additionally, is relatively contemporary, thus providing a sound basis for assessing potential environmental improvements to protect occupants in future railroad accidents.

## 5.1 ACCIDENT TYPES

The FRA Accident Bulletin data was used to determine the distribution of major accident types for the years considered in this study.

Figure 5-1 shows the percentage distributions for the various accident types and Table 5-1 a breakdown of the accident types per year. Derailments and grade crossing accidents predominate, accounting for 80 percent of all accidents, while switching accidents account for 81 percent of all collisions.

Accident types relevant to rail vehicle interior protection for occupants have been listed under four major headings:

- Head-On Collisions
- Rear-End Collisions
- Derailments
- Other Accidents

Tables 5-2, 5-3, 5-4, and 5-5 summarize the data for each of these major accident categories.

A further breakdown of injury data is given in Tables 5-6, 5-7, 5-8, and 5-9 identifying speed range, numbers of accidents for each speed range, and the fatalities and serious injuries associated with accidents involving primary structural failure, secondary impact, and their effects.

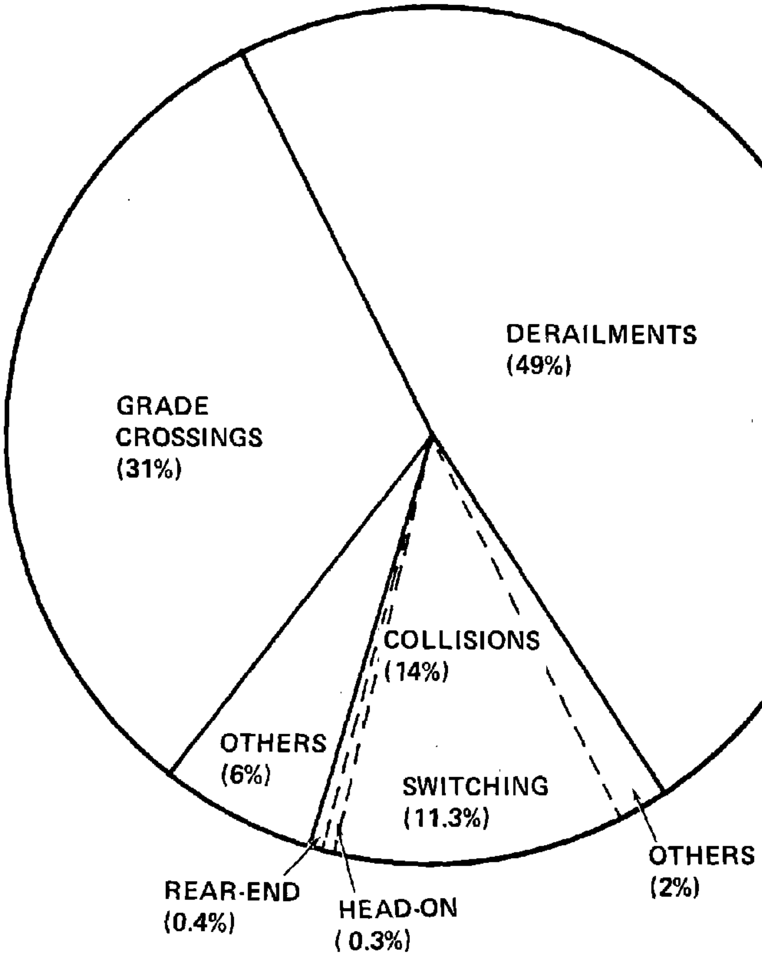


*Figure 5—1. FRA Accident Summary (1967 through 1973)*

## TABLE 5-1. FRA ACCIDENT BULLETIN DATA SUMMARY

| TYPE OF ACCIDENT | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | TOTAL | % DIST. |
|---|---|---|---|---|---|---|---|---|---|
| HEAD-ON COLLISION | 30 | 31 | 29 | 30 | 30 | 26 | 24 | 200 | 0.25 |
| REAR-END COLLISION | 24 | 36 | 57 | 48 | 34 | 42 | 59 | 300 | 0.37 |
| SWITCHING COLLISION | 1,204 | 1,427 | 1,409 | 1,426 | 1,279 | 1,090 | 1,383 | 9,218 | 11.32 |
| OTHER COLLISIONS | 264 | 233 | 315 | 252 | 186 | 190 | 191 | 1,631 | 2.00 |
| TOTAL COLLISIONS | 1,522 | 1,727 | 1,810 | 1,756 | 1,529 | 1,348 | 1,657 | 11,349 | 13.94 |
| DERAILMENT | 4,960 | 5,487 | 5,960 | 5,602 | 5,131 | 5,509 | 7,307 | 39,956 | 49.07 |
| OTHERS | 812 | 814 | 773 | 737 | 644 | 675 | 411 | 4,866 | 5.98 |
| TOTAL TRACK ACCIDENTS | 7,294 | 8,028 | 8,543 | 8,095 | 7,304 | 7,532 | 9,375 | 56,171 | 68.99 |
| GRADE CROSSING | 3,932 | 3,816 | 3,774 | 3,559 | 3,392 | 3,379 | 3,400 | 25,252 | 31.01 |
| TOTAL ACCIDENTS | 11,226 | 11,844 | 12,317 | 11,654 | 10,696 | 10,911 | 12,775 | 81,423 | 100.00 |

# TABLE 5-2. DATA SUMMARY FOR HEAD-ON COLLISIONS

| Date | Location | B-V Ref No. | NTSB Report No. | FRA Report No. | FRA Jacket No. | Closing Speed (mph) | Impacting Train | | | | | | | | | | | | Impacted Train | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Type of Train | | Speed (mph) | Consist | | | Occupant Injury Data | | | | | | Type of Train | | Speed (mph) | Consist | | | Occupant Injury Data | | | | | |
| | | | | | | | F | P | | Loco | Car | Cab. | Loco | | Car | | Caboose | | F | P | | Loco | Car | Cab. | Loco | | Car | | Caboose | |
| | | | | | | | | | | | | | FI | SI | FI | SI | FI | SI | | | | | | | FI | SI | FI | SI | FI | SI |
| 27 May 67 | New York, N.Y. | H001 | RAR 12-29-67 | - | 94199 | 68 | x | | 36 | 4 | 60 | 1 | 3 | - | - | - | - | 1 | x | | 32 | 3 | 15 | 1 | 3 | - | - | - | - | 2 |
| 5 Aug 68 | Winter Haven, Fla. | H007 | - | 4148 | 94237 | 55 | | x | 55 | 4 | 18 | - | - | 2 | 1 | 27* | - | - | | x | 0 | 3 | 17 | - | - | - | - | see* | - | - |
| 7 Jul 69 | McManus, La. | H008 | - | 4155 | 94277 | 80 | x | | 40 | 4 | 22 | 1 | 2 | 2 | - | - | - | 1 | x | | 40 | 4 | 29 | 1 | 2 | 1 | - | - | - | 2 |
| 20 Aug 69 | Darien, Conn. | H002 | RAR 70-3 | - | 94281 | 60 | | x | 30 | - | 3 | - | - | - | 2 | 1 | - | - | | x | 30 | - | 9 | - | - | - | 2 | 1 | - | - |
| 6 Jun 70 | Newport, Wash. | H009 | - | 4169 | 94303 | 16 | | x | 16 | 3 | 12 | - | - | - | - | ? | - | - | x | | 0 | 3 | 74 | 1 | - | - | - | - | - | - |
| 19 Aug 70 | Pembroke, Va. | H010 | - | 4171 | 94308 | 40 | x | | 40 | 5 | 200 | 1 | 2 | - | - | - | - | - | x | | →0 | 5 | 125 | 1 | - | - | - | - | - | - |
| 25 Aug 70 | Finney, Va. | H011 | - | 4175 | 94310 | 40 | x | | 25 | 3 | - | - | - | 1 | - | - | - | - | x | | 15 | 7 | 115 | 1 | 2 | - | - | - | - | - |
| 25 Oct 70 | Green Mtn., N.C. | H016 | - | SR-9 | 94315 | 30 | x | | 30 | 6 | 135 | 1 | - | 1 | - | - | - | - | x | | →0 | 4 | 60 | 1 | 2 | - | - | - | - | - |
| 19 Mar 71 | Palmer, Minn. | H017 | - | SR-13 | 94322 | 25 | x | | 15 | 2 | 12 | 1 | 1 | - | - | - | - | - | x | | 10 | 1 | 25 | 1 | - | - | - | - | - | - |
| 11 May 71 | Sheffels, Mont. | H012 | - | 4178 | 94328 | 78 | x | | 40 | 2 | 19 | 1 | 3 | - | - | - | - | - | x | | 38 | 4 | 63 | 1 | 1 | 2 | - | - | - | - |
| 7 Sep 71 | Pontiac, Mich. | H014 | - | 4182 | - | 45 | x | | 45 | 3 | 83 | 1 | - | - | - | - | - | - | x | | 0 | 2 | 67 | 1 | 3 | - | - | - | - | - |
| 18 Sep 71 | Belton, Mont. | H013 | - | 4180 | 94335 | 45 | x | | 40 | 4 | 63 | 1 | 1 | 1 | - | - | - | - | x | | 5 | 3 | 84 | 1 | - | 2 | - | - | - | - |
| 25 Dec 71 | Mt. Marion, N.Y. | H015 | - | 4183 | - | 30 | x | | 30 | 4 | 114 | 1 | - | 2 | - | - | - | - | x | | 0 | 12 | 116 | 1 | - | - | - | - | - | - |
| 12 Mar 72 | Herndon, Pa. | H003 | RAR 73-3 | - | 94343 | 60 | x | | 30 | 2 | 104 | 1 | 2 | - | - | - | - | - | x | | 30 | 2 | 103 | 1 | 2 | - | - | - | - | - |
| 24 May 72 | Maquon, Ill. | H004 | RAR 73-4 | - | 94349 | 80 | x | | 41 | 2 | 66 | 1 | 2 | - | - | - | - | - | x | | 39 | 3 | 36 | 1 | 2 | - | - | - | - | - |
| 21 Feb 73 | Taft, La. | H005 | RAR 73-6 | - | - | 45 | x | | 40 | 3 | 38 | 1 | 3 | 1 | - | - | - | - | x | | 5 | 1 | 36 | 1 | - | - | - | - | - | - |
| 1 Dec 73 | Cotulla, Tex. | H006 | RAR 74-3 | - | - | 40 | x | | 40 | 5 | 123 | 1 | 3 | - | - | - | - | - | x | | 0 | 1 | 11 | 1 | - | - | - | - | - | - |

**KEY:**
F = Freight
P = Passenger
FI = Fatal Injury
SI = Serious Injury

# TABLE 5-3. DATA SUMMARY FOR REAR-END COLLISONS

| Date | Location | B-V Ref No. | NTSB Report No. | FRA Report No. | FRA Jacket No. | Closing Speed (mph) | Impacting Train | | | | | | | | | | | | Impacted Train | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Type of Train | | Speed (mph) | Consist | | | Occupant Injury Data | | | | | | Type of Train | | Speed (mph) | Consist | | | Occupant Injury Data | | | | | |
| | | | | | | | | | | Loco | Car | Cab. | Loco | | Car | | Caboose | | | | | Loco | Car | Cab. | Loco | | Car | | Caboose | |
| | | | | | | | F | P | | | | | FI | SI | FI | SI | FI | SI | F | P | | | | | FI | SI | FI | SI | FI | SI |
| 1 Jan 69 | Coon Rapids, Iowa | R024 | - | SR-1 | 94249 | 41 | x | | 41 | 4 | 108 | 1 | 1 | - | - | - | - | - | x | | 0 | - | 8 | 1 | - | - | - | - | - | 1 |
| 12 May 69 | Parrish, Ala | R025 | - | SR-3 | 94269 | 15 | x | | 15 | 2 | 44 | 1 | 2 | - | - | - | - | - | x | | 0 | 3 | 42 | 1 | - | - | - | - | - | - |
| 6 Jun 69 | Marysville, Wash. | R007 | - | 4152 | 94271 | 63 | x | | 63 | 1 | 35 | 1 | - | 2 | - | - | - | - | x | | 0 | 1 | 3 | 1 | - | - | - | - | 2 | - |
| 23 Jun 69 | New York, N.Y. | R005 | - | 4150 | 94275 | Slow | | x | Slow | - | 7 | - | - | - | - | 3* | - | - | | x | 0 | - | 8 | - | - | - | - | See * | - | - |
| 13 Aug 69 | New York, N.Y. | R006 | - | 4150 | 94279 | 20 | | x | 30 | - | 10 | - | - | - | - | ? | - | - | | x | 10 | - | 10 | - | - | - | - | ? | - | - |
| 18 Aug 69 | Wellington, Ohio | R010 | - | 4158 | 94280 | 6 | x | | -6 | 2 | 48 | 1 | - | - | - | - | - | - | x | | 0 | 4 | 48 | 1 | 2 | 1 | - | - | - | - |
| 14 Sep 69 | Burtonville, Ill. | R009 | - | 4156 | 94283 | 25 | x | | 25 | 2 | 70 | 1 | 2 | 2 | - | - | - | - | x | | 0 | 3 | 109 | 1 | - | - | - | - | - | - |
| 21 Sep 69 | Colby, Ohio | R014 | - | 4165 | 94284 | 24 | x | | 24 | 2 | 118 | 1 | - | 1 | - | - | - | - | x | | 0 | 3 | 129 | 1 | - | - | - | - | 1 | - |
| 26 Sep 69 | Riverdale, Ill. | R012 | - | 4163 | 94286 | 60 | x | | 60 | 3 | 128 | 1 | 2 | - | - | - | - | - | x | | 0 | 1 | 13 | 1 | - | - | - | - | 1 | - |
| 26 Oct 69 | Leadvale Jct., Tenn. | R011 | - | 4160 | 94288 | 13 | x | | 13 | 4 | 61 | 1 | 1 | 1 | - | - | - | - | x | | 0 | 7 | 97 | 1 | - | - | - | - | - | - |
| 28 Oct 69 | Charleston, Ill. | R026 | - | SR-5 | 94289 | 31 | x | | 31 | 3 | 116 | 1 | - | 4 | - | - | - | - | x | | 0 | 1 | 12 | 1 | - | 1 | - | - | 2 | - |
| 11 Nov 69 | New Carlisle, Ind. | R008 | - | 4154 | 94291 | 50 | x | | 50 | 4 | 30 | - | 1 | - | - | - | - | - | x | | 0 | 4 | 137 | 1 | - | - | - | - | 1 | - |
| 9 Jan 70 | New York, N.Y. | R013 | - | 4164 | 94292 | Slow | | x | Slow | - | 5 | - | - | - | - | 3 | - | - | | x | 0 | - | 3 | - | - | - | - | 1 | - | - |
| 25 Mar 70 | Union, Mo. | R015 | - | 4168 | 94298 | 15 | x | | 15 | 2 | 20 | 1 | 1 | 1 | - | - | - | - | x | | 0 | 1 | 12 | 1 | - | - | - | - | - | - |
| 3 Jun 70 | Oluster, Ok. | R027 | - | SR-10 | 94302 | 35 | x | | 35 | 3 | 83 | 1 | 4 | - | - | - | - | - | x | | 0 | - | 10 | - | - | - | - | - | - | - |
| 14 Jun 70 | Masillon, Ohio | R016 | - | 4170 | 94304 | 25 | x | | 25 | 3 | 38 | 1 | 1 | 2 | - | - | - | - | x | | 0 | 2 | 16 | 1 | - | - | - | - | - | 1 |
| 21 Aug 70 | Ravenna, Ohio | R028 | | SR-11 | 94309 | 27 | x | | 27 | 3 | 62 | 1 | - | 2 | - | - | - | - | x | | 0 | | | 1 | - | - | - | - | - | - |
| 23 Sep 70 | Zwolle, La. | R017 | - | 4172 | 94313 | 27 | x | | 27 | 4 | 52 | 1 | 2 | - | - | - | - | - | x | | 0 | 2 | 15 | 1 | - | - | - | - | - | - |
| 9 Oct 70 | Langhorne, Pa. | R019 | - | 4176 | 94314 | 36 | x | | 36 | 4 | 44 | 2 | 2 | - | - | - | - | - | x | | 0 | 4 | 76 | 1 | - | - | - | - | 1 | 1 |
| 24 Oct 70 | Kings Mtn., Ky. | R018 | - | 4174 | 94317 | 35 | x | | 35 | 3 | 89 | 1 | - | 3 | - | - | - | - | x | | 0 | 3 | 110 | 1 | - | - | - | - | 1 | - |
| 30 Jan 71 | Duluth, Minn. | R020 | - | 4177 | 94320 | 44 | x | | 44 | 3 | 15 | 1 | 2 | 1 | - | - | - | - | x | | 0 | - | 26 | - | - | - | - | - | - | - |
| 3 Mar 71 | Shumla, Texas | R030 | - | SR-14 | 94321 | 15 | x | | 15 | 6 | - | - | 2 | 1 | - | - | - | - | x | | 0 | - | 24 | 1 | - | - | - | - | - | - |
| 26 Mar 71 | N. Manchester, Ind. | R029 | - | SR-12 | 94323 | 30 | x | | 30 | 2 | 46 | ? | 3 | - | - | - | - | - | x | | 0 | ? | 85 | 1 | - | - | - | - | - | - |
| 28 Mar 71 | Sheridon, Wy. | R001 | RAR 72-4 | - | 94324 | 15 | x | | 15 | 3 | 69 | 1 | 2 | - | - | - | - | - | x | | 0 | - | 69 | - | - | - | - | - | - | - |

KEY: F = Freight FI = Fatal Injury
P = Passenger SI = Serious Injury

# TABLE 5-4. DATA SUMMARY FOR DERAILMENTS

| Date | Location | B-V Ref No. | NTSB Report No. | FRA Report No. | FRA Jacket No. | Closing Speed (mph) | Impacting Train | | | | | | | | | | | | Impacted Train | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Type of Train | | Speed (mph) | Consist | | | Occupant Injury Data | | | | | | Type of Train | | Speed (mph) | Consist | | | Occupant Injury Data | | | | | |
| | | | | | | | | | | | | | Loco | | Car | | Caboose | | | | | | | | Loco | | Car | | Caboose | |
| | | | | | | | F | P | | Loco | Car | Cab. | FI | SI | FI | SI | FI | SI | F | P | | Loco | Car | Cab. | FI | SI | FI | SI | FI | SI |
| 28 Dec 66 | Everett, Mass. | D001 | RHAR 2-29-68 | 4107A | 94184 | 50 | | x | 50 | - | 1 | - | - | - | 13 | 18 | - | - | | | | | | | | | | | | |
| 1 Jan 68 | Dunreith, Ind. | D002 | RHAR 2-29-68 | - | 94225 | 42 | x | | 42 | 5 | 97 | 1 | - | - | - | - | - | - | | | | | | | | | | | | |
| 23 Sep 68 | Ashtabula, Ohio | D017 | - | 4167 | 94243 | 61 | x | | 61 | 5 | 93 | 1 | - | 2 | - | - | - | - | | | | | | | | | | | | |
| 2 Jan 69 | Rocklin, Cal. | D022 | - | SR-2 | 94250 | 87 | x | | 87 | 1 | - | - | 1 | 1 | - | - | - | - | | | | | | | | | | | | |
| 25 Jan 69 | Laurel, Miss. | D003 | RAR 10-6-69 | - | 94252 | 30 | x | | 30 | 4 | 139 | 1 | - | - | - | - | - | - | | | | | | | | | | | | |
| 18 Feb 69 | Crete, Neb. | D004 | RAR 71-2 | - | 94259 | 52 | x | | 52 | 7 | 92 | 3 | - | - | - | - | - | - | | | | | | | | | | | | |
| 18 Apr 69 | Ridgeway, Ohio | D015 | - | 4162 | 94262 | 47 | x | | 47 | 2 | 78 | 1 | 1 | - | - | - | - | - | | | | | | | | | | | | |
| 25 Apr 69 | Germantown, Ind. | D016 | - | 4159 | 94263 | 61 | x | | 61 | 3 | 110 | 1 | - | - | - | - | - | - | | | | | | | | | | | | |
| 28 Jun 69 | Glenn Dale, Md. | D005 | RAR 70-1 | - | 94276 | 85 | | x | 85 | 1 | 18 | - | - | - | 1 | 12 | - | - | | | | | | | | | | | | |
| 14 Jul 69 | Neosho Rapids, Kan. | D023 | - | SR-8 | 94278 | 40 | x | | 40 | 3 | 72 | 1 | 1 | 2 | - | - | - | - | | | | | | | | | | | | |
| 11 Sep 69 | Glendora, Miss. | D006 | RAR 70-2 | - | 94282 | 42 | x | | 42 | 5 | 97 | 1 | - | - | - | - | - | - | | | | | | | | | | | | |
| 21 Sep 69 | Colby, Ohio | D018 | - | 4165 | 94284 | 40 | x | | 40 | 3 | 145 | 1 | - | - | - | - | - | - | | | | | | | | | | | | |
| 27 Jan 70 | Franconia, Va. | D007 | RAR 71-1 | - | 94294 | 65 | | x | 65 | 3 | 10 | - | - | - | 3 | 5 | - | - | | | | | | | | | | | | |
| 21 Jun 70 | Crescent City, Ill. | D008 | RAR 72-2 | - | 94305 | 43 | x | | 43 | 4 | 109 | 1 | - | - | - | - | - | - | | | | | | | | | | | | |
| 8 Sep 70 | Riverdale, Ill. | D009 | RAR 71-3 | - | 94312 | -20 | | (See 0-014C, Cross Collision ⇨ Derailment.) | | | | | | | | | | | | | | | | | | | | | | |
| 8 Oct 70 | Sound View, Conn. | D010 | RAR 72-1 | - | B-5-71 | 60 | | x | 60 | 2 | 7 | - | - | 2 | - | 3 | - | - | | | | | | | | | | | | |
| 24 Oct 70 | Kings Mt., Ky. | D019 | - | 4174 | 94317 | 35 | x | | 35 | 3 | 72 | 1 | - | - | - | - | - | - | | | | | | | | | | | | |
| 5 Apr 71 | Collinsville, Ok. | D011 | RHR 72-1 | - | 94326 | 71 | | x | 71 | 2 | 3 | - | - | - | 2 | 4 | - | - | | | | | | | | | | | | |
| 22 Apr 71 | Truckee, Cal. | D020 | - | 4179 | C-48-71 | High | x | | High | 4 | 4 | - | 1 | 1 | - | - | - | - | | | | | | | | | | | | |
| 10 Jun 71 | Salem, Ill. | D012 | RAR 72-5 | - | - | 90 | | x | 90 | 4 | 14 | - | - | - | 11 | 26 | - | - | | | | | | | | | | | | |
| 7 Jul 71 | New York, N.Y. | D024 | - | SR-16 | 94330 | 10 | | x | 10 | 2 | 8 | - | - | - | 1 | 17 | - | - | | | | | | | | | | | | |
| 19 Oct 71 | Houston, Texas | D013 | RAR 72-6 | - | - | 40 | x | | 40 | 4 | 82 | 1 | - | - | - | - | - | - | | | | | | | | | | | | |
| 23 Dec 71 | Cross Bayou, Fla. | D025 | - | SR-21 | - | 55 | | x | 55 | 3 | 15 | - | - | 2 | - | 20 | - | - | | | | | | | | | | | | |
| 28 Jan 72 | Cut Bank, Mont. | D026 | - | SR-22 | - | 73 | | x | 73 | 5 | 9 | - | - | - | - | 3 | - | - | | | | | | | | | | | | |

**KEY:** F = Freight FI = Fatal Injury
P = Passenger SI = Serious Injury

# TABLE 5-5. DATA SUMMARY FOR OTHER ACCIDENTS

| Date | Location | B-V Ref | NTSB Report | FRA Report | FRA Jacket No. | Speed (mph) | Impacting Train | | | | | | | | | | | | | | Impacted Train | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Type of Train | | Speed (mph) | Consist | | | Occupant Injury Data | | | | | | Type of Train | | Speed (mph) | Consist | | | Occupant Injury Data | | | | | |
| | | | | | | | | | | | | | Loco | | Car | | Caboose | | | | | | | | Loco | | Car | | Caboose | |
| | | | | | | | F | P | | Loco | Car | Cab. | F | SI | F | SI | F | SI | F | P | | Loco | Car | Cab | F | SI | F | SI | F | SI |
| 2 Oct 67 | Waterloo, Neb. | 0-001G | HRAR 9-18-68 | - | 94215 | 56 | x | | 56 | 1 | 96 | 1 | - | - | - | - | - | - | | | | | | | | | | | | |
| 3 Mar 69 | Ama, La. | 0-006G | - | 4161 | 94260 | 45 | x | | 45 | 1 | 5 | 1 | 2 | - | - | - | - | - | | | | | | | | | | | | |
| 29 Jun 69 | Tobar, Nev. | 0-004E | - | 4153 | 94276 | 55 | x | | 55 | 4 | 70 | 1 | - | - | - | - | - | 1 | | | | | | | | | | | | |
| 12 Oct 69 | Conneautville, Pa. | 0-003G | - | 4151 | 94287 | 45 | x | | 45 | 3 | 80 | 1 | - | - | - | - | - | - | | | | | | | | | | | | |
| 3 Nov 69 | Walkerford, Va. | 0-005S | - | 4157 | 94290 | 60 | x | | 47 | 3 | 83 | 1 | 1 | 1 | - | - | - | - | x | | 35 | 3 | 187 | 1 | - | 2 | - | - | - | - |
| 24 Jan 70 | Loda, Ill. | 0-002G | RHR 71-1 | - | 94293 | 79 | | x | 79 | 3 | 15 | - | 3 | - | - | - | - | - | | | | | | | | | | | | |
| 17 Feb 70 | Fullerton, Cal. | 0-008S | - | 4173 | 94297 | 40 | x | | 40 | 3 | 38 | 1 | - | - | - | - | - | - | x | | 0 | 1 | 2 | 1 | - | - | - | - | 1 | - |
| 28 Mar 70 | Floka, Nev. | 0-007S | - | 4166 | 94299 | 55 | x | | 55 | 3 | 53 | 1 | 2 | 1 | - | - | - | - | x | | 6 | 3 | 103 | 1 | - | - | - | - | - | - |
| 6 May 70 | Otis Orchards, Wash. | 0-009S | - | SR-4 | 94300 | 55 | x | | 55 | 3 | 55 | 1 | - | - | - | - | - | - | | | | | | | | | | | | |
| 6 Jul 70 | Scotland, Ill. | 0-010G | - | SR-7 | 94307 | 33 | x | | 33 | 3 | 89 | 1 | 1 | 2 | - | - | - | - | | | | | | | | | | | | |
| 31 Oct 71 | East Gary, Ind. | 0-011G | - | SR-20 | - | 35 | x | | 35 | 2 | 74 | 1 | - | - | - | - | - | - | | | | | | | | | | | | |
| 20 Sep 72 | Arlington, Ill. | 0-012G | - | SR-27 | - | 85 | | x | 85 | 1 | 4 | - | 1 | 1 | 1 | - | - | - | | | | | | | | | | | | |
| 13 Mar 73 | Hortense, Ga. | 0-013G | - | SR-32 | - | 77 | | x | 77 | 2 | 30 | - | - | - | - | - | - | - | | | | | | | | | | | | |
| 8 Sep 70 | Riverdale, Ill. | 0-014C | RAR 71-3 | - | 94312 | 20 | x | | -20 | 1 | 22 | 1 | - | - | - | - | 1 | 1 | x | | →0 | 1 | 36 | 1 | 1 | 1 | - | - | - | - |

## TABLE 5-6. OCCUPANT INJURY DATA FOR SELECTED HEAD-ON COLLISION ACCIDENT SAMPLE

(98 accidents in sample; 17 accidents of this type; NTSB and FRA data, 1967-1973)

| Speed Range (mph) | Number of Accidents | Involving Primary Structure Failure | | | | | | Involving Secondary Impact Effects | | | | | | Others | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal | | | Serious Injury | | | Fatal | | | Serious Injury | | | Fatal | | | Serious Injury | | |
| | | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. |
| 0-10 | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 10-20 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 20-30 | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 30-40 | 2 | - | - | - | 2 | - | - | 2 | - | - | 1 | - | - | - | - | - | - | - | - |
| 40-50 | 6 | 14 | - | - | 5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 50-60 | 1 | - | - | - | 2 | - | - | - | 1 | - | - | 27 | - | - | - | - | - | - | - |
| 60 + | 6 | 19 | 4 | - | 5 | 2 | - | 3[A] | - | - | - | - | 6 | - | - | - | - | - | - |

COMMENT

A. Based on limited information

## TABLE 5-7. OCCUPANT INJURY DATA FOR SELECTED REAR-END COLLISION ACCIDENT SAMPLE

(98 accidents in sample; 39 accidents of this type; NTSB and FRA data, 1967-1973)

| Speed Range (mph) | Number of Accidents | Involving Primary Structure Failure |  |  |  |  |  | Involving Secondary Impact Effects |  |  |  |  |  | Others |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Fatal |  |  | Serious Injury |  |  | Fatal |  |  | Serious Injury |  |  | Fatal |  |  | Serious Injury |  |  |
|  |  | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. |
| 0-10 | 6 | 2 | - | - | 1 | - | - | - | - | $1^A$ | - | 9 | $2^A$ | - | - | - | - | - | - |
| 10-20 | 11 | 8 | - | 1 | 4 | - | 3 | 2 | $1^B$ | - | - | $6^B$ | - | - | - | - | - | - | - |
| 20-30 | 8 | 3 | - | 1 | 4 | - | 2 | 2 | - | 3 | 2 | - | - | - | - | - | $2^C$ | - | - |
| 30-40 | 6 | 9 | 1 | 2 | 3 | - | 1 | - | - | - | 5 | - | - | - | - | $2^D$ | - | - | - |
| 40-50 | 2 | 3 | - | - | 1 | - | 1 | - | - | - | - | - | - | $1^E$ | - | - | - | - | - |
| 50-60 | 1 | 1 | - | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 60+ | 5 | 5 | 45 | 3 | 3 | 28 | - | - | - | - | - | - | - | $1^F$ | - | - | - | - | - |

COMMENTS

A. Train moving, caboose leading.
B. Occupants of a highway railcar.
C. Jumped prior to impact.
D. Post-crash fire victims (trapped).
E. Heart-attack victim; distraction led to crash and death of other locomotive occupant.
F. Jumped prior to impact.

## TABLE 5-8. OCCUPANT INJURY DATA FOR SELECTED DERAILMENT SAMPLE

(98 accidents in sample; 28 accidents of this type;
NTSB and FRA data, 1967-1973)

| Speed Range (mph) | Number of Accidents | Involving Primary Structure Failure | | | | | | Involving Secondary Impact Effects | | | | | | Others | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal | | | Serious Injury | | | Fatal | | | Serious Injury | | | Fatal | | | Serious Injury | | |
| | | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. |
| 0-10 | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 10-20 | 1 | - | 1 | - | - | $17^A$ | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 20-30 | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 30-40 | 2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 40-50 | 8 | - | - | - | - | - | - | - | - | - | - | - | - | $3^B$ | - | - | 2 | - | - |
| 50-60 | 4 | - | - | - | - | - | - | - | - | - | 2 | 20 | - | - | $13^C$ | - | - | $18^C$ | - |
| 60+ | 13 | - | - | - | - | - | - | 2 | 6 | - | 5 | 48 | - | - | $11^D$ | - | 2 | $12^D$ | - |

COMMENTS

A. Hit concrete abutment which entered occupied area.
B. Occupant hit by open door of freight car; another hit by driver on adjacent track; another crushed under locomotive.
C. Post derailment fire and smoke after hitting tank truck at grade crossing.
D. Ejection or partial ejection through windows; crushed under vehicle (21 total).

TABLE 5-9. OCCUPANT INJURY DATA FOR SELECTED ACCIDENT SAMPLE FOR OTHER ACCIDENTS

(98 accidents in sample; 14 accidents of this type;
NTSB and FRA data, 1967-1973)

| Speed Range (mph) | Number of Accidents | Involving Primary Structure Failure | | | | | | Involving Secondary Impact Effects | | | | | | Others | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal | | | Serious Injury | | | Fatal | | | Serious Injury | | | Fatal | | | Serious Injury | | |
| | | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. | Loco | Car | Cab. |
| 0-10 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 10-20 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 20-30 | 1 | $1^A$ | - | $1^A$ | $1^A$ | - | $1^A$ | - | - | - | - | - | - | - | - | - | - | - | - |
| 30-40 | 2 | - | - | - | - | - | - | $1^B$ | - | - | $2^B$ | - | - | - | - | - | - | - | - |
| 40-50 | 3 | - | - | - | - | - | - | - | - | - | - | - | - | $2^C$ | - | $1^D$ | - | - | - |
| 50-60 | 4 | - | - | - | - | - | - | - | - | - | - | - | $1^E$ | $2^{F,G}$ | - | - | $1^F$ | - | - |
| 60+ | 4 | 1 | - | - | 3 | - | - | - | - | - | - | - | - | $4^H$ | - | - | $1^H$ | - | - |

COMMENTS

A. Crossing collision, caboose leading.
B. Grade crossing collision, locomotive overturned.
C. Grade crossing fire.
D. Occupant thrown out and crushed underneath.
E. Occupant thrown around inside by post-crash explosion.
F. Occupant burned.
G. Occupant thrown out and crushed underneath locomotive.
H. Grade crossing collision with tank truck; two accidents; burns from fire.

## 5.2 RANKING THE ACCIDENT CAUSAL FACTORS

For all types of railroad accidents in the data sample, the causal factor data were divided into three categories:

- Primary: Casualties resulting from the collapse of primary structure and reduction of occupied volume to an untenable level

- Secondary: Casualties resulting from occupants impacting with the interior of vehicles or being impacted by flying objects inside the vehicles

- Other Casualties resulting from occurrences outside the railcar, such as crushing after an occupant was ejected or jumped, or within the railcar in a post-crash environment which resulted in fire, toxic fumes, or other injurious conditions which preclude safe post-crash egress

Figures 5-2, 5-3, and 5-4 give distributions of such casualty causal factors for the three vehicle types: locomotives, passenger railcars, and cabooses, respectively.

This investigation is concerned with injuries sustained due to secondary impact only. This area accounts for 19 percent, 44 percent, and 41 percent of all casualties respectively for locomotives, railcars, and cabooses involved in all accident types. When fatalities are considered, secondary impact effects account for only 8 percent, 3 percent, and 12 percent respectively for locomotives, passenger railcars, and cabooses. These ratios will increase however, when improvements are made to locomotive and passenger railcar structures to prevent overclimb crushing and telescoping. This effort is being performed under a separate contract. Such improvement to prevent locomotive structural crushing is shown in Figure 5-5. A deflector is used which consists of structural steel members attached to the locomotive underframe at the front and angled upward and over the occupants in the cab. If anticlimbers or collision posts fail to stop the impacted rail vehicle, the inclined members would deflect the overclimbing vehicle upward and over the cab occupants.

Rail vehicle improvements for the "Other" category of accident causal factors such as egress, fire, toxic fumes, etc. are not within the scope of this investigation.

## 5.3 INJURY MECHANISM

Injury mechanisms are those objects which directly cause injury to a rail vehicle occupant. The object can be fixed

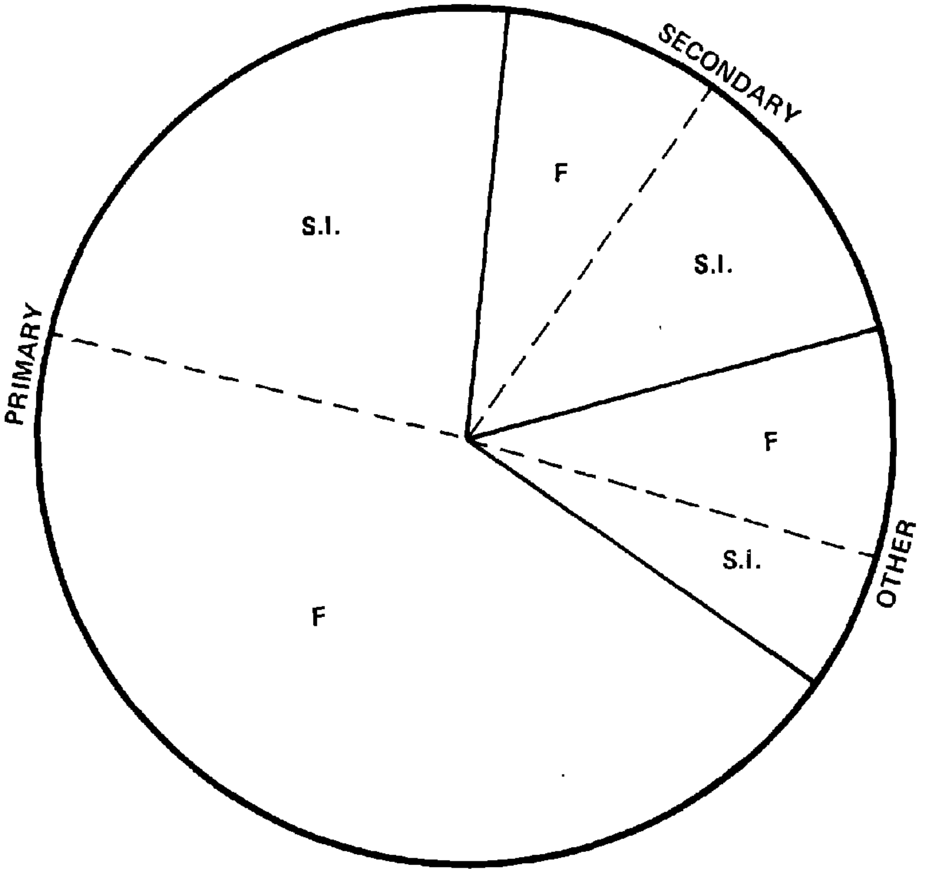


Figure 5–2. Distribution of Injury Causal Factors for Locomotives

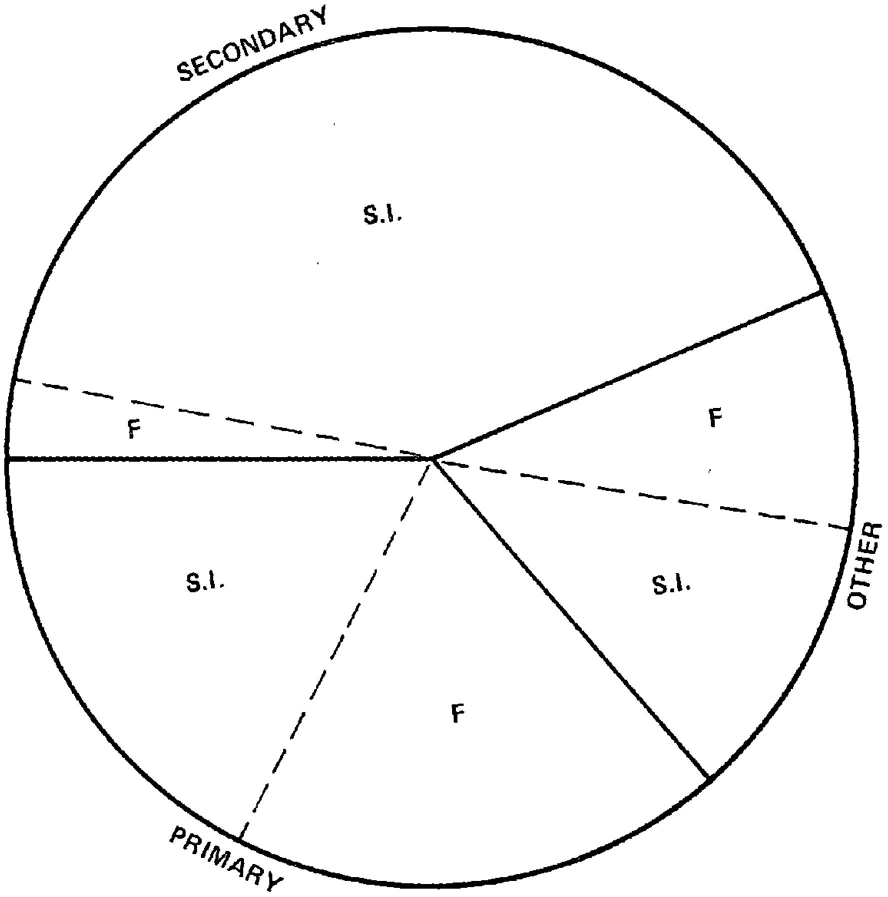


Figure 5–3. Distribution of Injury Causal Factors for Passenger Railcars

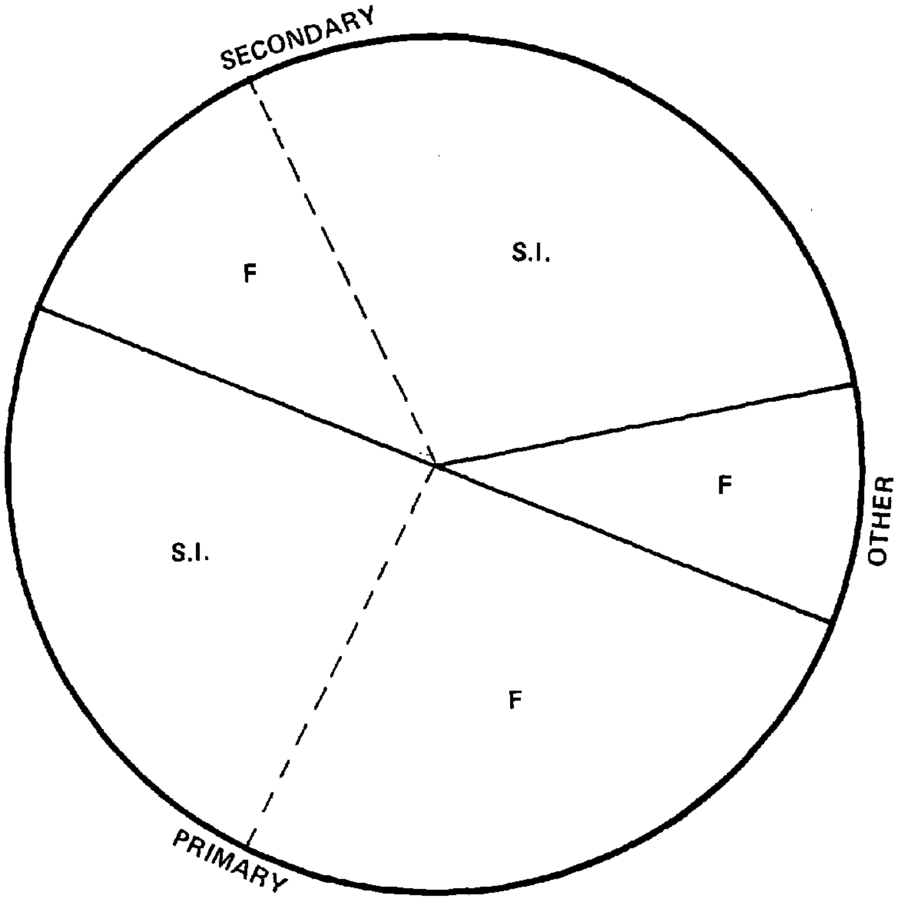


*Figure 5–4. Distribution of Injury Causal Factors for Cabooses*

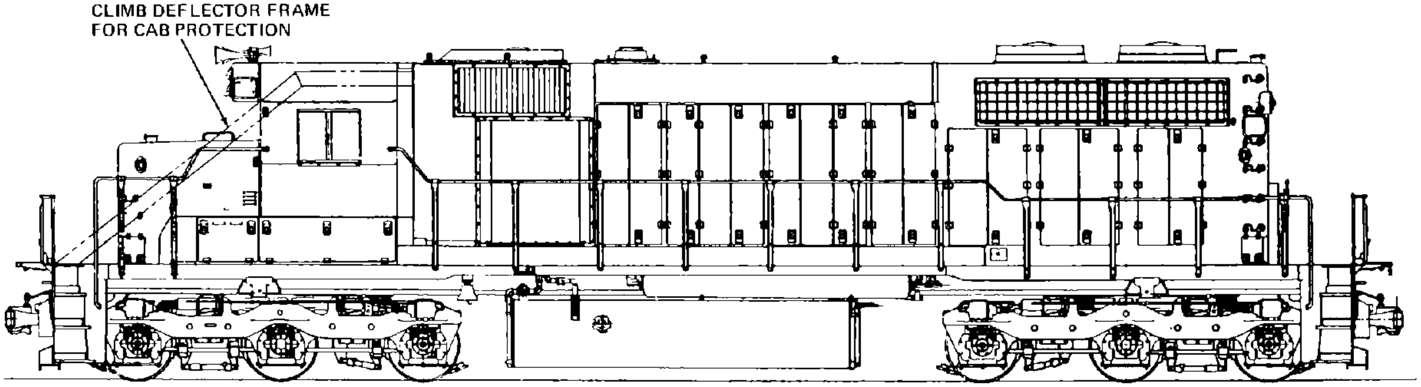


*Figure 5–5. Car Climbing Deflector for Locomotive Cab*

and the occupant thrown against it or it can be loose or torn loose and thrown against the occupant. Other injury mechanisms not involving collisions or motion can be objects which cause injury by improper use, malfunction or failure of the item or clumsiness on the part of the occupant.

### 5.3.1 Assumptions

Of the 1400 injury and fatality cases investigated in the FRA "T" forms, 352 reported the injury mechanism or situation. No rail vehicle mechanism was involved in 52 cases where shock, burned by fire or jumped out was reported. The remaining 966 cases, reported no mechanism and of these 116 were fatal injuries. It was assumed that most of the fatalities and 50 percent of the injuries were due to primary collision involving rail vehicle structural crushing. The number of injuries remaining not due to primary collision crushing is 430. This number is nearly equal to the number for which injury mechanisms were reported therefore, it is assumed that the injury mechanisms reported are increasec by a factor of 2.

To further substantiate the injury mechanism assumptions an investigation was made to determine the areas of the body most frequently injured. The data was obtained for occupants of locomotives, passenger railcars, and cabooses involved in head-on, rear-end, derailment, and other accidents. Cumulative frequency of injury occurrence was plotted for each of the above conditions (Figures 5-6, 5-7, and 5-8).

Studying typical interior arrangements in the vicinity of an injured occupant and using the injury data in the above figures probable injury mechanism assumptions can be made.

#### 5.3.1.1 Locomotive Occupant Injury Mechanism Assumptions

Locomotive occupant injuries can be due to accelerations caused by collision or abrubt changes in velocity due to hard coupling, slack action, etc. The majority of injuries occurring in locomotivescollisions are back injuries (Figure 5-6). Of all the back injuries documented in the data sample, enginemen received twice as many as fireman/helpers. The reverse was true for head injuries: fireman/helpers received twice as many head injuries as enginemen. It can be postulated why this ratio occurs. In a typical locomotive during forward accelerations, the engineman probably strikes the control console with his shoulder or side, which spins him around, twisting his back. Impact with the heater and front bulkhead would occur in this position, accounting for a higher number of back injuries than head injuries.

The fireman/helper does not have a console or equipment

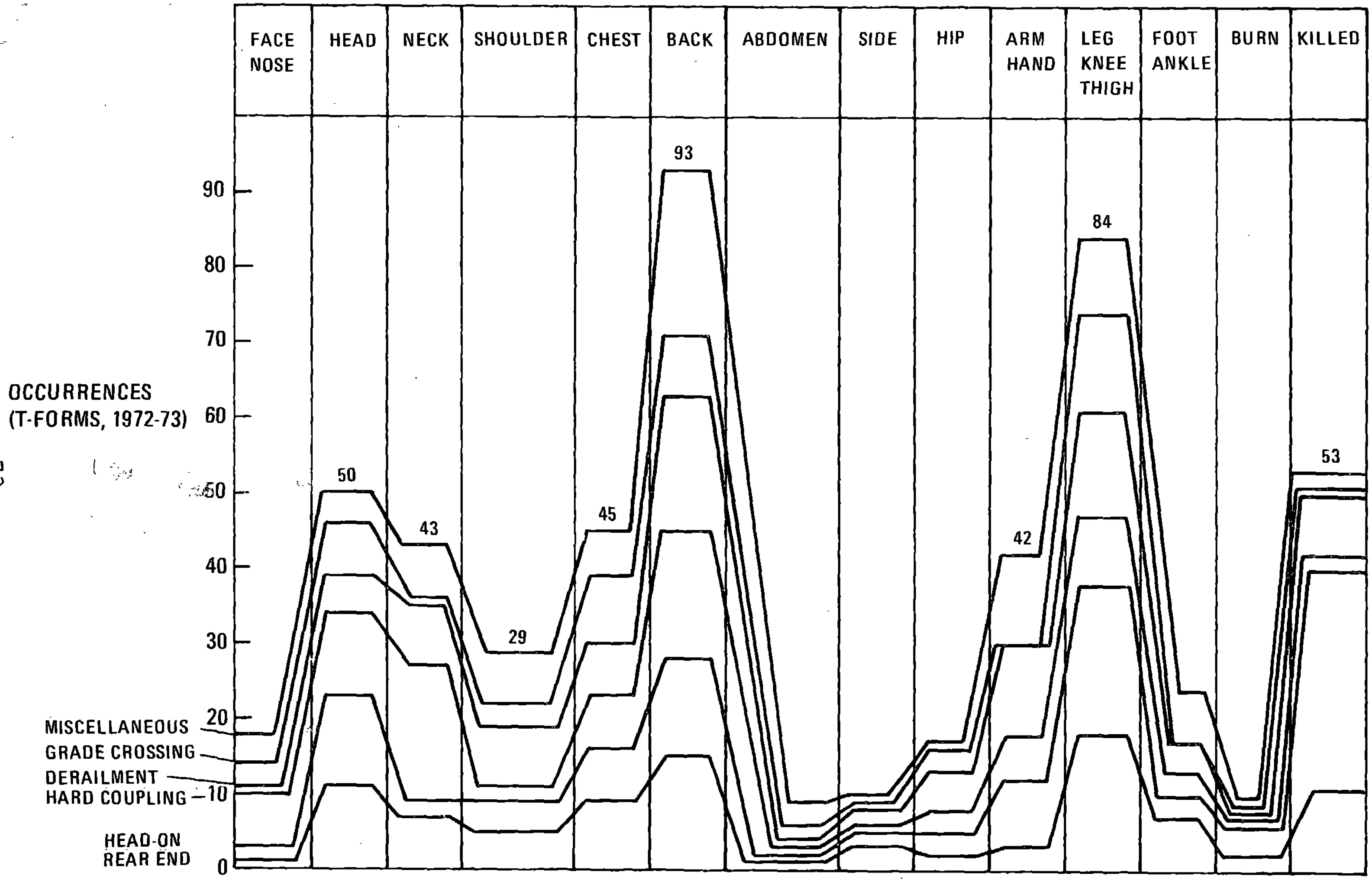


Figure 5–6. Cumulative Injuries in Locomotives

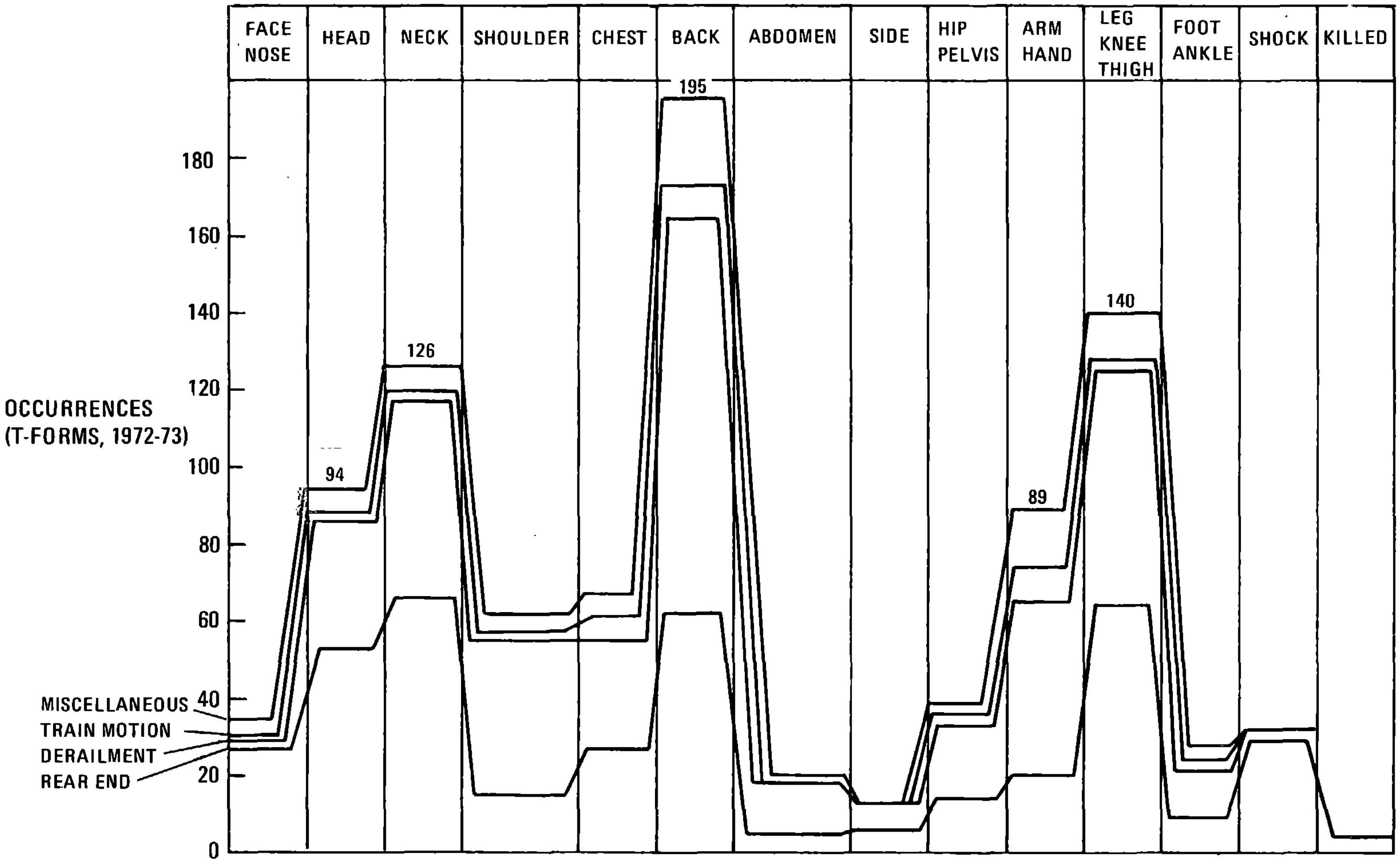


*Figure 5–7. Cumulative Injuries in Passenger Cars*

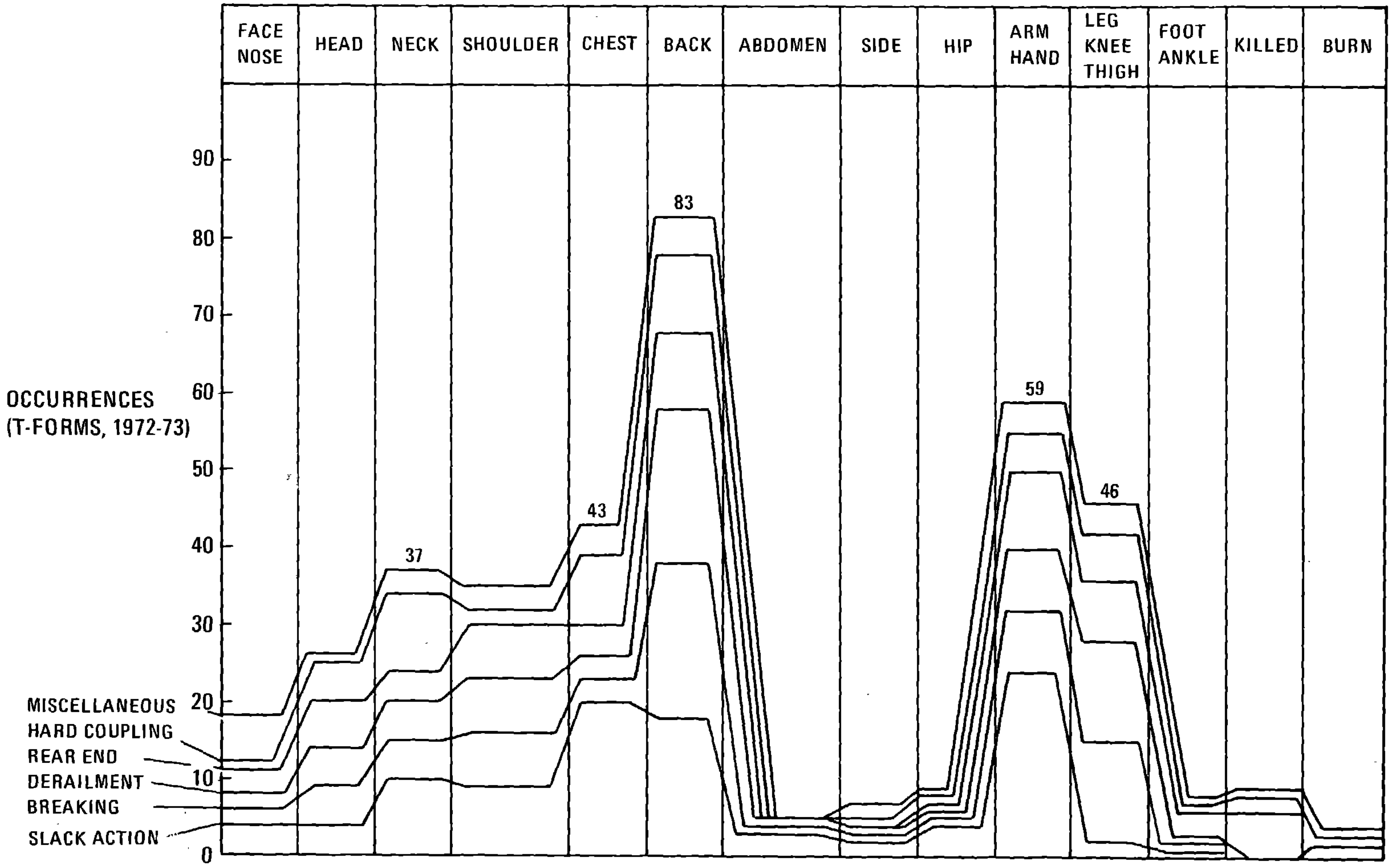


Figure 5–8. Cumulative Injuries in Cabooses

in front of him to alter his impact course. Forward accelerations would propel his head forward into the front bulkhead door. Seats located close to the rear bulkhead can result in head injuries in rearward accelerations.

Knee and leg injuries frequently accompany helpers' head injuries as a result of being thrown from the seat into the front door. Knee and leg injuries are the second most frequently occurring injury to the helpers (as well as enginemen) and occur about equally to the two types of locomotive crewmen.

Neck injuries occur about half as frequently as back injuries and nearly always occur during rearward accelerations. Frequently neck injuries (whiplash) accompany back injuries. Neck injuries in rearward accelerations are probably due to the low seat backs and lack of headrests.

Arm and hand injuries occur on an average frequency during forward or rearward accelerations. Enginemen receive more arm and hand injuries than firemen and brakemen. Control levers on the console are the probable cause of the greater number of enginemen hand injuries.

The least injuries were received in the area of the face, nose, abdomen, side, hips, foot and ankle. Enginemen received all but one of the face injuries. The proximity of the control console to the engineman is the probable cause of his face injuries. Only 10 cases of burns were reported in locomotives, six occurring in head-on and rear-end collisions and were probably due to ruptured fuel tank fires.

### 5.3.1.2 Passenger Railcar Occupant Injury Mechanism Assumptions

No data was available in the T-forms reviewed for the cause of injury to passengers as a result of collisions. The nature of the injuries and the limited objects that could be impacted by the passengers led to the compilation of the following list of probable mechanisms:

1. Head impact to seats
2. Face impact to seats
3. Knee-thigh-hip complex impacts to seats
4. Flexion or extension neck injuries due to lack of head support
5. Standees striking seats or bulkheads
6. Flailing limbs impacting parts of the seats, or car side

7. Back injuries from flexion or extension about seat back or armrests and/or caudal cephalad loading from falls

8. Thorax impact to seats

9. Crushing when several people pile into a bulkhead or each other

10. Bending fracture and/or sprains to lower limbs from entrapment of lower leg between the floor and the bottom of the seat in front of the occupant

11. Occupant-to-occupant impact when passenger seats face each other

With the intercity railcar designed primarily for seated occupants, the most likely source of injury during a front or rear collision is impact to the seat or other occupants in the seat. The predominant injury occurring to passengers is back injury most of which occur during derailments. Half as many back injuries occur during rear-end collisions. During derailments seats become unlocked allowing them to swivel. Occupants are not restrained by the seat in front of them and it is assumed they are pitched into the aisle twisting their backs. Lateral accelerations during derailment would cause an occupant to be thrown over the armrest, twisting their back and causing injury.

Back injuries can result to a standing passenger from flexion and extension over a seat or from caudal cephalad loading from falls. Falls can produce injury without any collision involvement other than causing the occupant to loose his balance. Falls on entering and leaving the car can also result in back injuries.

Leg, knee, thigh complex injuries are the second most frequently occurring injury to passengers. Derailments and collisions cause an equal amount of the injuries (Figure 5-7). It is assumed that the forward acceleration associated with a derailment thrusts the legs under the seat in front of a seated passenger or forces their knees into the seat back or bulkhead. In the seat situation, the leg becomes wedged in the space under the seat and the tibia and fibula are subjected to a bending load with the bottom rear corner of the seat acting as a fulcrum about which the lower leg bends. The high frequency of leg injuries in rear-end collisions of occupants in the impacting car is probably due to leg entrapment under the seat in front of them or knee impact with a partition.

Neck or whiplash injuries are the third highest injury, most of which occur in rear-end collisions (Figure 5-7). Low seat backs, not providing adequate head restraint, is the probable cause of the whiplash injuries. A high percentage of neck injuries occur in derailments where lateral and forward accelerations are involved. Impact of the head on the seat back or bulkhead in front of the passenger can cause the neck to be over extended producing neck injuries. Lateral whiplash can occur if the shoulder strikes the side of the car or the adjacent passenger, stopping the upper torso but allowing the head to rotate sideways over extending the neck. Occupants facing rearward in a face-to-face seating arrangement are subject to whiplash during derailment if seat back height is inadequate to support the head.

Head, arm and hand injuries occur at a medium frequency during rear-end collisions and derailments. These extremities can strike the seat or bulkhead in front, the window or car side beside them or the luggage rack above them. Injuries to other areas of the body such as face, shoulder, chest, abdomen, side, hip, pelvis, foot and ankle occurred at a much lesser frequency than the above injuries.

#### 5.3.1.3 Caboose Occupant Injury Mechanism Assumptions

Of the 272 cases reviewed of injuries to occupants in cabooses reported on FRA T-forms for a two-year period, 97 percent of 264 were caused by sudden acceleration or deceleration of the caboose. Injury mechanism data was available on 169 of these cases. In investigating each case it was determined that prior to injury the occupant was seated in 58 incidents, was standing or climbing in 49 incidents, and the remaining 62 were not documented. Using the more abundant injury mechanism data available for caboose occupant injuries and the areas of the body injury data (Figure 5-8) assumptions can be made on the injury mechanisms not documented. Areas of the body receiving the most injuries in caboose accidents are the back and limbs. It is understandable why these injuries occur. Seated caboose occupants face either a bulkhead with a window or a desk/table. Standing caboose occupants if thrown by forward or rearward accelerations can impact the end bulkheads or entrance doors. Standing or seated occupants can also be thrown to the floor. Impact with these surfaces would tend to cause back and limb injuries. If thrown against a bulkhead the tendency is to brace one's self with an arm resulting in arm injury and a tendency to rotate the body twisting the back. Seated occupants thrown into a bulkhead would contact with the knees first causing lower limb injury, then would contact with the upper limb causing a body twist resulting in upper limb and back injury. A fall to the floor in a seated position can result in spine or back injury. These injury mechanisms accounted for more than half of the total mechanisms documented and it is assumed that an equal percentage of those not documented were a result of similar mechanisms. The remaining mechanisms documented of being thrown into railing and stauntions, seats, stove, cabinets and other miscellaneous equipment and furnishings would likewise be similar mechanisms for those not documented.

### 5.3.2 Fault Tree

The fault tree shown in Figures 5-9 through 5-12 was developed to show the interrelations of the various causes resulting in occupant death or injury. The fault tree was developed in a very generalized form so that it could be used to represent any of the basic vehicles, locomotive, railcar, caboose, either individually or collectively. Figure 5-9 shows the "top tree" which identifies the 16 basic injury mechanisms (shock, burn, etc.)

Ten of these injury mechanisms have similar injury cause factors. These factors are; fall, occupant is thrown, loose object, and crush. These factors are represented by the matrix tree branches M1A, M2A and M3A shown in Figure 5-9. Figures 5-10 through 5-12 show the fault tree development of the remaining six injury mechanisms.

The fault tree (Figure 5-9) was developed basically to conform to injury categories established in the FRA T-Form. Each of these injury categories was developed in the fault tree to the level appropriate to the T-Form data. Generalized matrices were developed for the general injury mechanism caused by falls, persons thrown against structure, or by loose objects impacting occupants, M1*, M2*, and M3*. The general matrices were then filled by the data discussed previously. It would have required eleven times as many presentations to display each of the injury categories individually. This would have been too extensive to comprehend as a summary. As deemed necessary, any category can individually be presented in the form used for the general cases. Matrix M4K was developed to represent injuries to occupants which were caused by spilled hot liquids. Few instances of burns by this cause were indicated. However, since liquids hot enough to cause injury are used on trains, it is likely that in serious accidents, where reporting is poor, some of the occupants came into contact with hot liquids.

### 5.3.3 Catalog of Mechanisms

Data from the Injury Mechanism Catalog was classified to correlate to the events identified on the fault tree. This process was accomplished by encoding each injury to the event identified on the fault tree. The encoded data was then inputted onto computer data cards along with the extent of injury and the number of days disabled for each injury. Each injury

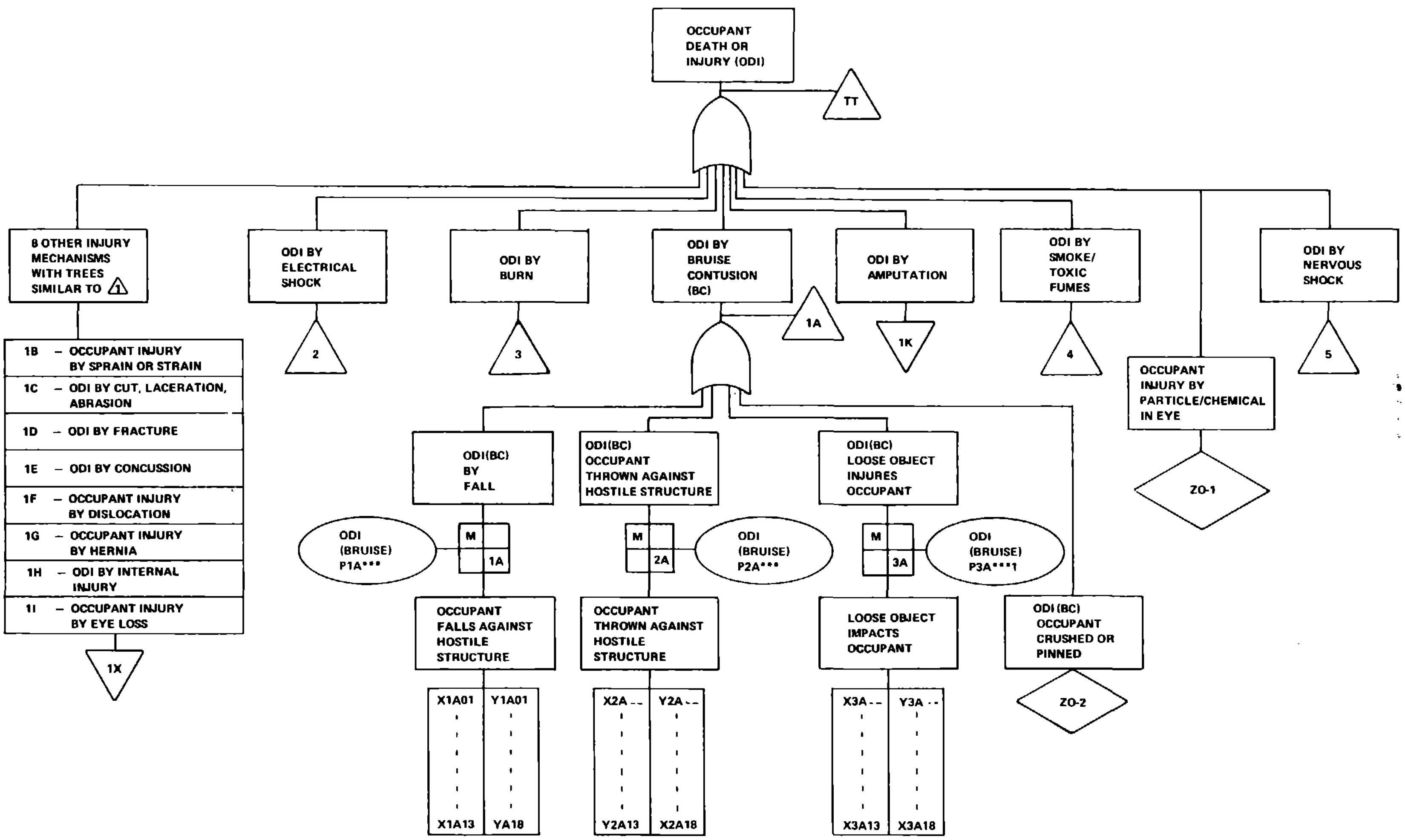


Figure 5-9. Tree Top

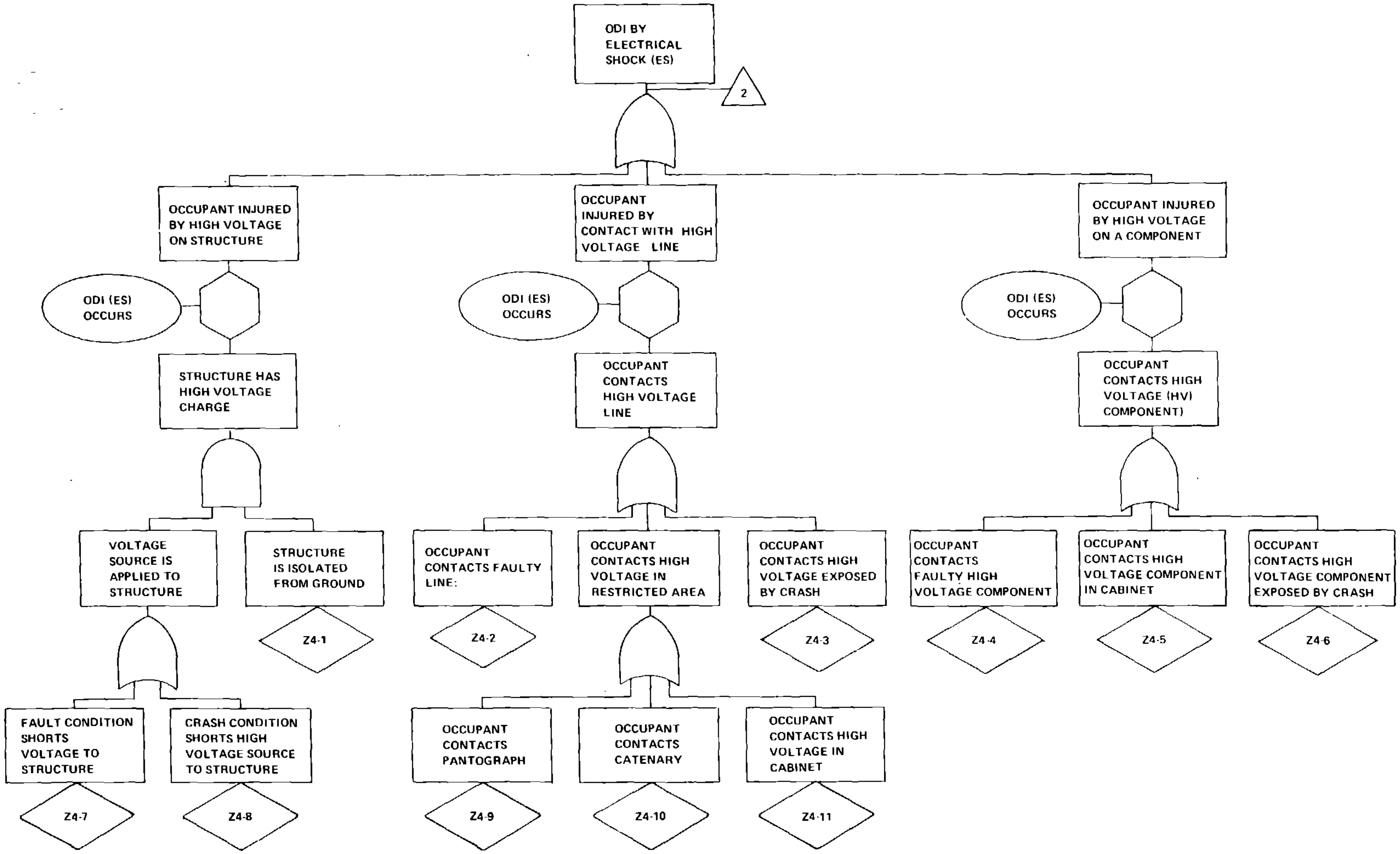


Figure 5-10. Fault Tree for Electrical Shock

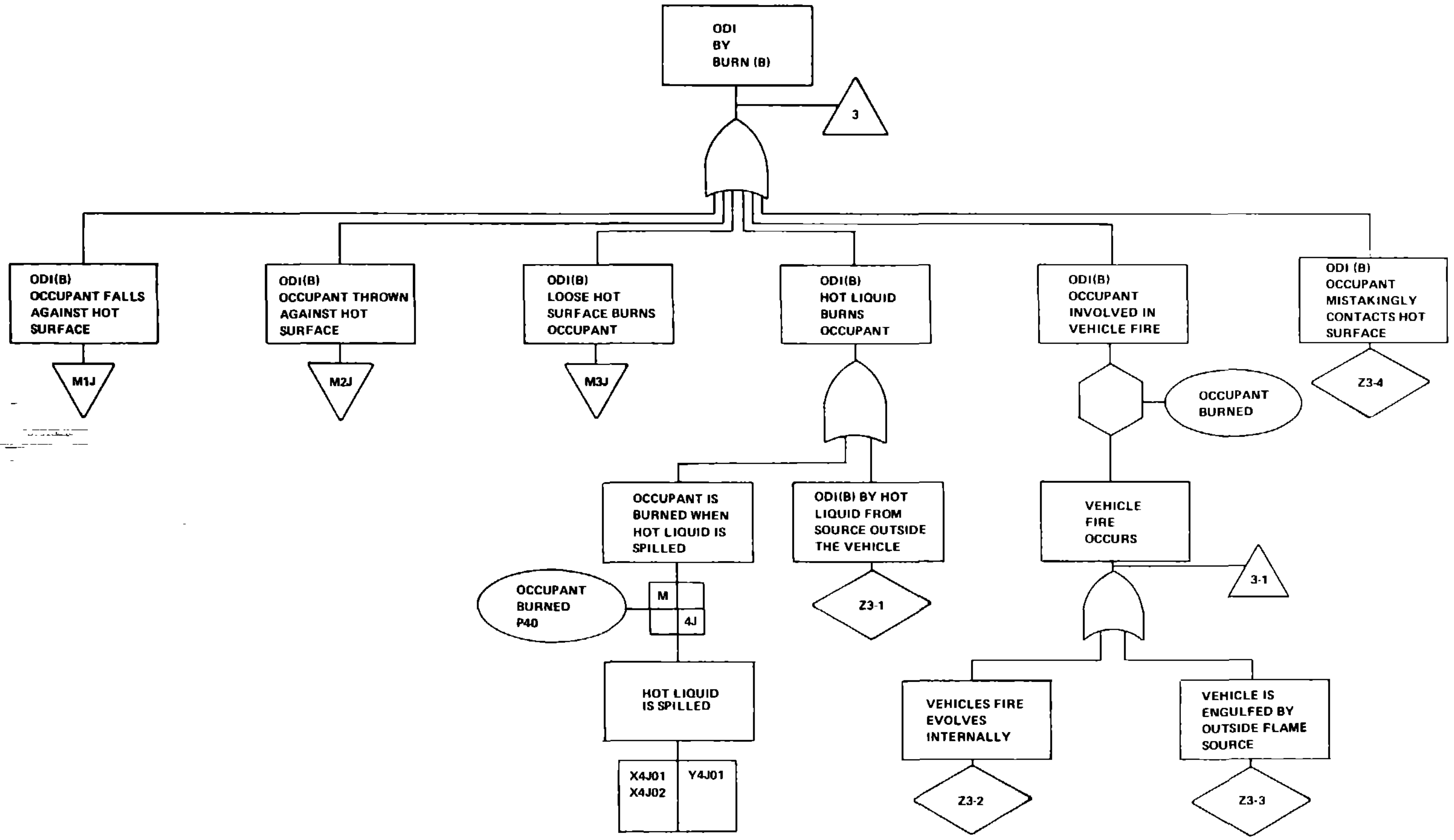


*Figure 5–11. Fault Tree for Burn Injury*

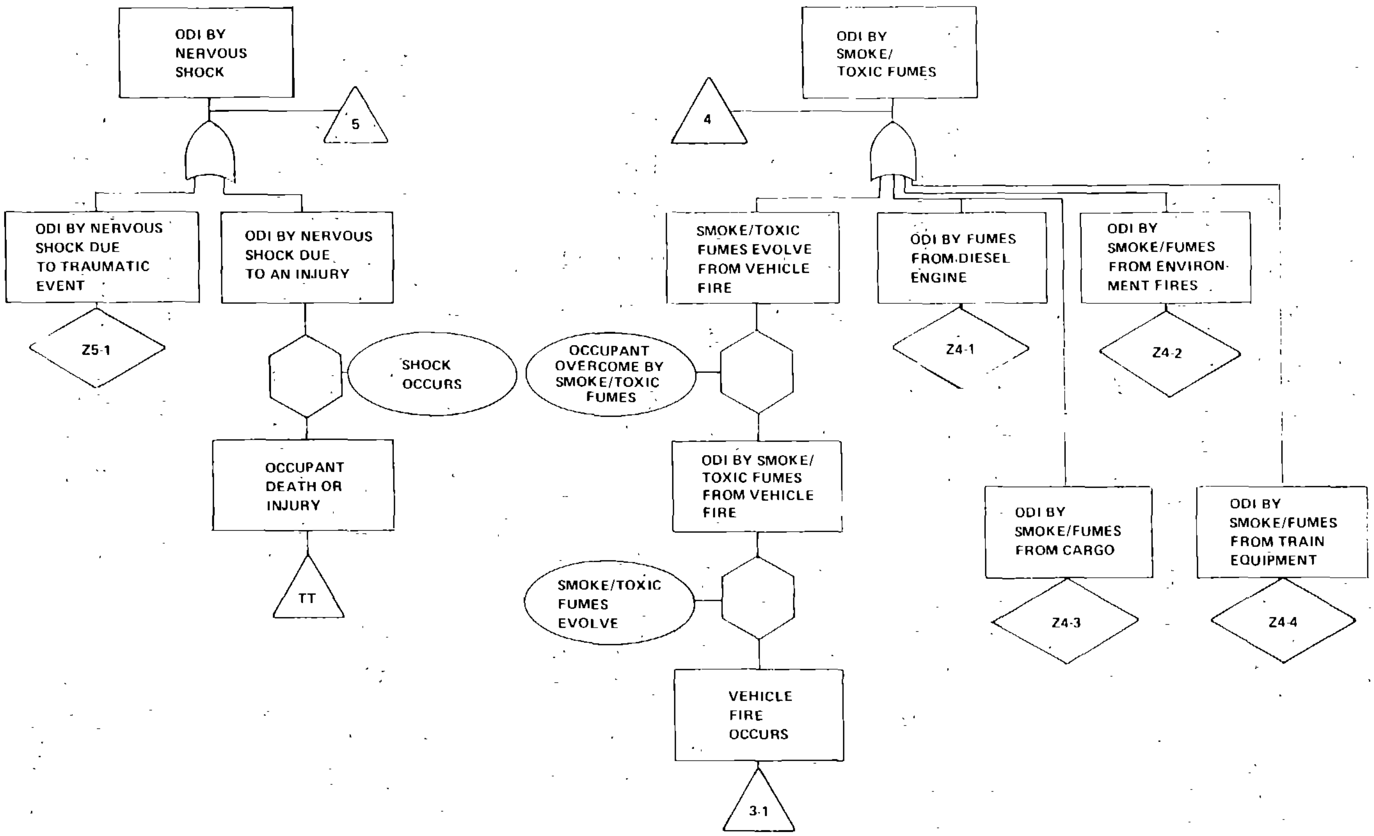


Figure 5–12. *Fault Tree for Injury by Shock, Smoke and Toxic Fumes*

event was also cataloged by type of vehicle. A sorting program was then used to group the data into the following groups:

a. Combined Locomotive, Passenger Car and Caboose for all Incidents of the Type M1*, M2*, and M3*.

b. Occupant Death or Injury (ODI) by Fall, Combined for Locomotive, Passenger Car and Caboose. Type M1*.

c. ODI by Fall, Locomotive, Type M1*.

d. ODI by Fall, Passenger Car, Type M1*.

e. ODI by Fall, Caboose, Type M1*.

f. ODI, Occupant Thrown Against Hostile Structure; combined for Locomotive, Passenger Car, Caboose, Type M2*.

g. ODI, Occupant Thrown, Locomotive, Type M2*.

h. ODI, Occupant Thrown, Passenger Car, Type M2*.

i. ODI, Occupant Thrown, Caboose, Type M2*.

j. ODI, Loose Object Injures Occupant, Combined for Locomotive, Passenger Car and Caboose, Type M3*.

k. ODI, Loose Object, Locomotive, Type M3*.

l. ODI, Loose Object, Passenger Car, Type M3*.

m. ODI, Loose Object, Caboose, Type M3*.

Each of these groups processed by the IBM 360 Computer through the use of a three-dimensional matrix program which compiled the number of injuries and deaths and computed the average number of days disabled per injury for each injury mechanism. Results are shown in Tables 5-10 through 5-22.

### 5.3.3.1 Data Code

The data was encoded by four basic parameters, namely:

1. Injury Initiating Factor: The factor which initiated an injury sequence, such as train motion, head-on collision, etc.

2. Injury Producing Factor: The factor which produced the injury, such as seat, stanchion, stove, etc.

3. Injury Class: Either death or injury.

4. Vehicle Type: Locomotive, passenger car or caboose.

Data shown in the tables were encoded by the following means:

M * *

- Injury Type: General case includes all of following:
  - A. Bruise or contusion
  - B Sprain or strain
  - C. Laceration or abrasion
  - D. Fracture
  - E. Concussion
  - F. Dislocation
  - G. Hernia
  - H. Eye loss
  - I. Burn by hot surface
  - J. Burn by spilled liquid
  - K. Amputation
- Class of Injury Mechanism
  - 1 Injury by fall
  - 2 Injury by being thrown
  - 3 Injury by being hit by a loose object
  - 0 Combined classes
- Code for Matrix Gate

X ** 01

- Injury Initiating Factor

| | |
|---|---|
| 01 Slip or trip | ) Listed |
| 02 Rear end collision, | ) with each |
| etc. | ) table |

- Same as for Matrix
- Code for Injury Initiating Factor

Y ** 01

- Injury Producing Factor

| | |
|---|---|
| 01 Floor | ) Listed with |
| 02 Desk/Table, etc. | ) each table |

- Same as for Matrix
- Code for Injury Producing Factor

## TABLE 5-10. OCCUPANT DEATH OR INJURY, COMBINED LOCOMOTIVE, PASSENGER, CABOOSE

RATE = Average Number of Days Disabled/Injury

| | | | | INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X | 1 | Y | 1 | 5 | 72 | 0 |
| X | 1 | Y | 7 | 2 | 22 | 0 |
| X | 1 | Y | 9 | 1 | 28 | 0 |
| X | 1 | Y | 11 | 2 | 46 | 0 |
| X | 1 | Y | 12 | 2 | 47 | 0 |
| X | 1 | Y | 13 | 6 | 33 | 0 |
| X | 1 | Y | 15 | 6 | 41 | 0 |
| X | 1 | Y | 17 | 2 | 17 | 0 |
| X | 2 | Y | 1 | 1 | 5 | 0 |
| X | 2 | Y | 3 | 2 | 8 | 0 |
| X | 2 | Y | 9 | 1 | 5 | 0 |
| X | 2 | Y | 13 | 2 | 7 | 0 |
| X | 2 | Y | 14 | 1 | 40 | 0 |
| X | 3 | Y | 3 | 1 | 10 | 0 |
| X | 3 | Y | 15 | 1 | 29 | 0 |
| X | 4 | Y | 3 | 1 | 21 | 0 |
| X | 4 | Y | 6 | 1 | 30 | 0 |
| X | 4 | Y | 7 | 1 | 40 | 0 |
| X | 5 | Y | 3 | 1 | 15 | 0 |
| X | 5 | Y | 5 | 2 | 7 | 0 |
| X | 5 | Y | 8 | 1 | 10 | 0 |
| X | 5 | Y | 9 | 1 | 8 | 0 |
| X | 5 | Y | 10 | 1 | 60 | 0 |
| X | 5 | Y | 11 | 1 | 180 | 0 |
| X | 5 | Y | 13 | 1 | 60 | 0 |
| X | 6 | Y | 1 | 12 | 25 | 0 |
| X | 6 | Y | 2 | 8 | 23 | 0 |
| X | 6 | Y | 3 | 7 | 27 | 0 |
| X | 6 | Y | 4 | 2 | 38 | 0 |
| X | 6 | Y | 6 | 1 | 30 | 0 |
| X | 6 | Y | 7 | 4 | 33 | 0 |
| X | 6 | Y | 8 | 9 | 23 | 0 |
| X | 6 | Y | 9 | 3 | 15 | 0 |
| X | 6 | Y | 10 | 4 | 10 | 0 |
| X | 6 | Y | 11 | 6 | 25 | 0 |
| X | 6 | Y | 12 | 14 | 24 | 0 |
| X | 6 | Y | 13 | 11 | 35 | 0 |
| X | 6 | Y | 15 | 1 | 2 | 0 |
| X | 7 | Y | 1 | 7 | 62 | 0 |
| X | 7 | Y | 2 | 13 | 12 | 0 |
| X | 7 | Y | 3 | 16 | 25 | 0 |
| X | 7 | Y | 4 | 7 | 25 | 0 |
| X | 7 | Y | 5 | 1 | 4 | 0 |
| X | 7 | Y | 6 | 10 | 21 | 0 |

X*j = Injury Initiated

where j is as follows:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

Y**b = Occupant is injured

where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Structure |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

## TABLE 5-10 - Continued

| | | | | INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X | 7 | Y | 7 | 13 | 21 | 0 |
| X | 7 | Y | 8 | 7 | 19 | 0 |
| X | 7 | Y | 9 | 3 | 11 | 0 |
| X | 7 | Y | 10 | 2 | 17 | 0 |
| X | 7 | Y | 11 | 6 | 8 | 0 |
| X | 7 | Y | 12 | 8 | 22 | 0 |
| X | 7 | Y | 13 | 6 | 10 | 0 |
| X | 7 | Y | 15 | 14 | 17 | 0 |
| X | 8 | Y | 1 | 7 | 24 | 0 |
| X | 8 | Y | 2 | 7 | 12 | 0 |
| X | 8 | Y | 3 | 16 | 28 | 0 |
| X | 8 | Y | 4 | 3 | 19 | 0 |
| X | 8 | Y | 6 | 10 | 19 | 0 |
| X | 8 | Y | 7 | 1 | 34 | 0 |
| X | 8 | Y | 8 | 1 | 30 | 0 |
| X | 8 | Y | 11 | 2 | 15 | 0 |
| X | 8 | Y | 12 | 3 | 19 | 0 |
| X | 8 | Y | 13 | 4 | 12 | 0 |
| X | 8 | Y | 15 | 5 | 19 | 0 |
| X | 9 | Y | 3 | 2 | 15 | 0 |
| X | 9 | Y | 4 | 1 | 6 | 0 |
| X | 9 | Y | 7 | 2 | 13 | 0 |
| X | 9 | Y | 9 | 1 | 30 | 0 |
| X | 9 | Y | 10 | 1 | 30 | 0 |
| X | 9 | Y | 12 | 3 | 47 | 0 |
| X | 9 | Y | 13 | 2 | 26 | 0 |
| X | 10 | Y | 1 | 4 | 15 | 0 |
| X | 10 | Y | 2 | 1 | 21 | 0 |
| X | 10 | Y | 7 | 2 | 8 | 0 |
| X | 10 | Y | 11 | 4 | 9 | 0 |
| X | 10 | Y | 12 | 2 | 7 | 0 |
| X | 10 | Y | 13 | 3 | 25 | 0 |
| X | 10 | Y | 14 | 1 | 7 | 0 |
| X | 10 | Y | 15 | 5 | 20 | 0 |
| X | 11 | Y | 6 | 1 | 4 | 0 |
| X | 11 | Y | 8 | 1 | 50 | 0 |
| X | 11 | Y | 9 | 2 | 14 | 0 |
| X | 11 | Y | 11 | 2 | 19 | 0 |
| X | 11 | Y | 13 | 2 | 8 | 0 |
| X | 11 | Y | 15 | 3 | 32 | 0 |
| X | 12 | Y | 1 | 2 | 47 | 0 |
| X | 12 | Y | 2 | 4 | 12 | 0 |
| X | 12 | Y | 3 | 4 | 20 | 0 |
| X | 12 | Y | 4 | 1 | 45 | 0 |
| X | 12 | Y | 6 | 1 | 28 | 0 |
| X | 12 | Y | 7 | 4 | 15 | 0 |
| X | 12 | Y | 10 | 1 | 4 | 0 |

X**j = Injury Initiated

where j is as follows:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

Y**b = Occupant is injured

where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge frame |
| 12 | Persons own reaction |
| 13 | Structure |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

TABLE 5-10 - Continued

| | | | | INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X | 12 | Y | 11 | 2 | 51 | 0 |
| X | 12 | Y | 12 | 1 | 20 | 0 |
| X | 12 | Y | 13 | 2 | 37 | 0 |
| X | 12 | Y | 15 | 8 | 11 | 0 |
| X | 13 | Y | 5 | 8 | 3 | 0 |
| X | 13 | Y | 15 | 1 | 3 | 0 |

X**j = Injury Initiated

where j is as follows:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

Y**b = Occupant is injured

where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Structure |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

TABLE 5-11. M1*(A) OCCUPANT DEATH OR INJURY BY FALL, COMBINED FOR LOCOMOTIVE, PASSENGER CAR AND CABOOSE

Rate = Average Number of Days Disabled/Injury

| | | | | INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X1 | 1 | Y1 | 1 | 5 | 72 | 0 |
| X1 | 1 | Y1 | 7 | 2 | 22 | 0 |
| X1 | 1 | Y1 | 9 | 1 | 28 | 0 |
| X1 | 1 | Y1 | 11 | 1 | 90 | 0 |
| X1 | 1 | Y1 | 12 | 2 | 47 | 0 |
| X1 | 1 | Y1 | 13 | 6 | 33 | 0 |
| X1 | 1 | Y1 | 15 | 6 | 41 | 0 |
| X1 | 1 | Y1 | 16 | 2 | 17 | 0 |
| X1 | 2 | Y1 | 1 | 1 | 5 | 0 |
| X1 | 6 | Y1 | 1 | 9 | 30 | 0 |
| X1 | 6 | Y1 | 7 | 1 | 18 | 0 |
| X1 | 6 | Y1 | 8 | 2 | 8 | 0 |
| X1 | 6 | Y1 | 9 | 1 | 10 | 0 |
| X1 | 6 | Y1 | 11 | 1 | 20 | 0 |
| X1 | 6 | Y1 | 13 | 1 | 90 | 0 |
| X1 | 6 | Y1 | 15 | 1 | 2 | 0 |
| X1 | 7 | Y1 | 1 | 6 | 58 | 0 |
| X1 | 7 | Y1 | 2 | 1 | 6 | 0 |
| X1 | 7 | Y1 | 3 | 3 | 26 | 0 |
| X1 | 7 | Y1 | 4 | 1 | 14 | 0 |
| X1 | 7 | Y1 | 5 | 1 | 4 | 0 |
| X1 | 7 | Y1 | 6 | 4 | 19 | 0 |
| X1 | 7 | Y1 | 7 | 4 | 26 | 0 |
| X1 | 7 | Y1 | 8 | 1 | 15 | 0 |
| X1 | 7 | Y1 | 10 | 1 | 6 | 0 |
| X1 | 7 | Y1 | 13 | 1 | 30 | 0 |
| X1 | 7 | Y1 | 15 | 5 | 18 | 0 |
| X1 | 8 | Y1 | 3 | 1 | 13 | 0 |
| X1 | 8 | Y1 | 6 | 1 | 35 | 0 |
| X1 | 9 | Y1 | 10 | 1 | 30 | 0 |
| X1 | 10 | Y1 | 1 | 4 | 15 | 0 |
| X1 | 10 | Y1 | 7 | 1 | 13 | 0 |
| X1 | 10 | Y1 | 11 | 1 | 6 | 0 |
| X1 | 10 | Y1 | 12 | 1 | 11 | 0 |
| X1 | 10 | Y1 | 13 | 3 | 25 | 0 |
| X1 | 10 | Y1 | 15 | 3 | 20 | 0 |
| X1 | 11 | Y1 | 13 | 1 | 7 | 0 |
| X1 | 12 | Y1 | 1 | 1 | 90 | 0 |
| X1 | 12 | Y1 | 2 | 2 | 16 | 0 |
| X1 | 12 | Y1 | 3 | 1 | 8 | 0 |
| X1 | 12 | Y1 | 6 | 1 | 28 | 0 |
| X1 | 12 | Y1 | 7 | 2 | 23 | 0 |
| X1 | 12 | Y1 | 10 | 1 | 4 | 0 |
| X1 | 12 | Y1 | 12 | 1 | 20 | 0 |
| X1 | 12 | Y1 | 13 | 2 | 37 | 0 |
| X1 | 12 | Y1 | 15 | 3 | 15 | 0 |

X1*j = Occupant falls due to j,

where j is as follows:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

Y1*b = Occupant is injured

where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Fall |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

TABLE 5-12. M1*(L) OCCUPANT DEATH OR INJURY BY FALL, LOCOMOTIVE

Rate = Average Number of Days Disabled/Injury

| | | | | LOCO. INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X1 | 1 | Y1 | 12 | 1 | 90 | 0 |
| X1 | 1 | Y1 | 15 | 1 | 42 | 0 |
| X1 | 2 | Y1 | 1 | 1 | 5 | 0 |
| X1 | 6 | Y1 | 1 | 6 | 11 | 0 |
| X1 | 6 | Y1 | 7 | 1 | 18 | 0 |
| X1 | 6 | Y1 | 8 | 2 | 8 | 0 |
| X1 | 6 | Y1 | 11 | 1 | 20 | 0 |
| X1 | 6 | Y1 | 13 | 1 | 90 | 0 |
| X1 | 6 | Y1 | 15 | 1 | 2 | 0 |
| X1 | 7 | Y1 | 8 | 1 | 15 | 0 |
| X1 | 10 | Y1 | 1 | 4 | 15 | 0 |
| X1 | 10 | Y1 | 7 | 1 | 13 | 0 |
| X1 | 10 | Y1 | 11 | 1 | 6 | 0 |
| X1 | 10 | Y1 | 12 | 1 | 11 | 0 |
| X1 | 10 | Y1 | 13 | 3 | 25 | 0 |
| X1 | 10 | Y1 | 15 | 1 | 39 | 0 |
| X1 | 12 | Y1 | 15 | 1 | 6 | 0 |

X1*j = Occupant falls

where j is as follows:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

Y1*b = Occupant is injured

where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Fall |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

TABLE 5-13. M1*(P) OCCUPANT DEATH OR INJURY BY FALL, PASSENGER CAR

Rate = Average Number of Days Disabled/Injury

| | | | | PASS. INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X1 | 1 | Y1 | 1 | 3 | 80 | 0 |
| X1 | 1 | Y1 | 7 | 2 | 22 | 0 |
| X1 | 1 | Y1 | 11 | 1 | 90 | 0 |
| X1 | 1 | Y1 | 12 | 1 | 4 | 0 |
| X1 | 1 | Y1 | 14 | 6 | 33 | 0 |
| X1 | 1 | Y1 | 15 | 4 | 50 | 0 |
| X1 | 1 | Y1 | 16 | 2 | 17 | 0 |
| X1 | 7 | Y1 | 3 | 1 | 14 | 0 |
| X1 | 7 | Y1 | 7 | 3 | 31 | 0 |
| X1 | 7 | Y1 | 15 | 2 | 9 | 0 |
| X1 | 10 | Y1 | 15 | 2 | 12 | 0 |
| X1 | 11 | Y1 | 13 | 1 | 7 | 0 |
| X1 | 12 | Y1 | 1 | 1 | 90 | 0 |
| X1 | 12 | Y1 | 2 | 2 | 16 | 0 |
| X1 | 12 | Y1 | 3 | 1 | 8 | 0 |
| X1 | 12 | Y1 | 6 | 1 | 28 | 0 |
| X1 | 12 | Y1 | 7 | 2 | 23 | 0 |
| X1 | 12 | Y1 | 10 | 1 | 4 | 0 |
| X1 | 12 | Y1 | 12 | 1 | 20 | 0 |
| X1 | 12 | Y1 | 13 | 1 | 45 | 0 |
| X1 | 12 | Y1 | 15 | 2 | 20 | 0 |

X1*j = Occupant falls

where j is as follows:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

Y1*b = Occupant is injured

where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Fall |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

## TABLE 5-14. M1*(C) OCCUPANT DEATH OR INJURY BY FALL, CABOOSE

Rate = Number of Days Disabled/Injury

| | | | | CABOOSE INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X1 | 1 | Y1 | 1 | 2 | 68 | 0 |
| X1 | 1 | Y1 | 9 | 1 | 28 | 0 |
| X1 | 1 | Y1 | 15 | 1 | 5 | 0 |
| X1 | 6 | Y1 | 1 | 3 | 66 | 0 |
| X1 | 6 | Y1 | 9 | 1 | 10 | 0 |
| X1 | 7 | Y1 | 1 | 6 | 58 | 0 |
| X1 | 7 | Y1 | 2 | 1 | 6 | 0 |
| X1 | 7 | Y1 | 3 | 2 | 32 | 0 |
| X1 | 7 | Y1 | 4 | 1 | 14 | 0 |
| X1 | 7 | Y1 | 5 | 1 | 4 | 0 |
| X1 | 7 | Y1 | 6 | 4 | 19 | 0 |
| X1 | 7 | Y1 | 7 | 1 | 12 | 0 |
| X1 | 7 | Y1 | 10 | 1 | 6 | 0 |
| X1 | 7 | Y1 | 13 | 1 | 30 | 0 |
| X1 | 7 | Y1 | 15 | 3 | 24 | 0 |
| X1 | 8 | Y1 | 3 | 1 | 13 | 0 |
| X1 | 8 | Y1 | 6 | 1 | 35 | 0 |
| X1 | 9 | Y1 | 10 | 1 | 30 | 0 |
| X1 | 12 | Y1 | 13 | 1 | 30 | 0 |

X1*j = Occupant falls

where j is as follows:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

Y1*b = Occupant is injured

where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Fall |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

## TABLE 5-15. M2*(A) OCCUPANT DEATH OR INJURY, OCCUPANT THROWN AGAINST HOSTILE STRUCTURE, COMBINED FOR LOCOMOTIVE, PASSENGER CAR, AND CABOOSE

Rate = Number of Days Disabled/Injury

| | | | | ALL INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X2 | 2 | Y2 | 3 | 2 | 8 | 0 |
| X2 | 2 | Y2 | 9 | 1 | 5 | 0 |
| X2 | 2 | Y2 | 13 | 2 | 7 | 0 |
| X2 | 2 | Y2 | 14 | 1 | 40 | 0 |
| X2 | 3 | Y2 | 3 | 1 | 10 | 0 |
| X2 | 3 | Y2 | 15 | 1 | 29 | 0 |
| X2 | 4 | Y2 | 3 | 1 | 21 | 0 |
| X2 | 4 | Y2 | 6 | 1 | 30 | 0 |
| X2 | 4 | Y2 | 7 | 1 | 40 | 0 |
| X2 | 5 | Y2 | 3 | 1 | 15 | 0 |
| X2 | 5 | Y2 | 8 | 1 | 10 | 0 |
| X2 | 5 | Y2 | 9 | 1 | 8 | 0 |
| X2 | 5 | Y2 | 10 | 1 | 60 | 0 |
| X2 | 5 | Y2 | 13 | 1 | 60 | 0 |
| X2 | 6 | Y2 | 1 | 3 | 10 | 0 |
| X2 | 6 | Y2 | 2 | 8 | 23 | 0 |
| X2 | 6 | Y2 | 2 | 8 | 23 | 0 |
| X2 | 6 | Y2 | 3 | 7 | 27 | 0 |
| X2 | 6 | Y2 | 4 | 2 | 38 | 0 |
| X2 | 6 | Y2 | 6 | 1 | 30 | 0 |
| X2 | 6 | Y2 | 7 | 3 | 38 | 0 |
| X2 | 6 | Y2 | 8 | 7 | 27 | 0 |
| X2 | 6 | Y2 | 10 | 4 | 10 | 0 |
| X2 | 6 | Y2 | 11 | 5 | 26 | 0 |
| X2 | 6 | Y2 | 12 | 14 | 24 | 0 |
| X2 | 6 | Y2 | 13 | 10 | 30 | 0 |
| X2 | 7 | Y2 | 1 | 1 | 14 | 0 |
| X2 | 7 | Y2 | 2 | 12 | 12 | 0 |
| X2 | 7 | Y2 | 3 | 13 | 25 | 0 |
| X2 | 7 | Y2 | 4 | 6 | 26 | 0 |
| X2 | 7 | Y2 | 6 | 6 | 23 | 0 |
| X2 | 7 | Y2 | 7 | 9 | 19 | 0 |
| X2 | 7 | Y2 | 8 | 6 | 20 | 0 |
| X2 | 7 | Y2 | 9 | 3 | 11 | 0 |
| X2 | 7 | Y2 | 10 | 1 | 28 | 0 |
| X2 | 7 | Y2 | 11 | 4 | 9 | 0 |
| X2 | 7 | Y2 | 12 | 8 | 22 | 0 |
| X2 | 7 | Y2 | 13 | 5 | 7 | 0 |
| X2 | 7 | Y2 | 15 | 9 | 16 | 0 |
| X2 | 8 | Y2 | 1 | 7 | 24 | 0 |
| X2 | 8 | Y2 | 2 | 7 | 13 | 0 |
| X2 | 8 | Y2 | 3 | 15 | 29 | 0 |

X1*j = Occupant falls

where j is as follows:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

Y1*b = Occupant is injured

where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Fall |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

TABLE 5-15 - Continued

| | | | | ALL INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X2 | 8 | Y2 | 4 | 3 | 19 | 0 |
| X2 | 8 | Y2 | 6 | 9 | 17 | 0 |
| X2 | 8 | Y2 | 7 | 1 | 34 | 0 |
| X2 | 8 | Y2 | 8 | 1 | 30 | 0 |
| X2 | 8 | Y2 | 11 | 2 | 15 | 0 |
| X2 | 8 | Y2 | 12 | 3 | 19 | 0 |
| X2 | 8 | Y2 | 13 | 4 | 12 | 0 |
| X2 | 8 | Y2 | 15 | 5 | 19 | 0 |
| X2 | 9 | Y2 | 3 | 2 | 15 | 0 |
| X2 | 9 | Y2 | 4 | 1 | 6 | 0 |
| X2 | 9 | Y2 | 7 | 2 | 13 | 0 |
| X2 | 9 | Y2 | 9 | 1 | 30 | 0 |
| X2 | 9 | Y2 | 12 | 3 | 47 | 0 |
| X2 | 9 | Y2 | 13 | 2 | 26 | 0 |
| X2 | 10 | Y2 | 12 | 1 | 4 | 0 |
| X2 | 10 | Y2 | 14 | 1 | 7 | 0 |
| X2 | 11 | Y2 | 6 | 1 | 4 | 0 |
| X2 | 11 | Y2 | 8 | 1 | 50 | 0 |
| X2 | 11 | Y2 | 9 | 1 | 7 | 0 |
| X2 | 11 | Y2 | 13 | 1 | 9 | 0 |
| X2 | 11 | Y2 | 15 | 1 | 30 | 0 |
| X2 | 12 | Y2 | 1 | 1 | 5 | 0 |
| X2 | 12 | Y2 | 2 | 2 | 10 | 0 |
| X2 | 12 | Y2 | 3 | 3 | 24 | 0 |
| X2 | 12 | Y2 | 4 | 1 | 45 | 0 |
| X2 | 12 | Y2 | 7 | 2 | 8 | 0 |
| X2 | 12 | Y2 | 11 | 1 | 3 | 0 |
| X2 | 12 | Y2 | 15 | 3 | 10 | 0 |

X2*j = Occupant is thrown,

where j is:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

Y2*b = Occupant is injured

where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Fall |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

TABLE 5-16. M2*(L) OCCUPANT DEATH OR INJURY, OCCUPANT THROWN AGAINST HOSTILE STRUCTURE, LOCOMOTIVE

Rate = Number of Days Disabled/Injury

| | | | | LOCO. INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X2 | 2 | Y2 | 3 | 1 | 8 | 0 |
| X2 | 2 | Y2 | 9 | 1 | 5 | 0 |
| X2 | 2 | Y2 | 13 | 1 | 5 | 0 |
| X2 | 2 | Y2 | 14 | 1 | 40 | 0 |
| X2 | 3 | Y2 | 15 | 1 | 29 | 0 |
| X2 | 4 | Y2 | 3 | 1 | 21 | 0 |
| X2 | 4 | Y2 | 6 | 1 | 30 | 0 |
| X2 | 4 | Y2 | 7 | 1 | 40 | 0 |
| X2 | 5 | Y2 | 8 | 1 | 10 | 0 |
| X2 | 5 | Y2 | 9 | 1 | 8 | 0 |
| X2 | 5 | Y2 | 10 | 1 | 60 | 0 |
| X2 | 5 | Y2 | 13 | 1 | 60 | 0 |
| X2 | 6 | Y2 | 3 | 3 | 15 | 0 |
| X2 | 6 | Y2 | 7 | 2 | 50 | 0 |
| X2 | 6 | Y2 | 8 | 7 | 27 | 0 |
| X2 | 6 | Y2 | 10 | 1 | 4 | 0 |
| X2 | 6 | Y2 | 11 | 5 | 26 | 0 |
| X2 | 6 | Y2 | 12 | 12 | 27 | 0 |
| X2 | 6 | Y2 | 13 | 7 | 27 | 0 |
| X2 | 7 | Y2 | 3 | 1 | 90 | 0 |
| X2 | 7 | Y2 | 8 | 3 | 7 | 0 |
| X2 | 7 | Y2 | 9 | 2 | 15 | 0 |
| X2 | 7 | Y2 | 11 | 2 | 10 | 0 |
| X2 | 7 | Y2 | 12 | 3 | 13 | 0 |
| X2 | 8 | Y2 | 3 | 1 | 90 | 0 |
| X2 | 8 | Y2 | 6 | 1 | 10 | 0 |
| X2 | 8 | Y2 | 8 | 1 | 30 | 0 |
| X2 | 8 | Y2 | 15 | 1 | 35 | 0 |
| X2 | 9 | Y2 | 3 | 1 | 5 | 0 |
| X2 | 9 | Y2 | 9 | 1 | 30 | 0 |
| X2 | 9 | Y2 | 13 | 1 | 45 | 0 |
| X2 | 10 | Y2 | 12 | 1 | 4 | 0 |
| X2 | 11 | Y2 | 8 | 1 | 50 | 0 |
| X2 | 11 | Y2 | 9 | 1 | 7 | 0 |
| X2 | 11 | Y2 | 13 | 1 | 9 | 0 |

X2*j = Occupant is thrown

where j is:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

Y2*b = Occupant is injured

where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Structure |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

TABLE 5-17. M2*(P) OCCUPANT DEATH OR INJURY, OCCUPANT THROWN AGAINST HOSTILE STRUCTURE, PASSENGER CAR

| | | | | PASS. INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X2 | 6 | Y2 | 13 | 1 | 30 | 0 |
| X2 | 7 | Y2 | 1 | 1 | 14 | 0 |
| X2 | 7 | Y2 | 3 | 1 | 14 | 0 |
| X2 | 7 | Y2 | 7 | 3 | 25 | 0 |
| X2 | 7 | Y2 | 12 | 1 | 21 | 0 |
| X2 | 7 | Y2 | 13 | 2 | 10 | 0 |
| X2 | 7 | Y2 | 15 | 1 | 9 | 0 |
| X2 | 8 | Y2 | 1 | 1 | 3 | 0 |
| X2 | 8 | Y2 | 2 | 1 | 7 | 0 |
| X2 | 8 | Y2 | 3 | 4 | 29 | 0 |
| X2 | 8 | Y2 | 6 | 1 | 21 | 0 |
| X2 | 8 | Y2 | 15 | 1 | 10 | 0 |
| X2 | 10 | Y2 | 14 | 1 | 7 | 0 |
| X2 | 12 | Y2 | 1 | 1 | 5 | 0 |
| X2 | 12 | Y2 | 2 | 2 | 10 | 0 |
| X2 | 12 | Y2 | 3 | 2 | 30 | 0 |
| X2 | 12 | Y2 | 7 | 1 | 14 | 0 |
| X2 | 12 | Y2 | 11 | 1 | 3 | 0 |
| X2 | 12 | Y2 | 15 | 3 | 10 | 0 |

X2*j = Occupant is thrown

where j is:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

Y2*b = Occupant is injured

where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Structure |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

TABLE 5-18. M2*(C) OCCUPANT DEATH OR INJURY, OCCUPANT THROWN AGAINST HOSTILE STRUCTURE, CABOOSE

Rate = Number of Days Disabled/Injury

| | | | | CABOOSE INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X2 | 2 | Y2 | 3 | 1 | 8 | 0 |
| X2 | 2 | Y2 | 13 | 1 | 10 | 0 |
| X2 | 3 | Y2 | 3 | 1 | 10 | 0 |
| X2 | 5 | Y2 | 3 | 1 | 15 | 0 |
| X2 | 6 | Y2 | 1 | 3 | 10 | 0 |
| X2 | 6 | Y2 | 2 | 8 | 23 | 0 |
| X2 | 6 | Y2 | 3 | 4 | 37 | 0 |
| X2 | 6 | Y2 | 4 | 2 | 38 | 0 |
| X2 | 6 | Y2 | 6 | 1 | 30 | 0 |
| X2 | 6 | Y2 | 7 | 1 | 14 | 0 |
| X2 | 6 | Y2 | 10 | 3 | 12 | 0 |
| X2 | 6 | Y2 | 12 | 2 | 10 | 0 |
| X2 | 6 | Y2 | 13 | 2 | 38 | 0 |
| X2 | 7 | Y2 | 2 | 12 | 12 | 0 |
| X2 | 7 | Y2 | 3 | 11 | 20 | 0 |
| X2 | 7 | Y2 | 4 | 6 | 26 | 0 |
| X2 | 7 | Y2 | 6 | 6 | 23 | 0 |
| X2 | 7 | Y2 | 7 | 6 | 16 | 0 |
| X2 | 7 | Y2 | 8 | 3 | 33 | 0 |
| X2 | 7 | Y2 | 9 | 1 | 3 | 0 |
| X2 | 7 | Y2 | 10 | 1 | 28 | 0 |
| X2 | 7 | Y2 | 11 | 2 | 9 | 0 |
| X2 | 7 | Y2 | 12 | 4 | 29 | 0 |
| X2 | 7 | Y2 | 13 | 3 | 5 | 0 |
| X2 | 7 | Y2 | 15 | 8 | 17 | 0 |
| X2 | 8 | Y2 | 1 | 6 | 28 | 0 |
| X2 | 8 | Y2 | 2 | 6 | 14 | 0 |
| X2 | 8 | Y2 | 3 | 10 | 23 | 0 |
| X2 | 8 | Y2 | 4 | 3 | 19 | 0 |
| X2 | 8 | Y2 | 6 | 7 | 18 | 0 |
| X2 | 8 | Y2 | 7 | 1 | 34 | 0 |
| X2 | 8 | Y2 | 11 | 2 | 15 | 0 |
| X2 | 8 | Y2 | 13 | 3 | 19 | 0 |
| X2 | 8 | Y2 | 13 | 4 | 12 | 0 |
| X2 | 8 | Y2 | 15 | 3 | 16 | 0 |
| X2 | 9 | Y2 | 3 | 1 | 25 | 0 |
| X2 | 9 | Y2 | 4 | 1 | 6 | 0 |
| X2 | 9 | Y2 | 7 | 2 | 13 | 0 |
| X2 | 9 | Y2 | 12 | 3 | 47 | 0 |
| X2 | 9 | Y2 | 13 | 1 | 7 | 0 |
| X2 | 11 | Y2 | 6 | 1 | 4 | 0 |
| X2 | 11 | Y2 | 15 | 1 | 30 | 0 |
| X2 | 12 | Y2 | 3 | 1 | 14 | 0 |
| X2 | 12 | Y2 | 4 | 1 | 45 | 0 |
| X2 | 12 | Y2 | 7 | 1 | 2 | 0 |

X2*j = Occupant is thrown

where j is:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

Y2*b = Occupant is injured

where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Structure |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

TABLE 5-19. M3*(A) OCCUPANT DEATH OR INJURY, LOOSE OBJECT INJURES OCCUPANT, COMBINED FOR LOCOMOTIVE, PASSENGER, CABOOSE

Rate = Number of Days Disabled/Injury

| | | | | ALL INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X3 | 1 | Y3 | 11 | 1 | 2 | 0 |
| X3 | 5 | Y3 | 5 | 2 | 7 | 0 |
| X3 | 5 | Y3 | 11 | 1 | 180 | 0 |
| X3 | 6 | Y3 | 9 | 2 | 17 | 0 |
| X3 | 7 | Y3 | 11 | 2 | 6 | 0 |
| X3 | 10 | Y3 | 2 | 1 | 21 | 0 |
| X3 | 10 | Y3 | 7 | 1 | 3 | 0 |
| X3 | 10 | Y3 | 11 | 3 | 10 | 0 |
| X3 | 10 | Y3 | 15 | 2 | 20 | 0 |
| X3 | 11 | Y3 | 9 | 1 | 22 | 0 |
| X3 | 11 | Y3 | 11 | 2 | 19 | 0 |
| X3 | 11 | Y3 | 15 | 2 | 34 | 0 |
| X3 | 12 | Y3 | 11 | 1 | 100 | 0 |
| X3 | 12 | Y3 | 15 | 2 | 7 | 0 |
| X3 | 13 | Y3 | 5 | 8 | 3 | 0 |
| X3 | 13 | Y3 | 15 | 1 | 3 | 0 |

X3*j = Loose object is thrown where j is:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

TABLE 5-20. M3*(L) OCCUPANT DEATH OR INJURY, LOOSE OBJECT INJURES OCCUPANT, LOCOMOTIVE

Rate = Number of Days Disabled/Injury

| | | | | LOCO. INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X3 | 5 | Y3 | 5 | 1 | 4 | 0 |
| X3 | 5 | Y3 | 11 | 1 | 180 | 0 |
| X3 | 6 | Y3 | 9 | 2 | 17 | 0 |
| X3 | 10 | Y3 | 11 | 1 | 10 | 0 |
| X3 | 10 | Y3 | 15 | 1 | 30 | 0 |
| X3 | 11 | Y3 | 9 | 1 | 22 | 0 |
| X3 | 11 | Y3 | 11 | 2 | 19 | 0 |
| X3 | 11 | Y3 | 15 | 1 | 60 | 0 |
| X3 | 13 | Y3 | 5 | 1 | 5 | 0 |

Y3*b = Occupant is injured where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabiner/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Loose object |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

## TABLE 5-21. M3*(P) OCCUPANT DEATH OR INJURY, LOOSE OBJECT INJURES OCCUPANT, PASSENGER CAR

Rate = Number of Days Disabled/Injury

| | | | | PASS. INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X3 | 1 | Y3 | 11 | 1 | 2 | 0 |
| X3 | 5 | Y3 | 5 | 1 | 10 | 0 |
| X3 | 7 | Y3 | 11 | 1 | 3 | 0 |
| X3 | 10 | Y3 | 11 | 2 | 10 | 0 |
| X3 | 10 | Y3 | 15 | 1 | 10 | 0 |
| X3 | 11 | Ye | 15 | 1 | 8 | 0 |
| X3 | 12 | Y3 | 11 | 1 | 100 | 0 |
| X3 | 12 | Y3 | 15 | 2 | 7 | 0 |
| X3 | 13 | Y3 | 5 | 6 | 2 | 0 |
| X3 | 13 | Y3 | 15 | 1 | 3 | 0 |

X3*j = Loose object is thrown where j is:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear end collision |
| 03 | Head on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

## TABLE 5-22. M3*(C) OCCUPANT DEATH OR INJURY, LOOSE OBJECT INJURES OCCUPANT, CABOOSE

Rate = Number of Days Disabled/Injury

| | | | | CABOOSE INJURIES | RATE | DEATHS |
|---|---|---|---|---|---|---|
| X3 | 7 | Y3 | 11 | 1 | 10 | 0 |
| X3 | 10 | Y3 | 2 | 1 | 21 | 0 |
| X3 | 10 | Y3 | 7 | 1 | 3 | 0 |
| X3 | 13 | Y3 | 5 | 1 | 6 | 0 |

Y3*b = Occupant is injured where b is:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Loose object |
| 14 | Boxes/baggage |
| 15 | Miscellaneous equipment |
| 16 | Platform edge |

### 5.3.3.2 Data Summary

The data from the Injury Mechanism catalog is summarized in Table 5-23.

Injury Producing Factors are summarized in Tables 5-24 and 5-25.

Table 5-26 summarized injury mechanisms which were undeterminable from the date.

In reviewing the available data it was found that two-thirds of the incidents applicable to this study were placed in the unknown injury mechanism category. For most of these, the number of days disabled and the type of injury were known, but the information required for injury prevention was unknown. Most of the instances where the injury mechanism was not listed occurred during large accidents. It is understandable that in these accidents the primary concern is rescue and evaluation for treatment; however, future investigations should provide follow-up interviews with the train occupants to determine how the people were injured.

For the purpose of this study it can be assumed that the injury mechanism of the unknown incidents were approximately proportional to those of the known. This being the case, the listed injury mechanisms can be multiplied by a factor of three to reflect the magnitude of the injury mechanism.

The data developed above was applied to the fault tree matrices to provide dimension. These values are shown on the matrices (Tables 5-27 through 5-30) where the conditional probabilities, P***, would normally appear.

### 5.3.3.3 Discussion

Three hundred eighty-four injuries were attributed to specific injury mechanisms involving general items of train equipment; that is, an injury sequence was initiated and a given piece of train equipment caused the injury. These injuries were distributed among 56 general items of train equipment or structure. No single problem item was identified; rather, it was considered important that all of the problem items be addressed on order to significantly reduce the injury hazard of the vehicle interiors. Future vehicle designs should certainly address the hazardous equipment revealed by the past, but it is equally important that all equipment placed in vehicles be reviewed for characteristics similar to those of other equipment which has proved hazardous in the past.

TABLE 5-23. SUMMARY

| | NO. INJ. | DAYS DISABLED | DAYS/ INJ. | NO. KILLED | NO. PERM. INJ. |
|---|---|---|---|---|---|
| UNKNOWN | 836 | 28,048 | 30 | 105 | 2 |
| KNOWN MECH. GEN. | 384 | 8,639 | 22 | 0 | 0 |
| SHOCK | 28 | 366 | 13 | 0 | 0 |
| BURNED | 11 | 1,105 | 100 | 5 | 0 |
| JUMPED OR THROWN | 8 | 345 | 43 | 0 | 0 |
| MISCELLANEOUS | 11 | 305 | 28 | 0 | 0 |
| | 1,278 | 38,808 | 30 | 110 | 2 |

## TABLE 5-24. INJURY PRODUCING FACTORS

| | | NUMBER OF INJURIES | DAYS DISABLED PER INJ. | NO. DAYS DISABLED |
|---|---|---|---|---|
| 1. | FLOORING | 38 | 36 | 1,351 |
| 2. | TABLES/DESKS | 33 | 15 | 493 |
| 3. | BULKHEADS/WALLS/ DOOR FLATS | 50 | 24 | 1,209 |
| 4. | STOVE | 13 | 24 | 309 |
| 5. | GLASS PANE (Shattered) | 12 | 7 | 86 |
| 6. | RAILS/BARS/ STANCHIONS | 24 | 13 | 302 |
| 7. | SEATS | 29 | 22 | 641 |
| 8. | CONTROL CONSOLE | 19 | 23 | 430 |
| 9. | WATER COOLER | 12 | 15 | 177 |
| 10. | CABINETS/LOCKER/ SHELVES | 9 | 19 | 168 |
| 11. | DOOR & WINDOW FRAMES AND EDGING | 25 | 27 | 676 |
| 12. | PERSONS' REACTION | 34 | 25 | 850 |
| 13. | UNKNOWN | 38 | 26 | 980 |
| 14. | BOXES/BAGGAGE | 2 | 24 | 47 |
| 15. | MISC. EQUIPMENT | 43 | 20 | 886 |
| 16. | PLATFORM EDGING | 2 | 17 | 34 |
| | | 383 | 22 | 8,639 |

TABLE 5-25. MISCELLANEOUS EQUIPMENT (43)

HEATER MOTOR
STEAM GENERATOR EXHAUST
CHINA PLATE
OVEN DOOR
BROILER PAN
FOOT REST (3)
PLATFORM
BUNK (2)
STAIRWELL TRAP DOOR (2)
BENCH (2)
WASH BASIN (2)
TOILET (3)
OIL TANK
FIRE EXTINGUISHER (2)
ELECTRICAL BOX (2)
BETWEEN-CAR CURTAIN
AIR HOSE
FAN BLADE
TIE BOX/CHEST (2)
STEPS (5)
OBJECT THROWN BY VANDAL
CONDUCTOR VALVE
WASHING MACHINE
CHAIR
LIGHT FIXTURE
THERMOSTAT
HOT ASHES
STIRRUP

TABLE 5-26. INJURY MECHANISMS NOT DOCUMENTED

| | NO. INJ. | DAYS DISABLED | DAYS/ INJ. | NO. DEATHS | NO. PERM. INJ. |
|---|---|---|---|---|---|
| REAR-END COLLISION | | | | | |
| Locomotive | 57 | 1,529 | 47.8 | 3 | 1 |
| Passenger | 268 | 8,665 | 32.3 | 47 | 1 |
| Caboose | 37 | 1,710 | 46.2 | 4 | - |
| HEAD-ON COLLISION | | | | | |
| Locomotive | 43 | 1,955 | 45.5 | 29 | - |
| Passenger | - | - | - | - | - |
| Caboose | 2 | 44 | 22.0 | - | - |
| CROSS COLLISION | | | | | |
| Locomotive | 21 | 849 | 40.4 | - | - |
| Passenger | - | - | - | - | - |
| Caboose | 2 | 4 | 2.0 | - | - |
| GRADE CROSSING COLLISION | | | | | |
| Locomotive | 29 | 770 | 26.6 | - | - |
| Passenger | 7 | 247 | 35.3 | - | - |
| Caboose | 1 | 45 | 45.0 | - | - |
| HARD COUPLING | | | | | |
| Locomotive | 5 | 119 | 23.8 | - | - |
| Passenger | - | - | - | - | - |
| Caboose | 3 | 199 | 66.3 | 2 | - |
| SLACK ACTION | | | | | |
| Locomotive | 3 | 120 | 40.0 | - | - |
| Passenger | - | - | - | - | - |
| Caboose | 1 | 10 | 10.0 | - | - |
| BRAKING | | | | | |
| Locomotive | 3 | 48 | 16.0 | - | - |
| Passenger | 5 | 193 | 36.6 | - | - |
| Caboose | 2 | 90 | 45.0 | - | - |
| DERAILMENT | | | | | |
| Locomotive | 32 | 1,529 | 47.8 | 3 | - |
| Passenger | 286 | 5,207 | 18.2 | 2 | - |
| Caboose | 26 | 963 | 37.0 | - | - |
| | 833 | 24,743 | 29.7 | 100 | 2 |

# TABLE 5-27. MATRIX M1*, GENERAL CASE FOR OCCUPANT DEATH OR INJURY BY FALL

NOTE: Numbers in matrix are (Number of Injuries)/(Days Disabled per Injury)

M1* = Occupant Death or Injury by Fall

.X1*j = Occupant falls due to j, where j is as follows:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear-end collision |
| 03 | Head-on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

.Y1*b = Occupant is injured by b, where b is as follows:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Unknown |
| 14 | Boxes/baggage |
| 15 | Misc. equipment |
| 16 | Platform edge |

| | | Y1*01 | Y1*02 | Y1*03 | Y1*04 | Y1*05 | Y1*06 | Y1*07 | Y1*08 | Y1*09 | Y1*10 | Y1*11 | Y1*12 | Y1*13 | Y1*14 | Y1*15 | Y1*16 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X1*01 | Loco | | | | | | | | | | | | 1/90 | | | 1/42 | | 2 |
| | Pass | 3/80 | | | | | | 2/22 | | | | 1/90 | 1/4 | 6/33 | | 4/50 | 2/17 | 19 |
| | Cab. | 2/60 | | | | | | | | 1/28 | | | | | | 1/5 | | 4 |
| X1*02 | Loco | 1/5 | | | | | | | | | | | | | | | | 1 |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | | | | | | | | | | | | | | | |
| X1*03 | Loco | | | | | | | | | | | | | | | | | |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | | | | | | | | | | | | | | | |
| X1*04 | Loco | | | | | | | | | | | | | | | | | |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | | | | | | | | | | | | | | | |
| X1*05 | Loco | | | | | | | | | | | | | | | | | |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | | | | | | | | | | | | | | | |
| X1*06 | Loco | 6/11 | | | | | | 1/18 | 2/8 | | | 1/20 | | 1/90 | | 1/2 | | 12 |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | 3/66 | | | | | | | | 1/10 | | | | | | | | 4 |
| X1*07 | Loco | | | | | | | | 1/15 | | | | | | | | | 1 |
| | Pass | | | 1/14 | | | | 3/31 | | | | | | | | 2/9 | | 6 |
| | Cab. | 6/58 | 1/6 | 2/32 | 1/14 | 1/4 | 4/19 | 1/12 | | | 1/6 | | | 1/30 | | 3/24 | | 21 |
| X1*08 | Loco | | | | | | | | | | | | | | | | | |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | 1/13 | | | 1/35 | | | | | | | | | | | 2 |
| X1*09 | Loco | | | | | | | | | | | | | | | | | |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | | | | | | | | 1/30 | | | | | | | 1 |
| X1*10 | Loco | 4/15 | | | | | | 1/13 | | | | 1/6 | 1/11 | 3/25 | | 1/39 | | 11 |
| | Pass | | | | | | | | | | | | | | | 2/12 | | 2 |
| | Cab. | | | | | | | | | | | | | | | | | |
| X1*11 | Loco | | | | | | | | | | | | | | | | | |
| | Pass | | | | | | | | | | | | | 1/7 | | | | 1 |
| | Cab. | | | | | | | | | | | | | | | | | |
| X1*12 | Loco | | | | | | | | | | | | | | | 1/6 | | 1 |
| | Pass | 1/90 | 2/16 | 1/8 | | | 1/28 | 2/23 | | | 1/4 | | 1/20 | 1/45 | | 2/20 | | 12 |
| | Cab. | | | | | | | | | | | | | 1/30 | | | | 1 |
| X1*13 | Loco | | | | | | | | | | | | | | | | | |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | | | | | | | | | | | | | | | |
| Total | | 26 | 3 | 5 | 1 | 1 | 6 | 10 | 3 | 2 | 3 | 3 | 4 | 14 | | 18 | 2 | |

## TABLE 5-28. MATRIX M2*, GENERAL CASE FOR OCCUPANT DEATH OR INJURY, OCCUPANT THROWN AGAINST HOSTILE STRUCTURE

NOTE: Numbers in matrix are: (Number of Injuries)/(Days Disabled per Injury)

M2* = Occupant death or injury, occupant thrown against hostile structure

.X2*j = Occupant thrown due to j, where j is as follows:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear-end collision |
| 03 | Head-on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

.Y2*b = Occupant is injured by b, where b is as follows:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Unknown |
| 14 | Boxes/baggage |
| 15 | Misc. equipment |
| 16 | Platform edge |

| | | Y2*01 | Y2*02 | Y2*03 | Y2*04 | Y2*05 | Y2*06 | Y2*07 | Y2*08 | Y2*09 | Y2*10 | Y2*11 | Y2*12 | Y2*13 | Y2*14 | Y2*15 | Y2*16 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X2*01 | Loco | | | | | | | | | | | | | | | | | |
| | Pass | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | |
| | Cab. | | | | | | | | | | | | | | | | | |
| X2*02 | Loco | | | 1/8 | | | | | | 1/5 | | | | 1/5 | 1/40 | | | 4 |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | 1/8 | | | | | | | | | | 1/10 | | | | 2 |
| X2*03 | Loco | | | | | | | | | | | | | | | 1/29 | | 1 |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | 1/10 | | | | | | | | | | | | | | 1 |
| X2*04 | Loco | | | 1/21 | | | 1/30 | 1/40 | | | | | | | | | | 3 |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | | | | | | | | | | | | | | | |
| X2*05 | Loco | | | | | | | | 1/10 | 1/8 | 1/60 | | | 1/60 | | | | 4 |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | 1/15 | | | | | | | | | | | | | | 1 |
| X2*06 | Loco | | | 3/15 | | | | 2/50 | 7/27 | | 1/4 | 5/26 | 12/27 | 7/27 | | | | 37 |
| | Pass | | | | | | | | | | | | | 1/30 | | | | 1 |
| | Cab. | 3/10 | 8/23 | 4/37 | 2/38 | | 1'30 | 1/14 | | | 3/12 | | 2/10 | 2/38 | | | | 26 |
| X2*07 | Loco | | | 1/90 | | | | | 3/7 | 2/15 | | 2/10 | 3/13 | | | | | 11 |
| | Pass | 1/14 | | 1/14 | | | | 3/25 | | | | | 1/21 | 2/10 | | 1/9 | | 9 |
| | Cab. | | 12/12 | 11/20 | 6/26 | | 6/23 | 6/16 | 3/33 | 1/3 | 1/28 | 2/9 | 4/29 | 3/5 | | 8/17 | | 63 |
| X2*08 | Loco | | | 1/90 | | | 1/10 | | 1/30 | | | | | | | 1/35 | | 4 |
| | Pass | 1/3 | 1/7 | 4/29 | | | 1/21 | | | | | | | | | 1/10 | | 8 |
| | Cab. | 6/28 | 6/4 | 10/23 | 3/19 | | 7/18 | 1/34 | | | | 2/15 | 3/19 | 4/12 | | 3/16 | | 45 |
| X2*09 | Loco | | | 1/5 | | | | | | 1/30 | | | | 1/45 | | | | 3 |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | 1/25 | 1/6 | | | 2/13 | | | | | 3/47 | 1/7 | | | | 8 |
| X2*10 | Loco | | | | | | | | | | | | 1/4 | | | | | 1 |
| | Pass | | | | | | | | | | | | | | 1/7 | | | 1 |
| | Cab. | | | | | | | | | | | | | | | | | |
| X2*11 | Loco | | | | | | | | 1/50 | 1/7 | | | 1/9 | | | | | 3 |
| | Pass | | | | | | | | | | | | | | | | | |
| | Cab. | | | | | | 1/4 | | | | | | | | | 1/30 | | 2 |
| X2*12 | Loco | | | | | | | | | | | | | | | | | |
| | Pass | 1/5 | 2/10 | 2/30 | | | | 1/14 | | | | 1/3 | | | | 3/10 | | 10 |
| | Cab. | | | 1/14 | | 1/45 | | 1/2 | | | | | | | | | | 3 |
| Total | | 12 | 29 | 45 | 12 | 1 | 18 | 18 | 16 | 7 | 6 | 12 | 30 | 24 | 2 | 19 | | |

## TABLE 5-29. MATRIX M3*, GENERAL CASE FOR OCCUPANT DEATH OR INJURY, LOOSE OBJECT INJURES OCCUPANT

NOTE: Numbers in Matrix are: (Number of Injuries)/(Days disabled per Injury)

M3* = Occupant death or injury, loose object injures occupant

.X3*j = Object is released due to j, where j is as follows:

| j | INJURY INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear-end collision |
| 03 | Head-on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other person |
| 12 | Other train motion |
| 13 | Vandal |

.Y3*b = Occupant is injured by b, where b is as follows:

| b | INJURY PRODUCING FACTOR |
|---|---|
| 01 | Floor |
| 02 | Table or desk |
| 03 | Bulkheads/walls/door flat |
| 04 | Stove |
| 05 | Shattered glass pane |
| 06 | Bars/rails/stancheons |
| 07 | Seat |
| 08 | Control console |
| 09 | Water cooler |
| 10 | Cabinet/locker/shelf |
| 11 | Door or window edge/frame |
| 12 | Persons own reaction |
| 13 | Unknown |
| 14 | Boxes/baggage |
| 15 | Misc. equipment |
| 16 | Platform edge |

|  |  | Y3*01 | Y3*02 | Y3*03 | Y3*04 | Y3*05 | Y3*06 | Y3*07 | Y3*08 | Y3*09 | Y3*10 | Y3*11 | Y3*12 | Y3*13 | Y3*14 | Y3*15 | Y3*16 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X3*01 | Loco |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Pass | N/A |  |  |  |  |  |  |  |  |  | 1/2 | N/A |  |  |  |  | 1 |
|  | Cab. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| X3*02 | Loco |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Pass | N/A |  |  |  |  |  |  |  |  |  |  | N/A |  |  |  |  |  |
|  | Cab. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| X3*03 | Loco |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Pass | N/A |  |  |  |  |  |  |  |  |  |  | N/A |  |  |  |  |  |
|  | Cab. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| X3*04 | Loco |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Pass | N/A |  |  |  |  |  |  |  |  |  |  | N/A |  |  |  |  |  |
|  | Cab. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| X3*05 | Loco |  |  |  |  | 1/4 |  |  |  |  |  | 1/180 |  |  |  |  |  | 2 |
|  | Pass | N/A |  |  |  | 1/10 |  |  |  |  |  |  | N/A |  |  |  |  | 1 |
|  | Cab. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| X3*06 | Loco |  |  |  |  |  |  |  |  | 2/17 |  |  |  |  |  |  |  | 2 |
|  | Pass | N/A |  |  |  |  |  |  |  |  |  |  | N/A |  |  |  |  |  |
|  | Cab. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| X3*07 | Loco |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Pass | N/A |  |  |  |  |  |  |  |  |  | 1/3 | N/A |  |  |  |  | 1 |
|  | Cab. |  |  |  |  |  |  |  |  |  |  | 1/10 |  |  |  |  |  | 1 |
| X3*08 | Loco |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Pass | N/A |  |  |  |  |  |  |  |  |  |  | N/A |  |  |  |  |  |
|  | Cab. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| X3*09 | Loco |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Pass | N/A |  |  |  |  |  |  |  |  |  |  | N/A |  |  |  |  |  |
|  | Cab. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| X3*10 | Loco |  |  |  |  |  |  |  |  |  |  | 1/10 |  |  |  | 1/30 |  | 2 |
|  | Pass | N/A |  |  |  |  |  |  |  |  |  | 2/10 | N/A |  |  | 1/10 |  | 3 |
|  | Cab. |  | 1/25 |  |  |  |  | 1/3 |  |  |  |  |  |  |  |  |  |  |
| X3*11 | Loco |  |  |  |  |  |  |  |  | 1/22 |  | 2/19 |  |  |  | 1/60 |  | 4 |
|  | Pass | N/A |  |  |  |  |  |  |  |  |  |  | N/A |  |  | 1/8 |  | 1 |
|  | Cab. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| X3*12 | Loco |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Pass | N/A |  |  |  |  |  |  |  |  |  | 1/100 | N/A |  |  | 2/7 |  | 3 |
|  | Cab. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| X3*13 | Loco |  |  |  |  | 1/5 |  |  |  |  |  |  |  |  |  |  |  | 1 |
|  | Pass | N/A |  |  |  | 6/2 |  |  |  |  |  |  | N/A |  |  | 1/3 |  | 7 |
|  | Cab. |  |  |  |  | 1/6 |  |  |  |  |  |  |  |  |  |  |  | 1 |
| Total |  |  | 1 |  |  | 10 |  | 1 |  | 3 |  | 10 |  |  |  | 7 |  |  |

## TABLE 5-30. MATRIX M4K, OCCUPANT IS BURNED WHEN HOT LIQUID IS SPILLED

NOTE: Numbers in Matrix are: (Number of Injuries)/(Days Disabled per Injury)

M4K = Occupant is burned when hot liquid is spilled. K indicates burn involvement

X4Kj = Hot spill is initiated, where j is the initiating factor as follows:

| j | INITIATING FACTOR |
|---|---|
| 01 | Tripped or lost balance |
| 02 | Rear-end collision |
| 03 | Head-on collision |
| 04 | Cross collision |
| 05 | Grade crossing collision |
| 06 | Hard coupling |
| 07 | Slack action/lurch/jerk |
| 08 | Braking |
| 09 | Derailment |
| 10 | Equipment failure |
| 11 | Person or other persons |
| 12 | Other train motion |
| 13 | Vandal |

X4Kb = Hot liquid is involved, where b is as follows:

| b | HOT LIQUID CAUSING BURN |
|---|---|
| 01 | Coffee |
| 02 | Cooking grease |
| 03 | Hot water |

| | | YK401 | YK402 | YK403 | Total |
|---|---|---|---|---|---|
| X4K01 | Loco | | | | |
| | Pass | | | | |
| | Cab. | | | | |
| X4K02 | Loco | | | | |
| | Pass | | | | |
| | Cab. | | | | |
| X4K03 | Loco | | | | |
| | Pass | | | | |
| | Cab. | | | | |
| X4K04 | Loco | | | | |
| | Pass | | | | |
| | Cab. | | | | |
| X4K05 | Loco | | | | |
| | Pass | | | | |
| | Cab. | | | | |
| X4K06 | Loco | | | | |
| | Pass | | | | |
| | Cab. | | | | |
| X4K07 | Loco | | | | |
| | Pass | | | | |
| | Cab. | 1/30 | | | 1/30 |
| X4K08 | Loco | | | | |
| | Pass | | 1/18 | | 1/18 |
| | Cab. | | | | |
| X4K09 | Loco | | | | |
| | Pass | | | | |
| | Cab. | | | | |
| X4K10 | Loco | | | | |
| | Pass | | | | |
| | Cab. | | | | |
| X4K11 | Loco | | | | |
| | Pass | | | | |
| | Cab. | | | | |
| X4K12 | Loco | | | | |
| | Pass | 2/9 | 1/30 | | 3/16 |
| | Cab. | | | | |
| X4K13 | Loco | | | | |
| | Pass | | | | |
| | Cab. | | | | |
| Total | | 3/13 | 2/24 | | |

### 5.3.4 Preliminary Hazards Analysis Matrix

Events identified in the fault tree were analyzed on the Preliminary Hazards Analysis Matrices. The Preliminary Hazard Matrix serves two purposes: (1) Means of isolating important hazard mechanisms and (2) Preliminary identification of methods to reduce engine and or their severity.

The injury initiating and injury producing factors from the injury matrices of the fault tree, as well as the other injury mechanisms were systematically entered on the columnar format of Table 5-31. Here the safety considerations which might be implemented to avoid injuries in the future, were discussed. The entries to the columnar format were kept in the general case for all factors, including type of vehicle. This was done to avoid repetition, since most of the safety practices are applicable to all vehicles. In a few instances the injury mechanism is vehicle type oriented. These were noted on the form.

## 5.4 RANKING OF INJURY PRODUCING MECHANISMS

Using the data from Table 5-27, charts were prepared showing the relative frequency of occurrence for the principal injury mechanisms for locomotive, passenger railcars and cabooses. Added to these charts is the average injury severity for each incident.

### 5.4.1 Locomotive Injury Mechanisms

Injury mechanism frequency of occurrence for locomotives is shown in Figure 5-13. The most frequent injury mechanism was impact with the bulkhead, door and window frame. Due to the rigid construction of these surfaces the severity of injury resulting from impact is the highest of all mechanisms (Tables 5-27 through 5-29).

Second in frequency and also second in severity were impacts with the floor (Figure 5-13). Impacts with the water cooler was third in frequency but the severity was relatively low. Miscellaneous equipment and the control console accounted for the next two mechanisms in the order of frequency of occurrence and the severities were in the medium range. Seats accounted for the next most frequent injury mechanism and the severity of the injury was above the medium range. The remaining injury mechanisms of handrails, cabinets, window glass, etc. were on the low end of the frequency scale.

### 5.4.2 Passenger Railcar Injury Mechanisms

In combining the many items of equipment which produced

# TABLE 5-31. PRELIMINARY HAZARD ANALYSIS

| HAZARD | CAUSAL FACTORS | SAFETY CONSIDERATIONS |
|---|---|---|
| X**02 Rear-End Collision<br>X**03 Head-On Collision<br>X**04 Cross Collision<br>X**05 Grade Crossing Collision<br>X**06 Hard Coupling<br>X**07 Slack Action/Jerk/Lurch<br>X**08 Braking<br>X**09 Derailment<br>X**11 Person or Other Person<br>X**12 Other Train Motion<br>X**13 Vandals | ● Elimination of these injury initiating factors is beyond the scope of this study. Hazard control in this study will be primarily through vehicle design to reduce hostile structure presented after one of these events occur. Future studies should address means of preventing these injury initiating factors through hazard analyses (subsystem, maintenance, operational). | |
| X**10 Equipment Failure | ● Seat pin failure caused occupant to fall (Loco.) | ● Double seat-height-retention should be provided. For example, a screw type adjustment could be locked by pressure from a seated person.<br>● Seat support should be sized for crash loads.<br>● Seat belts should be considered to minimize injuries resulting from collisions, shock action and hard couplings. |
| | ● Seat cushion slipped and caused occupant to fall | ● Provide positive security for cushion; cushion could be integral to seat. |
| | ● Seat failure | ● Size seat structure for crash loads. |
| | ● Bunk strap failed, allowing occupant to fall to lower bunk | ● Eliminate bunk strap design or provide for periodic safety inspections of the strap. |
| | ● Desk top hinge failed and permitted top to fall on person (Caboose) | ● Use drawers for storage; drawers should have device to prevent them from falling out due to train motions. |
| | ● Window fell (Loco.) | ● Use horizontal sliding windows; windows should latch at whatever position they are left. |
| | (Pass.) | ● Provide only emergency openings for windows. |

## TABLE 5-31 - Continued

| HAZARD | CAUSAL FACTORS | SAFETY CONSIDERATIONS |
|---|---|---|
| X**10 Equipment Failure (Continued) | ● Window stuck (strained muscle) (Loco.) | ● Acceptable window designs are available; proper maintenance must be practiced on equipment. |
| | ● Stairwell trap door (inadvertently raised and passenger fell into stairwell while boarding) | ● Provide interlock to retain trap door in position while boarding door is open. |
| | ● Stairwell trap door (sprung up striking a passenger) | ● Provide interlock to retain trap door in position while boarding door is open. |
| | ● Water cooler (broke away) | ● Water cooler should be located in a closet or behind a wall or bulkhead. See injury cause mechanism, IB, for further consideration for water coolers. |
| | ● Seat armrest broke (Loco.) | ● Seat should be designed for crash loads. |
| | ● Seat support failed (Loco.) | ● Seat should be designed for crash loads. |
| | ● Seat improperly secured in slot | ● See considerations for seat pin caused factors. |
| | ● Bolt (fastens seat to cab) came out (Loco.) | ● Use multiple fastening to secure seat to cab. |
| | ● Baggage rack failure (Pass.) | ● Overhead baggage storage should be avoided. Where it is employed, the baggage rack should completely contain the baggage and should be designed for a crash condition. The latch securing baggage compartment doors should be positive and should remain latched even in crashes where the structure may buckle. |
| | ● Air hose blew back causing injury | ● Locate all pressurized hoses outside the occupied areas. |
| X**11 Person or Other Person Initiates Injury | ● Person jumped and fell from bunk after being startled | ● Safety rails should be provided |
| | ● Struck self with stairwell trap door | ● Use steps which can be raised for platform passenger embarkment. This arrangement would eliminate the requirement for a stairwell trap door. |
| | ● Stuck finger in fan | ● Eliminate use of exposed blade fans. |
| | ● Closed door on engineer's hand (Loco.) | ● Use sliding door with soft edge seal. |

# TABLE 5-31 - Continued

| HAZARD | CAUSAL FACTORS | SAFETY CONSIDERATIONS |
|---|---|---|
| X**11 Person or Other Person Initiates Injury (Continued) | ● Struck knee on control stand | ● Pad the control stand. |
| | ● Dropped water cooler on foot | ● Water cooler should be located in a closet or behind a bulkhead and should be fillable from the outside without a requirement for changing water bottles. |
| | ● Closed window on hand (Caboose) | ● Use horizontally closing windows with soft edge seals. |
| | ● Bumped side while boarding (Loco.) | ● Stairs and walkways for entering the locomotive should be free of protrusions which could cause injury. |
| | ● Dove to floor to avoid injury | ● Consider using carpets inside locomotive to reduce injuries from fall to floor. |
| B. INJURY PRODUCING FACTORS | | |
| Y**01 Injury by Contact with Floor | ● Hardness | ● Consider using carpeting to reduce severity of impact. |
| | ● Abrasion | ● Consider using carpeting to reduce severity of impact. |
| | ● Limb twisted or broken | ● Provide hazard control by eliminating cause of fall. |
| Y**02 Injury by Contact with Desk or Table | ● Sharp edge causes lacerations | ● Eliminate tables or desks where practical. |
| | ● Edge causes contusion, bruise, or broken bones | ● Provide padded edge for tables and desks much like the padding used on tavern bars. |
| | ● Edge causes internal injury | ● Isolate desks and tables by walls or bulkheads. |
| Y**03 Injury by Contact with Bulkheads/Walls/Doors (flat area) | ● Hardness<br>● Abrasion | ● Consider resilient walls or doors which give but do not shatter. |
| Y**04 Injury by Contact with Stove | ● Hardness<br>● Sharp Edges | ● Eliminate exposed stoves and use flush wall heaters or heated air ducts. |
| Y**05 Injury by Glass Pane (Shattered) | ● Items thrown by vandals | ● Reduce size of windows. |
| | ● Crash impact | ● Use shatterproof windows. |

TABLE 5-31 - Continued

| HAZARD | CAUSAL FACTORS | SAFETY CONSIDERATIONS |
|---|---|---|
| Y**06 Injury Caused by Contact with Bars/ Stanchions/Safety Railings | ● Hardness and Rigidity<br>● Engine Rail<br>● Grab Post/Stanchion<br>● Handrail<br>● Pipe (Plumbing)<br>● Stove Guard Rail<br>● Safety Brace Pipe<br>● Bunk End Pipes | ● Grab Posts/Stanchions<br>These devices are provided to prevent loss of balance or to serve as a means of reestablishing balance during unexpected train motions.<br>There is no measure of the number of injuries that these devices prevent but it is most likely that they prevent more injuries than they cause. Some considerations which might reduce their hazard are: terminate stanchions and other vertical posts at seats or divider partitions where possible, pad the lower section of stanchions which extend to the floor, use large diameter to increase contact area, use energy absorbing stanchions.<br>● Protective Railings (Stairs and Elevated Platforms)<br>Some kind of protective device is essential to prevent day-to-day falls from stairs, platform, balconies, etc. Where possible, consideration should be given to using protective barriers instead of rails. A configuration resembling the sides and railing of most escalators offers better injury protection than a pipe rail or other such devices.<br>● Safety Brace Pipe/Bunk End Pipes<br>Use resilient brace bumpers instead of solid pipes.<br>● Stove Guard Rail<br>Eliminate exposed stoves. Use flush wall heaters or heated air ducts. |
| Y**07 Injury Caused by Contact with Seat | ● Hard edges | ● All seat edges should be delethalized by padding and by providing large edge radii.<br>● Pedestal or cantilever seat support should be used to eliminate exposed support edges.<br>● Eliminate foot rests. |
|  | ● Seat arm rests | ● Use a riser between the seat pad and the arm rest. This will increase the impact area that a seated person would experience from side motions.<br>● Pad all exposed surfaces of the armrest.<br>● Use large radii between surfaces. |
|  | ● Seat back | ● Seat backs should be full height to provide support for head and upper body of occupants. |

## TABLE 5-31 - Continued

| HAZARD | CAUSAL FACTORS | SAFETY CONSIDERATIONS |
|---|---|---|
| Y**07 Injury Caused by Contact with Seat (Continued) | ● Seat back (continued) | ● High seat backs will offer greater protection to people who are thrown across or against the seat.<br>● Pad all sides and edges of seat back.<br>● Use soft seat-back passenger-assist (eliminate pipes and sharp metal assists). Transbus has incorporated soft assists.<br>● Locate seat back assists above shoulders of seated passengers. |
| Y**08 Injury Caused by Contact with Control Console | ● Hard Sharp edges | ● Pad all edges<br>● Use large radii between surfaces |
| | ● Protruding controls (handles, levers, toggle switches) | ● Eliminate handles, levers, toggle switches and other such protrusions which can impale or cause internal injury. |
| | ● Radio bracket/mount | ● Build radio into console. |
| | ● Hard surfaces | ● Eliminate heavy valve bodies from the locomotive cab. These can be activated remotely by less lethal devices on the console. |
| | ● Brake valves<br>● Brake lever<br>● Console surfaces | ● Make console surfaces of resilient materials. |
| Y**09 Water Cooler (Loco. and Caboose) | ● Broken glass<br>● Bottle hits person<br>● Person impaled by valve<br>● Hard edges<br>● Sharp edges | ● Build water cooler into the cab or caboose so that the unit can be externally filled and so that no edges or protrusions are exposed to occupants of the vehicles. Spigot should be recessed into wall or bulkhead. An inexpensive water system which could be adapted to rail vehicles is currently being manufactured for recreational vehicles. |
| Y**10 Cabinets/Lockers/ Shelves | ● Hard/sharp edges | ● All cabinets or lockers should be built-in to eliminate edges. |
| | ● Protruding handles | ● Sliding doors should be used (hinged doors open into occupied space and present hostile edges).<br>● Door latches and releases should be recessed.<br>● All shelves should be behind sliding doors. |

## TABLE 5-31 - Continued

| HAZARD | CAUSAL FACTORS | SAFETY CONSIDERATIONS |
|---|---|---|
| Y**11 Injury Caused by Door/ Window (Edge/Frames) | • Hard/sharp edge | • Where air conditioning is provided, use non-opening windows which are flush with inside wall.<br>• Use horizontally sliding windows which are flush with inside wall.<br>• Eliminate sills and frames.<br>• Use large radii at surface intersections. |
| Y**12 Injury Results from Person's Own Reaction to the Initiating Factor | • Strain/sprain | • Provide adequate grab devices.<br>• Provide seat belts to retain people. |
| Y**13 Unknown | | |
| Y**14 Injury Caused by Boxes/Baggage | • Sharp edges | • Store baggage in separate compartments. |
| | • Heavy mass | • Store carry-on baggage under seats.<br>• If storage above seat is provided, use positive latching doors to retain the items. |
| Y**15 Injury Caused by Miscellaneous Items | • Protruding items<br>  • Heater motor<br>  • Thermostat<br>  • Electrical box<br>  • Fire extinguisher | • Recess all such items into the walls or bulkheads. |
| | • Hard sharp edges<br>  • Bunks<br>  • Platform<br>  • Work basin<br>  • Toilet<br>  • Ice chest/box<br>  • Washing machine<br>  • Benches<br>  • Chair<br>  • Broiler pan<br>  • Oven door | • Where possible, these items should be built-in or recessed so that edges are eliminated.<br>• Where edges are unavoidable, they should be padded and large radii should be used. |
| | • Steps | • Use carpeting on steps where practical.<br>• Provide adequate hand rails to prevent falls. Handrails should extend to ground level. (Add rails to door.) |
| | • Foot rests | • Eliminate foot rests. |

## TABLE 5-31 - Continued

| HAZARD | CAUSAL FACTORS | SAFETY CONSIDERATIONS |
|---|---|---|
| Y**15 Injury Caused by Miscellaneous Items (Continued) | ● Fan blade | ● Do not use exposed blade fans. |
| | ● Stairwell trap door | ● Use elevating steps to provide for platform entry into passenger cars. |
| | ● Object thrown by vandal | ● Use small windows. |
| | | ● Make windows shatterproof. |
| | ● Light fixture | ● Use nonbreakable fixtures. |
| | ● China plate | ● Use nonbreakable dishes. |
| | ● Hot ashes | ● Eliminate coal-fired stoves. |
| | ● Air hose | ● Eliminate pressurized hoses from locomotive cab. |
| | ● Steam generator/exhaust | ● Locate such equipment so that it does not present a hazard to personnel. |
| Y**16 Injury Caused by Platform Edge | ● Hard/sharp edge | ● Eliminate platform where possible. |
| | | ● Use large radii corners or edges. |
| II. OCCUPANT DEATH OR INJURY BY BURN | | |
| | ● ODI, occupant falls against hot surface, M1J<br>ODI, occupant thrown against hot surface, M2J<br>ODI, loose hot surface burns occupant | ● There was no incident of burn by a hot surface in the data sample. If this hazard had occurred in the data it would have been considered under the general analysis of 1*. |
| | ● Occupant is burned when hot liquid is spilled, Matrix M-40 | |
| | ● Initiating factors related to vehicle interior design | |
| | ..X4001 - Occupant trips or slips | ● See X**01 discussed above. |
| | ..X4002 - Equipment failure | ● See X**10 discussed above. |

## TABLE 5-31 - Continued

| HAZARD | CAUSAL FACTORS | SAFETY CONSIDERATIONS |
|---|---|---|
| II. OCCUPANT DEATH OR INJURY BY BURN (Continued) | ● Hot liquids | |
| | .X4001 - Coffee | ● Keep coffee at 180°F or less. |
| | .X4002 - Grease | ● Eliminate use of hot grease cooking onboard a train. |
| | ● ODI (burn) by hot liquid from source outside the vehicle | ● There was one incident where a train hit an asphalt truck and a trainman received burns which cost 5 days disability. No train changes are recommended. |
| | ● ODI (burn) occupant mistakingly contacts hot surface | ● The data had no record of this hazard occurring. This is probably indicative that hot surfaces are sufficiently reduced or protected. New designs should continue to provide adequate consideration. |
| | ● Death or injury by fire evolved from within the train | |
| | ● Locomotive fires originated by crash | ● Diesel fuel is the most likely flammable substance involved in locomotive fires. Current fuel tanks are located between the running gear in a protected, isolated position. Consideration should be given to improving the impact resistance of the fuel tanks. (Burn injuries from this cause usually result in a high number of days disabled or fatalities.) |
| | ● Other train fires, kerosene stove exploded | ● Eliminate kerosene stove. Use flush wall heaters or hot air ducts. |
| | ● Death or injury by fire from flame source outside the vehicle | ● Trainmen were injured or killed when fire from an outside source, such as a gasoline truck or a propane truck, was drawn into the locomotive by the ventilation system. Smoke and flame detectors in the inlet duct could be used to stop the ventilation system in such instances. |

## TABLE 5-31 - Continued

| HAZARD | CAUSAL FACTORS | SAFETY CONSIDERATIONS |
|---|---|---|
| III. OCCUPANT DEATH OR INJURY BY SHOCK | • Traumatic event | • Little can be done to vehicle design to minimize shock injury after a traumatic experience has occurred. Pre-event considerations are beyond the scope of this study. Shock can be minimized if railroad personnel are properly trained to handle emergencies and shock cases. |
| IV. ELECTRICAL SHOCK | | • No instance of electrical shock was recorded in the data sample. |
| V. OCCUPANT INJURY BY PARTICLE/CHEMICAL IN EYE | • Fire extinguisher discharged in eye | • No design change is proposed. Railroads should instruct their personnel on the proper use of fire extinguishers. |
| VI. OCCUPANT DEATH OR INJURY BY SMOKE/TOXIC FUMES | • Trainmen overcome by diesel fumes | • No change is proposed. Incidence of this occurring is low and possible solution would be expensive (such as using charcoal filter). |

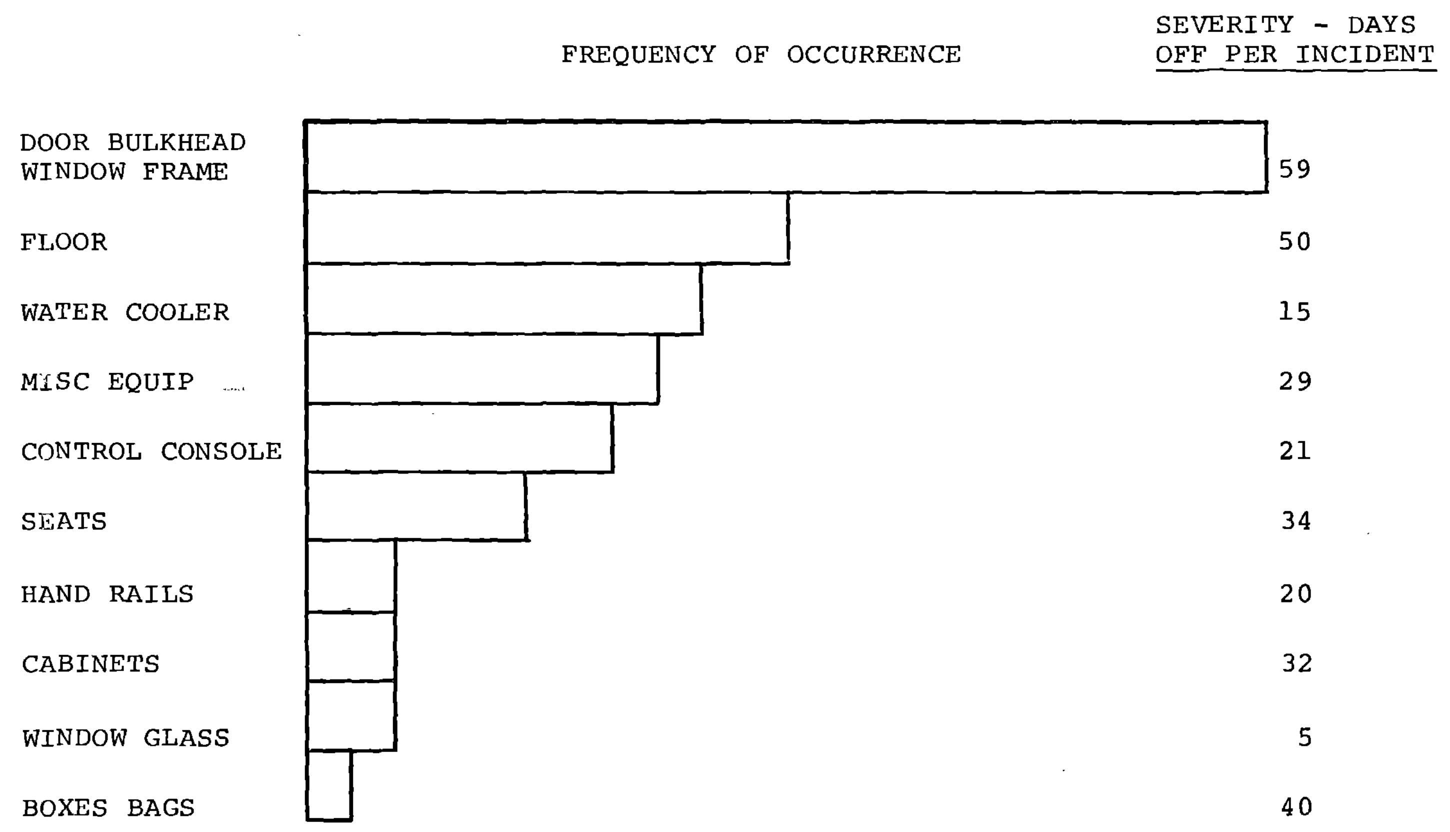


*Figure 5–13. Locomotive Injury Mechanism Frequency*

injury in the passenger railcars, miscellaneous equipment was the most frequently occurring injury mechanism (Figure 5-14). However, the individual pieces of equipment causing the injury reoccurred no more than two or three times in the survey. These ranged from lavatory furnishings to food preparation equipment such as dish washers, cooking stoves, and dining car equipment. The severity of injury produced by these equipments was relatively minor (Tables 5-27 through 5-29). Bulkheads doors and window frames produced the next highest frequency of injury and the severity of the injuries was from minor to moderate. Seats accounted for the third highest frequency of injury producing mechanisms. The resulting injury averages fell into the moderate range. Impact with the floor and injuries by window glass occurred at an average frequency (Figure 5-14). The floor impacts produced severe injuries while the window glass resulted in very minor injuries. Impacts with tables and counters occurred at less than an average frequency and resulted in minor injuries. Injuries from handrails, entrance platforms, luggage, cabinets etc., occurred in frequently.

### 5.4.3 Caboose Injury Mechanism

The most frequently occurring mechanism causing injury in cabooses involved bulkheads, doors or window frames (Figure 5-15). The severity of injuries associated with these mechanisms was moderate. Tables and desks were the mechanism causing the next greatest number of injuries and the injuries were minor to moderate. Bars rails and stantions ranked along with impacts to the floor as the third greatest cause of injury. The railing impacts caused moderate injury while floor impacts produced serious injuries. Injuries due to impacts with a stove or a seat occurred on an average frequency and produced moderate injuries. Impacts with cabinets, lockers, control valves, water cooler, or as a result of breaking window glass occurred at a low frequency and moderate injuries resulted.

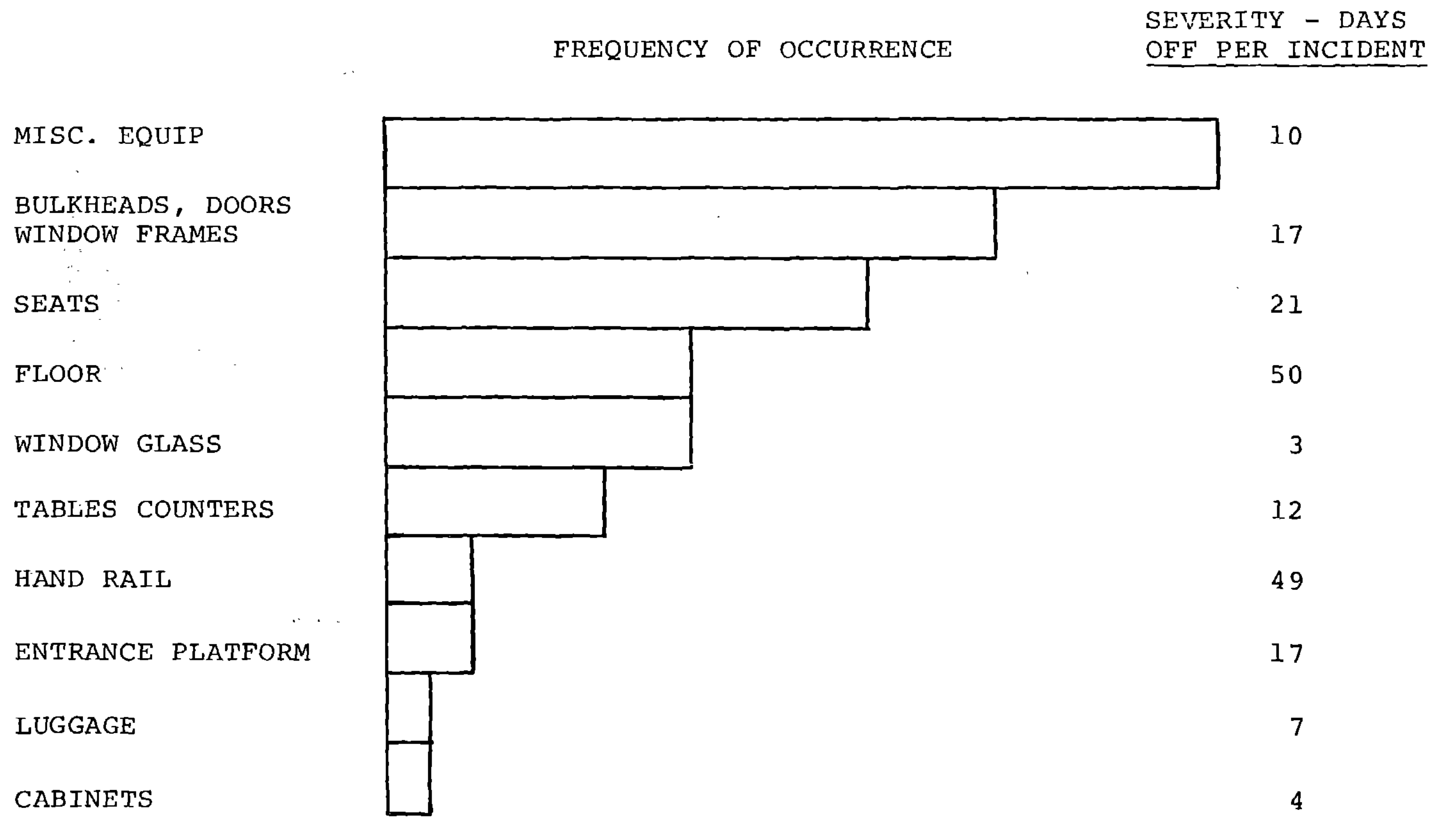


*Figure 5–14. Passenger Railcar Injury Mechanism Frequency*

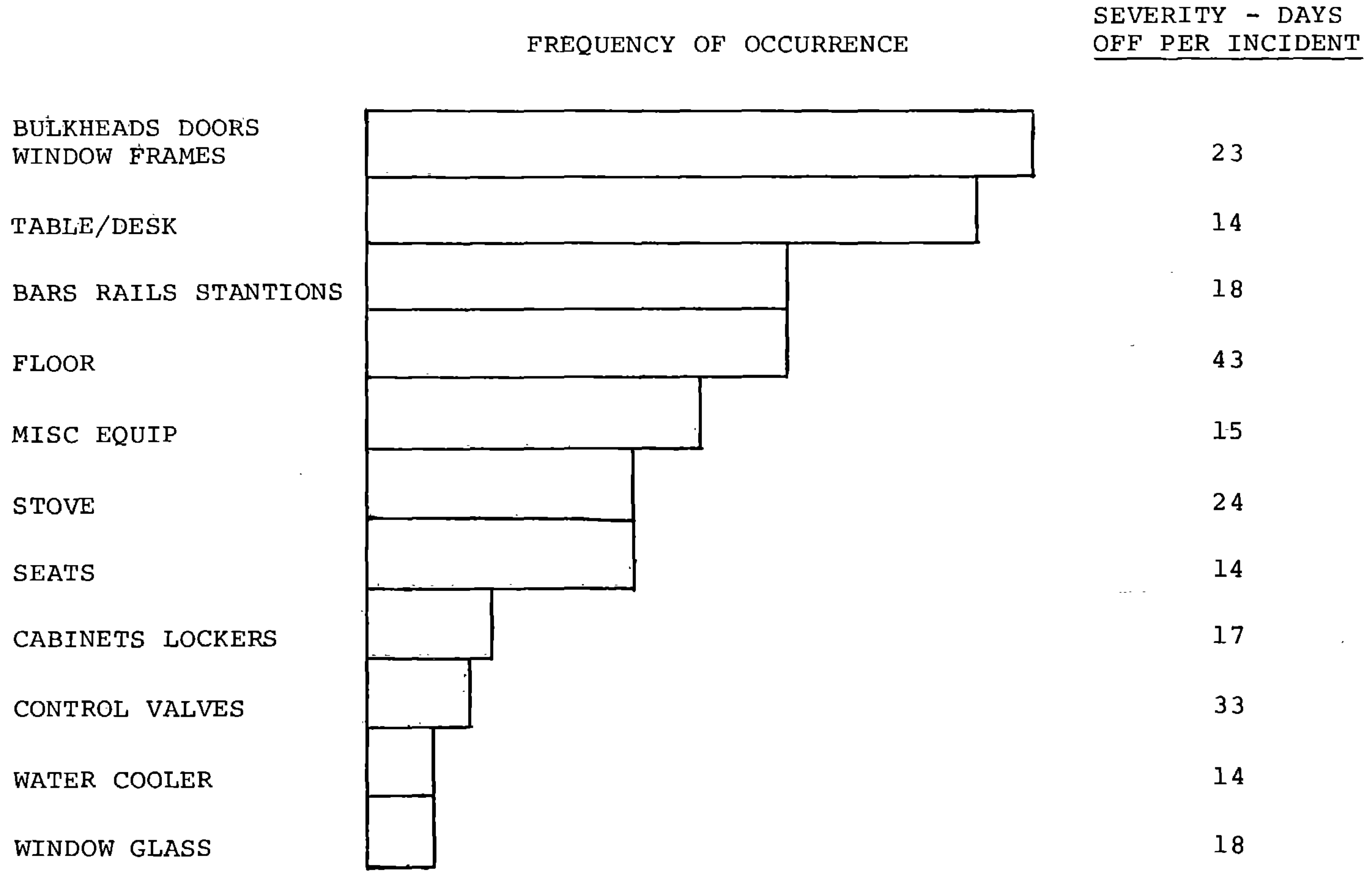


*Figure 5–15. Caboose Injury Mechanism Frequency*

# 6. CRASH SIMULATION

The primary purpose of trying to simulate an injury mechanism is to have a model with which injury minimization devices and procedures can be tested. Whatever procedure is used should clearly demonstrate a verification of mechanisms and show the quantitative benefit for a particular mitigation in reducing the ranking of a causal factor.

## 6.1 COMPARISON OF AVAILABLE COMPUTER PROGRAMS

A review of available models of vehicle occupants in crash environments was conducted with a view to selecting a prospective candidate for adaptation to rail veiicle accidents. In the review activity maximum usage was made of the results of a previous critical review by Karnes and Tocher[1] of five existing occupant simulation programs.

In the Karnes and Tocher review, five programs readily available from the public domain were identified and evaluated in actual simulation applications. The five programs involved are:

CAL3D: A three-dimensional model developed by Cornell Aeronautical Laboratory.

ROS: "Revised Occupant Simulation" is a two-dimensional model also developed by Cornell Aeronautical Laboratory.

SIMULA: A two dimensional model developed by Arizona State University and Dynamics Science.

TTI: Texas Transportation Institute's three-dimensional model.

UCIN: University of Cincinnati's three-dimensional automobile occupant simulation.

In all five models the occupant is represented as a lumped mass 'stickman' with joint restraints of various types. They differed among themselves in the number of segments and mass

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[1] Karnes, R.N. and Tocher, J.L.: "BIODYNAMICAL PROBLEMS RELATED TO TRANSPORTATION VEHICLES - DIGITAL SIMULATION OF OCCUPANTS," Surveys of Research in Transportation Technology, ASME Document AMD - Vol. 5

points per occupant model. CAL3D has the flexibility of being able to handle more than one occupant simultaneously.

Interior features of the vehicle are modelled in a variety of ways. SIMULA provides for an occupant seat model in the form of a space truss. Seat cushions are also provided. Seat belts and shoulder harness models are available. No other interior features are considered although the flexibility of the seat modelling concept can be adapted to a representation of interior features such as cockpits, windshield, etc. UCIN provides for seat belts and shoulder harness only. CAL3D provides a general rectangular panel model which can be used to construct both interior features and external vehicle structure. Seat belt and shoulder harness models are also available. ROS and TTI have interior feature representation similar to CAL3D.

Load deformation characterization of the various features interacting with the occupant, is represented to varying degrees of sophistication in the five programs. CAL3D, ROS, and TTI provide for general non-linear, energy-absorbing (inelastic) relations for all elements. SIMULA provides for a limited number of inelastic seat elements. All other features (cushions, seat belts, etc.) are characterized by non-linear elastic relations. UCIN has no energy dissipating elements in the model.

All five programs were found to contain the following deficiencies:

- The input schemes are fixed-field. This is unsatisfactory for interactive remote terminal use because fixed-field data is difficult to construct or edit on-line. Free-field schemes should be substituted.

- There is no default data built into any of the programs. The user must specify relatively large amounts of data describing the occupant properties. Geometry, mass properties, and joint properties of "standard" men should be built into the programs, with the user having the option of overriding built-in (default) data.

- There is no provision in any program for checking "reasonableness" of input data. In view of the relatively large amount of computer resources required for program execution, data consistency checks are essential.

Numerical integration schemes used in the five programs varied widely. SIMULA uses a simple two stage predictor-corrector algorithm which proved to be reasonably accurate and stable for small but acceptable integration time step. ROS has a fourth order, fixed step Runge-Kutter integrator which gave very poor results even for a time step one-tenth that used in SIMULA. A fourth order, variable step Runge-Kutter scheme used by both UCIN and TTI was found to be adequate. CAL3D integration strategy is non standard and not well documented but yielded reasonably accurate results.

The results of the Karnes and Tocher review indicated that the SIMULA model most closely met the following selection criteria: two dimensional model, with capabilities in human body modelling, software structure, computational speed and accuracy, and simple user interface. Improvements however, were needed in these features and the PROMETHEUS program was created from the original SIMULA model.

## 6.2 PROMETHEUS PROGRAM

The Prometheus program is a digital computer software package for the analytical simulation of occupant dynamics in a vehicle crash situations involving longitudinal impact of the vehicle and longitudinal, vertical and pitching motion of the occupant. It was developed by the Boeing Computer Services (BCS) under Office of Naval Research Contract N00014-72-C-0223 as a greatly enhanced version of an existing program, SIMULA, developed at Arizona State University for Dynamic Science under a NASA contract.

### 6.2.1 Reason for Selection

The Prometheus program was selected for the following reasons:

a. Good correlation with Navy crash results.

b. Ability to analyze elastic-plastic behavior of structure

c. Advanced integration solution (algorithm)

d. Batch or interactive computer solution

e. Detailed or descriptive solution

### 6.2.2 Prometheus Program Capabilities

The Prometheus program simulates a vehicle occupant's dynamics in a crash situation in which the primary motions of both occupant and vehicle before and after the crash are in a single plane. It incorporates a mathematical model of the occupant consisting of seven segments representing the neck, upper and lower arms, upper and lower legs and upper and lower torso. Relative motion of the segments at the joints is restrained by coulomb and viscous frictional resistances and by joint "stops" representing physical limits of limb relative mobility. The mass of the occupant is lumped at eight points located at the joints and extremeties of the body segments and representing the head, chest, torso, pelvis, knees, feet, elbows and hands. Each lumped mass has translational degrees of freedom in the vertical and longitudinal directions. Each pair of limbs (arms and legs) is assumed to move in unison as though tied to each other. The body thickness at the various node points is represented by an offset radius.

A considerable flexibility exists in the spatial orientation of the body segments so that various configurations of the occupant, including seated and standing stances, can be easily simulated.

A "seat" model is provided in the form of a space truss whose geometric configuration is specified by the user. The nodes of the seat are either attached to the vehicle or free in space. They can also be identified as attachment points for seat belt or shoulder harness restraint systems. The seat element weights are lumped (internally within the program) at the nodes. The load deformation properties can be one of four types:

- non-linear elastic spring
- viscous damper
- tension only inelastic spring
- compression only inelastic spring

A seat cushion model can be specified for any seat element on either of its two sides and provides the only means of interaction forces between occupant and the seat; i.e., seat elements not associated with cushions are "transparent" to occupant penetration. The cushion model is characterized by non-linear elastic load-deformation relations.

Seat belt and shoulder harness restraint models are also provided with non-linear inelastic load-deformation characteristics. The crash environment is represented in the model by an acceleration-time pulse applied to the vehicle.

The dynamic equations of the model are represented in a general manner by a Lagragian formulation which takes account of the ever changing geometry and loading of the various elements. A numerical integration scheme with variable time step and error control is used to solve the equations.

The program is written to be highly user oriented. It runs on a CDC 6600 computer in either a batch or interactive mode. In either node the input data is free format with pre-established default values for practically all items. The output consists of time histories of displacements, velocities and accelerations of the occupant lumped masses and of the seat nodes; seat element, seat cushion, seat belt and shoulder harness force time histories; and graphical display of the occupant configurations at a number of selected time frames. In the interactive mode of execution, the user controls the amount and type of output.

### 6.2.3 Prometheus Program Limitations

The limitations of the Prometheus program are as follows:

a. Limited number of nodes prohibits detailed description of crash environment

b. Limbs and body segments are not load limited

c. Costly for general use or preliminary evaluation of structural crashworthiness

d. Body motions for an unrestrained occupant are more difficult to simulate than a restrained occupant for which the program was developed

### 6.2.4 Program Modifications Required

A number of minor modifications were made to the PROMETHEUS program to enhance its application to rail accidents. They include:

1. HIC - A routine was added to calculate the HIC index.[1] The original program calculated the GADD index.[2]

2. Cushion Sidedness - To use the seat cushion modelling capability for representation of features other than actual seats (e.g., padded partitions, containment buffers, etc.) it was necessary to introduce a "sidedness" index to distinguish between the impacted face and the face against the backup structure.

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[1] "Occupant Crash Protection in Passenger Cars, and Multipurpose Passenger Vehicles, Trucks, and Buses", Motor Vehicle Safety Standard No. 208, National Highway Transportation Safety Administration, Department of Transportation, Washington, D.C.

[2] C. W. Gadd, "Use of a Weighted-Impulse Criterion for Estimating Injury Hazard," Proceedings of Tenth Stapp Car Crash Conference,p 12, paper 660793, New York Society of Automotive Engineers, Inc., 1966.

3. Restart Capability - A modification was made to permit a given simulation to be terminated at some point in time and subsequently re-started from that time.

4. Pitching Accelerations - The basic capability of the program was upgraded to include consideration of pitching accelerations of the vehicle.

5. Limb Reactions - Arms and legs were added to the model to obtain dynamic interaction of limbs of an unrestrained occupant with impact points remote from the seat. Original model reacted all torso loads into the seat through a restraint system.

6. Mass Distribution - Point masses were replaced with distributed masses to get inertia effects.

### 6.2.5 Experience with Prometheus Program and Results

In order to demonstrate the Prometheus model performance a seated rail vehicle occupant was used to show the dynamics during a collision. The scenario is of a seated passenger, in a passenger railcar, during collision, being thrown into the back of the adjacent seat. Velocities, accelerations, and times were determined for the areas of the body which impacted the seat back. Graphic displays of the occupants time history showing plots, critical body segment velocities and accelerations are produced by the Prometheus program. These results are included in Appendix A.

The impact velocity and total body motions are calculated internally in the Prometheus Program. The user specifies the mass distribution, initial orientation of the occupant, stiffness and locations of the car interior, and the vehicle deceleration-time pulse from which all motion and reactions are calculated. This is a great advantage since no assumptions involving body motion or impact speed are required by the user.

This program also considers frictional forces, restraint force, body joint rotation and viscous damping forces. The knee/seat back impact velocity calculated from the Prometheus Program was 105 in/sec. The head impact velocity calculated in the Prometheus Program was 100 in/sec. However, the occupant represented in the Prometheus Program was a dummy with a flexible rubber neck which caused the head velocity to oscillate between 70 in/sec and 120 in/sec before impact. This oscillation would not be expected or experienced in an actual collision, and the overall effect on the answer is small.

Using the maximum acceleration data for the head and knees, forces of 325 lbs were exerted on the knees, the fracture threshold being 1700 lbs. The head experienced a HIC index of 1.2 compared to the HIC index of 1000 which can be fatal. Head or knee injury, if any, experienced by the occupant in the above scenerio would be minor.

## 6.3 ALTERNATE METHODS FOR SIMULATION

The single degree of freedom model provides an excellent initial design tool from which an order of magnitude answer can quickly and easily be determined. A schematic presentation of the model is shown in Figure 6-1. This model assumes that an occupant collision which could involve various body segments impacting different surfaces can be represented by a series of individual body segment masses impacting into nonlinear springs. Each individual body segment collision is characterized by an effective mass and impact speed. This solution technique assumes that both the motion and impact velocity of the occupant can be determined either from analytical approximations or actual crash data. The determination of impact velocity can be complex with the simultaneous application of vehicle deceleration and reaction forces to the body. To simplify the analysis the assumption can be made that the deceleration pulse is completed prior to occupant impact. In some cases this may result in a conservative solution. The idealization of the impact as a pure mass and spring system also is conservative since it does not consider energy losses from friction damping or structural deformation. The predicted impact forces would greater than actually experienced.

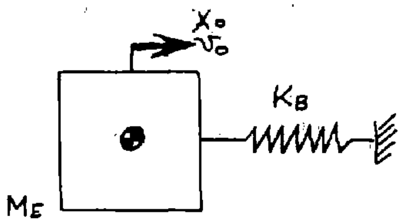
### 6.3.1 Alternate Method Simulation Approach

The single degree of freedom simulation method was used with the same accident scenario used for the Prometheus test case which was of a passenger being hurled forward into the adjacent seat back. This alternate method idealizes the accident as two collisions; one involving the mass of the pelvis and upper leg impacting the seat back center and a second collision involving the head mass and the upper seat back cushion.

In order to calculate the potential injury level with the one degree of freedom model, the impact velocity and effective body mass must be determined. The impact velocity for the knee impacting into the seat back center was calculated by numerically integrating the train deceleration-time pulse. The knee/seat back impact velocity calculated by this method was 120 in/sec.

The pelvic and upper leg are assumed to be the effective body segment mass in this knee/seat back collision. This assumption is based upon a normal impact of the seat back with the knees which is the most probable strike in a standard seated position. The calculated knee impact force using the one degree of freedom model was 490 lbs.

The next "individual impact" idealized using the single degree of freedom model was the head and upper seat back interaction. The impact velocity of the head was calculated using the model presented in Figure 6-2. This model idealizes



KINETIC ENERGY

$$T = 1/2 \cdot M_E \cdot \dot{X}_o^2$$

POTENTIAL ENERGY

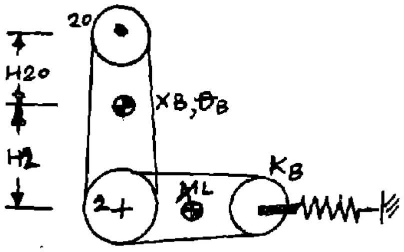
$$V = 1/2 \cdot K_B \cdot X_o^2$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{X}_o}\right) = M_E \cdot \ddot{X}_o$$

$$\frac{\partial V}{\partial X_o} = K_B \cdot X_o$$

$$\ddot{X}_o = -\frac{K_B}{M_E} \cdot X_o$$

Figure 6–1. Single Degree of Freedom Model



### GENERALIZED COORDINATES

$X_B \equiv$ UPPER BODY TRANSLATION
$X_L \equiv$ LOWER BODY TRANSLATION
$\theta_B \equiv$ UPPER BODY ROTATION

### KINETIC ENERGY

$$T = 1/2 \cdot M_B \cdot \dot{X}_B^{\,2} + 1/2 \cdot M_L \cdot \dot{X}_L^{\,2} + 1/2 \cdot I_B \cdot \dot{\theta}_B^{\,2}$$

### POTENTIAL ENERGY

$$V = 1/2 \cdot K_B \cdot X_2^{\,2}$$

### TRANSFORMATION EQUATIONS

$$X_1 = X_L$$

$$X_2 = X_B - \theta_B \cdot H_2$$

$$X_L = X_B - \theta_B \cdot H_2$$

Figure 6–2. Lumped Mass Dynamic Model for Head Impact Velocity Calculation

SUBSTITUTING INTO ENERGY EQUATIONS

$$T = \tfrac{1}{2}\cdot M_B\cdot \dot{X}_B^{2} + \tfrac{1}{2}\cdot M_L\cdot\left(\dot{X}_B - \dot{\theta}_B\cdot H2\right)^{2} + \tfrac{1}{2}\cdot I_B\cdot\dot{\theta}_B^{2}$$

$$V = \tfrac{1}{2}\cdot K_B\cdot\left(X_B - \theta_B\cdot H2\right)^{2}$$

SOLVING $\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_r}\right) + \frac{\partial V}{\partial q} = \frac{\partial W}{\partial q}$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{X}_B}\right) = M_B\cdot\ddot{X}_B + M_L\cdot\left(\ddot{X}_B - \ddot{\theta}_B\cdot H2\right)$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\theta}_B}\right) = M_L\cdot\left(\ddot{X}_B - \ddot{\theta}_B\cdot H2\right)(H2)(-1) + I_B\cdot\ddot{\theta}_B$$

$$\left(\frac{\partial V}{\partial X_B}\right) = K_B\cdot\left(X_B - \theta_B\cdot H2\right)$$

$$\left(\frac{\partial V}{\partial \theta_B}\right) = K_B\cdot\left(X_B - \theta_B\cdot H2\right)(H2)(-1)$$

PLACING IN MATRIX FORM:

$$\begin{bmatrix} MB + ML & -ML\cdot H2 \\ -ML\cdot H2 & ML\cdot H2^{2} + IB \end{bmatrix}\begin{bmatrix} \ddot{X}_B \\ \ddot{\theta}_B \end{bmatrix} +$$

$$\begin{bmatrix} KB & -KB\cdot H2 \\ -KB\cdot H2 & KB\cdot H2^{2} \end{bmatrix}\begin{bmatrix} X_B \\ \theta_B \end{bmatrix} = 0$$

*Figure 6–2 — Continued*

the upper body as a rigid link rotating about the pelvis. The reaction force from the knee impact is applied at the pelvis causing rotation of the upper body about the pelvis.

There is no rotational stiffness of the pelvic joint in this model; this again is a conservative assumption since pelvic rotational stiffness would decrease the head and upper seat back impact velocity. The head impact velocity calculated using this model was 135 in/sec.

The outputs from the one degree of freedom model were Total Force and HIC Index. The HIC Index is defined by the following equation:

$$HIC = (t_2-t_1)\left[\frac{\int_{t_1}^{t_2} a\,dt}{t_2-t_1}\right]^{2.5}$$

where $a$ = Lead accel. in G's

$t_2-t_1$ = Time interval in collision in which HIC is maximum

A value of 1000 is considered to be fatal on the HIC Index. The HIC calculated using the single degree of freedom model was 3.5.

The velocities for head impact were 100 in/sec by Prometheus and 135 in/sec by hand calculations. The velocities for knee impact were 105 in/sec by Prometheus and 120 in/sec by hand calculations. Velocities determined by both methods compare favorably being in the same order of magnitude. The manual determination of the impact velocity is higher as expected, based upon conservative assumptions. Velocities of the hip and knee respectively versus time were plotted by Prometheus (Appendix A) and show that the pelvic mass and knee actually behave as a single effective body segment mass as assumed in the one degree of freedom analysis.

Good correlation was obtained with both methods in obtaining head and knee impact forces. The calculated knee impact force using the one degree of freedom model was 490 lbs compared to a knee force from the Prometheus Program of 325 lbs. The HIC Index calculated using the single degree of freedom model was 3.5 and 1.2 using the Prometheus Program.

A comparison of the two methods is shown in Table 6-1.

TABLE 6-1. COMPARISON OF PROMETHEUS MODEL AND SIMPLE MODEL

| | One D.O.F. Model | Prometheus Model |
|---|---|---|
| Body Kinematics | Body segment impact velocity only input; deceleration pulse must be over before collision, simple motion only can be analized, motion assumed by user | Handles all body motion where deceleration pulse can be defined - motion calculated by program |
| Body Mass | User must evaluate effective mass in collision | User defines individual body segment masses and flesh thickness program solves for motion |
| Body Orientation | Normal strike to cushion assumed | Program determines angle of incidence |
| Interior Definition | Interior defined as non-linear elastic spring | Seat can be modeled for energy absorbing type column, nonlinear elastic-plastic cushion-nonlinear elastic spring |
| External Forces | Not handled in analysis | Models frictional force at seat and foot |
| Constraint Systems | Not handled in analysis | Models seat belt and shoulder harness - forces on occupant |
| Solution Requirements | Desk calculator hand solution | Large digital computer |
| Output | Numerical output | Numerical output<br>Cross-plots of body velocities, and acceleration, joint loads plots shows motion of occupant |
| Advantages | Simple to use, inexpensive, simpler to change cushion values, etc., rapid solution | Handles complex kinematic motions, external body forces, detailed seat models, excellent output format |
| Disadvantages | Cannot analize complex body kinematics with external forces, | Costly, only as accurate as deceleration pulse, subject to computer turnaround times. |

### 6.3.2 Alternate Method Simulation Procedure

Based on the excellent correlation between the Prometheus Program results and the alternate simulation results a graphical solution was developed to permit the engineer to quickly evaluate the injury potential of rail vehicle interiors. To use these graphical solutions, the design engineer must know the rail vehicle deceleration pulse, the effective body mass, and the effective stiffness of the object impacted by the occupant.

#### 6.3.2.1 Rail Vehicle Deceleration Pulse

A simple FORTRAN coded program was developed to provide a consistent basis for estimating the vehicle acceleration/ deceleration pulses occurring in longitudinal impacts. The program currently runs on an IBM 370/58 computer using the WATFOR compiler.

The idealized model for the program consists of a linear chain of lumped masses interconnected by axial springs. The load-deflection characteristics of the springs are considered to be nonlinear inelastic with compressive loads only being considered. Extensional deflections from zero load are assumed to occur at zero load. Each mass has a single degree of freedom along the axis of the chain and an initial velocity specified by the user. The program determines the time history solutions of the masses, subject to the specified initial velocities, and the various spring forces.

In applying the program to the train crash environment, each car of the train is idealized as a lumped mass whose weight is based on that of the car. The longitudinal load-deformation characteristics are idealized as outlined above and split up between two axial springs located to the front and rear of the mass. The individual car models are then placed end to end (spring to spring) to represent train consists. By appropriately defining the number and distribution of masses and springs, spring load-deflection relations, and initial velocities of the masses, the user can simulate any combination of train consists in head-on or rear-end collisions or combinations of the two.

Analyses were performed to determine the acceleration pulse produced during the collision of various types of train consists in head-on and rear-end collisions at various velocities. The accident scenarios selected for analysis are:

1. Head-on collision between two freight trains
2. Rear-end collision between two freight trains
3. Rear-end collision between two passenger trains.

The vehicles are represented by lumped mass and spring idealization for the simulation of longitudinal impact behavior. Each car is represented by a single mass with the longitudinal stiffness properties of the portions on either side of the cg represented by springs. The springs are assumed to be perfectly elastic-plastic with the plastic load representing the longitudinal crushing strength of the car. Figure 6-3 represents an idealization of a typical freight train impact. Figure 6-4 is a typical boxcar idealized spring load-displacement relationship; and a similar relationship is shown for a locomotive in Figure 6-5.

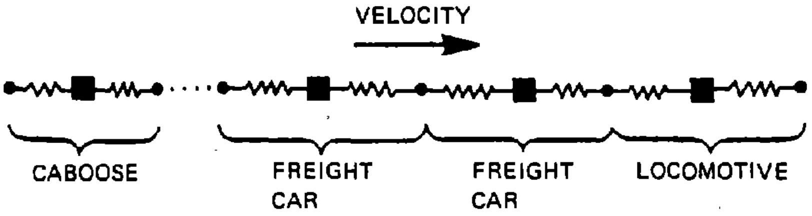


*Figure 6–3. Idealization of a Typical Freight Train Impact*

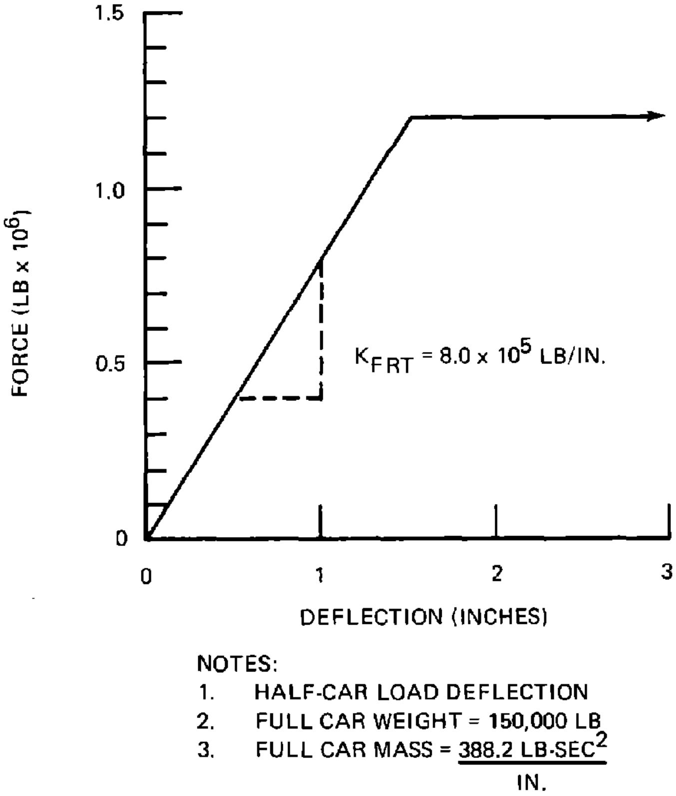
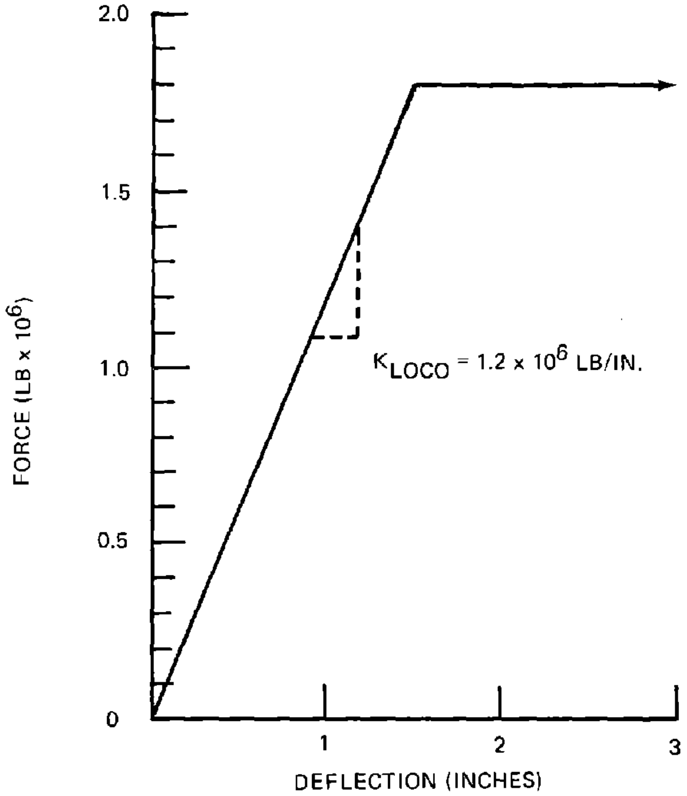


*Figure 6–4. Boxcar Idealized Spring Load/Displacement Relationship*



NOTES

1. HALF-CAR LOAD DEFLECTION
2. FULL CAR WEIGHT = 400,000 LB
3. FULL CAR MASS = $\frac{1035.2 \text{ LB-SEC}^2}{\text{IN.}}$

*Figure 6—5. Locomotive Idealized Spring Load/Displacement Relationship*

Figure 6-6 shows a plot of deceleration versus time for either of the impacting locomotives in a head-on collision of two freight trains at a contact speed of 20 mph. Three distinct regions are immediately evident.

The first region is characterized by a rapid rise to a peak followed by a more gentle drop to a plateau. This represents crushing of the locomotive front and rear ends and the front end of the car immediately behind the locomotive. The initial rise is due to buildup of compressive load in the front ends of the locomotives as they collide. The loads quickly reach a maximum value as the front ends start to crush. The following cars, in the meantime, are plowing into the locomotives. The forward push resulting from this tends to relieve the decelerative forces in the front end, and gives rise to the fall-off of deceleration. The peak deceleration is closely approximated by the ratio of locomotive front end crush load to the locomotive mass:

$$\text{peak deceleration} = \frac{\text{front end crush load}}{\text{locomotive mass}}$$

The second zone develops as the second car ploss into the locomotive, the compressive forces developed between the locomotive rear end and the car rapidly leads to crushing of the car front end, accompanied by attenuation of compressive loads. The locomotive then continues to decelerate at a constant rate, given by:

$$\text{constant deceleration} = \frac{\text{(locomotive crush load)} - \text{(second car crush load)}}{\text{locomotive mass}}$$

The third zone is initiated by the two locomotives rebounding off each other. Subsequently, a series of rebounds between each locomotive and its following car, as well as between the two locomotives, give rise to an oscillatory response. In practice, these rebounds will be quickly arrested by several mechanisms not included in the analysis, such as structural damping, friction, entanglement of strurctural components as crushing occurs, and energy dissipation due to pieces of structure being shed off at high velocities.

Figure 6-7 shows plots for 10, 40, and 80 mph contact velocities. Note that except for the 10 mph case, the general characteristics observed at the 20 mph closure speed are repeated at the other speeds.

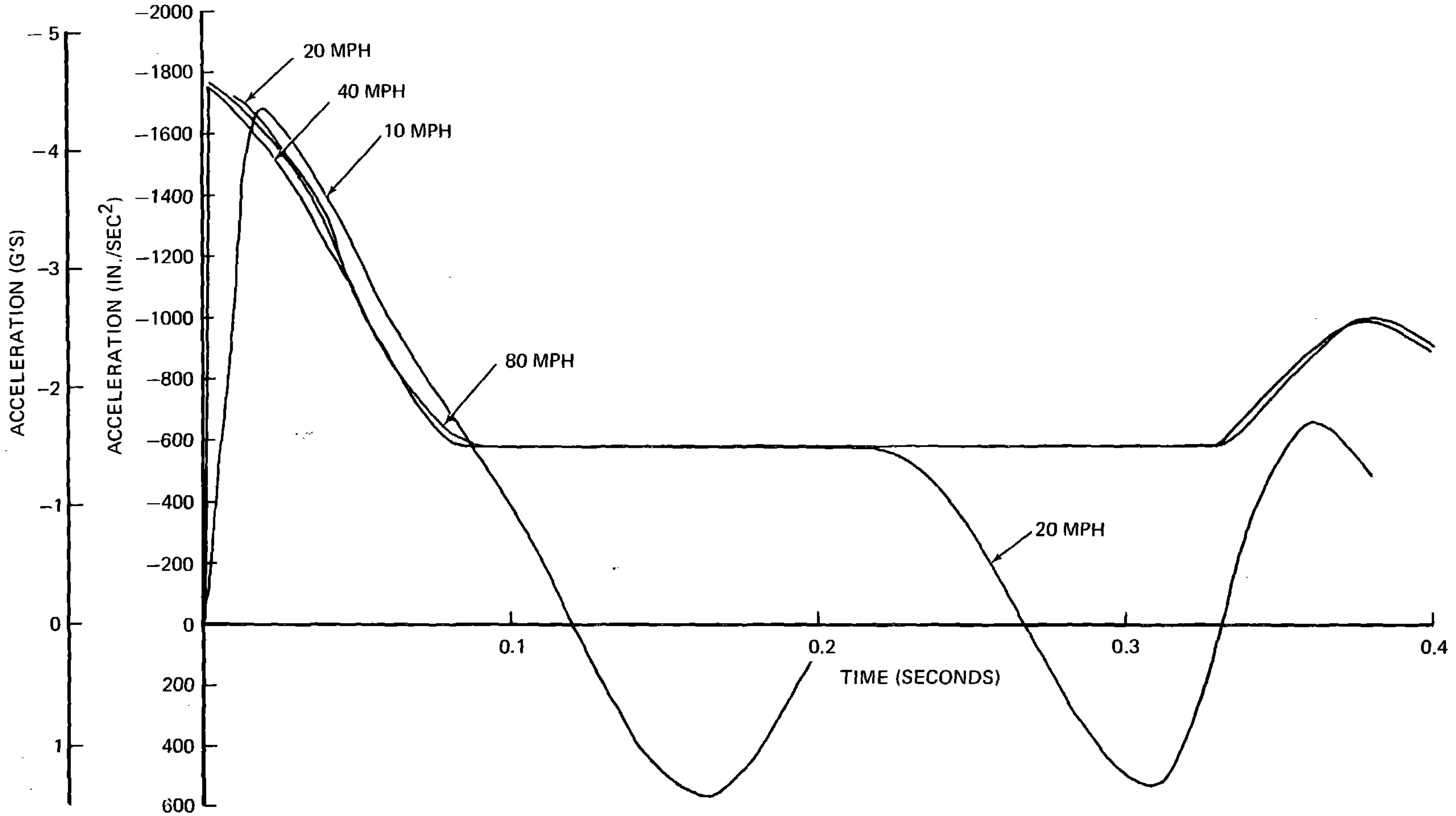


*Figure 6–6. Freight Train Locomotives in Head-On Collision: Acceleration vs Time*

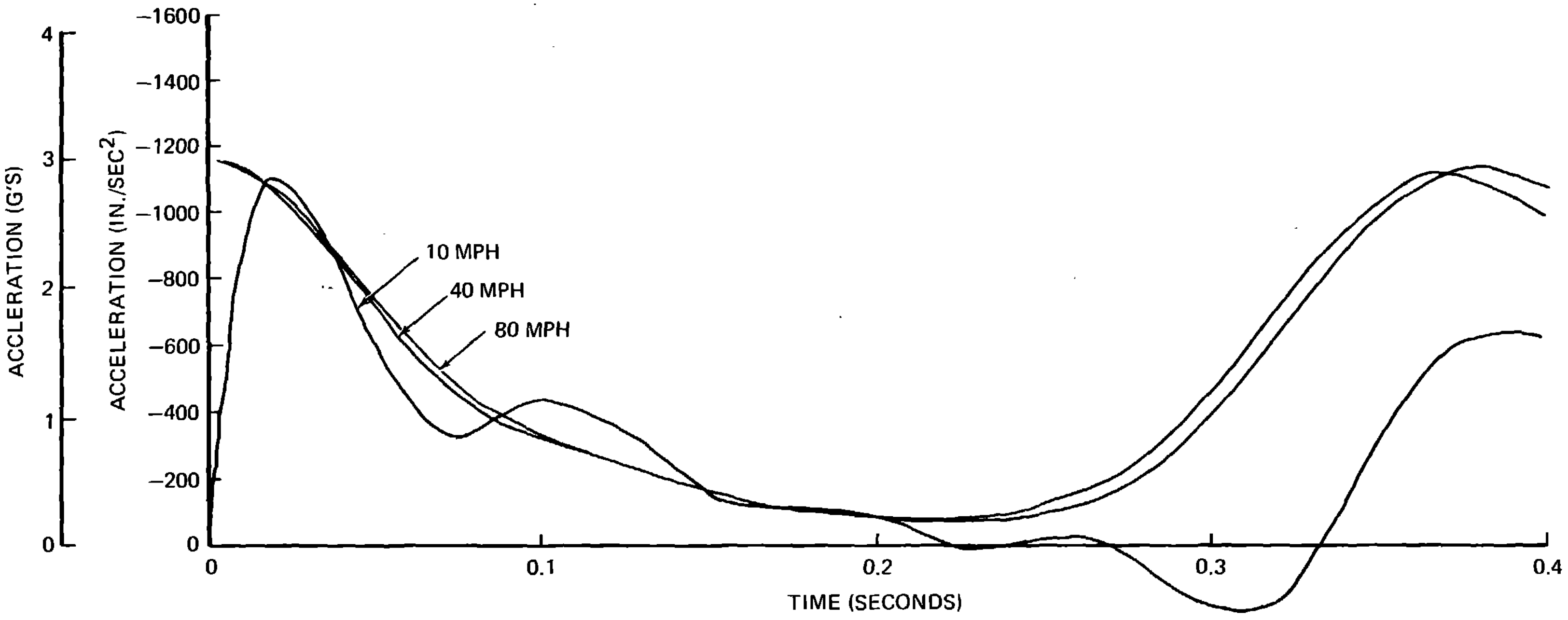


*Figure 6–7. Freight Trains in Rear-End Collision: Locomotive Impulse During Collision with Caboose*

The peak deceleration is the same in all cases, although the time to peak deceleration decreases with increasing contact speed. The total duration of the first zone, representing the time to initiate structural crushing in the locomotive and the second car, varies little with contact speed above 20 mph. Typically, this lies in the time range of 0.08 to 0.09 seconds.

The duration of the second zone is the period of crushing in the front end of the first car following the locomotive. The end of crushing occurs when either of the two locomotives rebound off each other, as is the case at 20 mph, or when the second car bounces off the locomotive. Figure 6-6 indicates that the duration increases with contact speed.

At low contact velocities, the deceleration-time characteristics, typified by the plot for 10 mph, differs markedly from those discussed above. The peak deceleration at 10 mph is slightly less than at the higher velocities, indicating that crushing of the locomotive does not occur. The system behavior is entirely elastic, comprising a series of rebounds which are quickly arrested by effective damping mechanisms such as those previously noted.

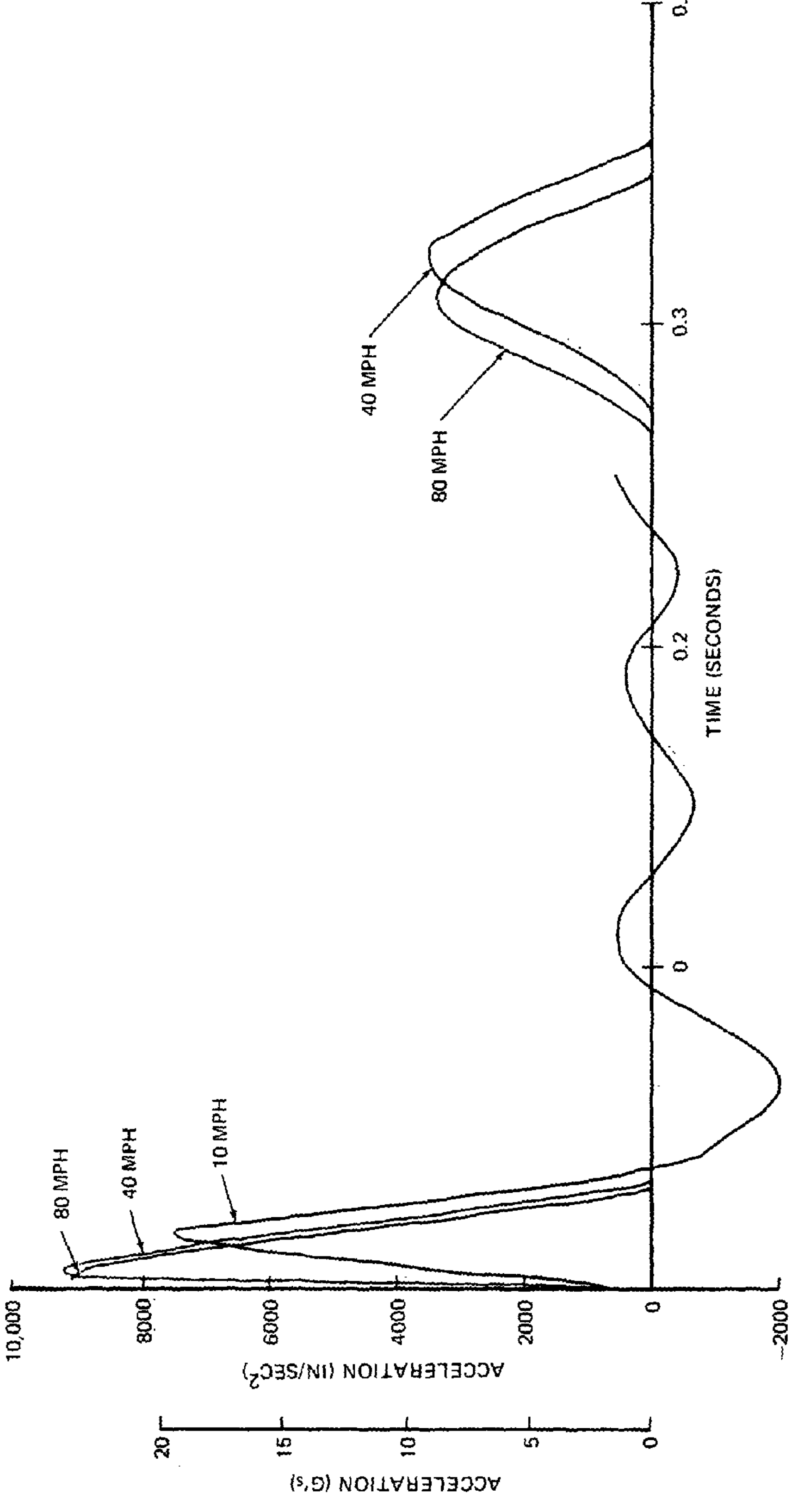
For a rear-end collision between two freight trains, Figure 6-7 shows the locomotive deceleration pulses for various closure speeds, and Figure 6-8 shows the corresponding plots for the caboose. The locomotive curves show distinct departures from those observed in the head-On case. This is because crushing occurs in the caboose and the car ahead of it instead of the locomotive and the car behind it. This is borne out by the curves for the caboose, which show the same shapes as in Figure 6-6 except that the plateau of zone two occurs at zero value of deceleration (the caboose and boxcars are assumed to have the same crush load).

Figure 6-9 shows the deceleration pulses for passenger cars impacted at 10, 20, 40 and 80 mph for the third accident scenario (rear-end collision between two passenger trains).

#### 6.3.2.2 Occupant Impact Energy Absorption Analysis

Occupant injury due to acceleration into a surface during a collision is dependent upon the following factors:

- The distance the occupant travels to the surface
- The part or parts of the body which contact the surface
- The area of the body that contacts the surface
- The area of the surface contacted


80 MPH
40 MPH
10 MPH
40 MPH
80 MPH
10,000
8000
6000
4000
2000
0
−2000
ACCELERATION (IN/SEC²)
20
15
10
5
0
ACCELERATION (G's)
0
0.2
0.3
TIME (SECONDS)

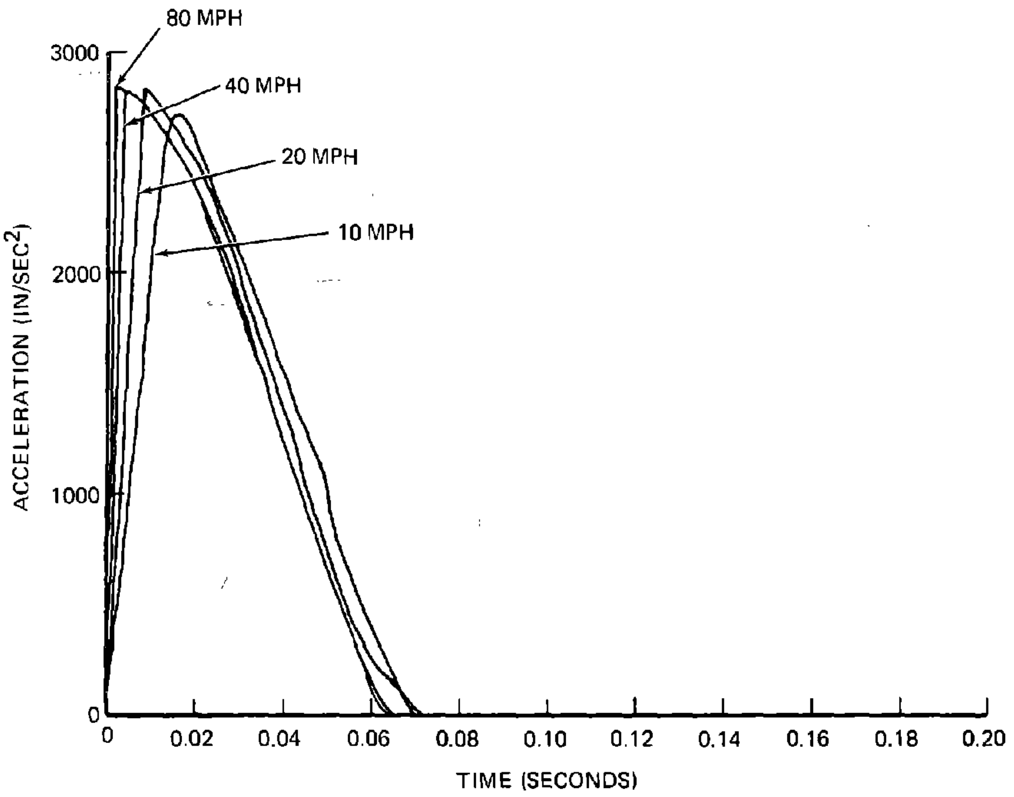


*Figure 6—9. Passenger Car Impulse During Impact by Locomotive*

- The energy absorption characteristics or controlled deformation of the surface.

to design a bulkhead, seat back, buffer or other padded surface for crashworthiness the above factors must be considered.

Energy-absorbing characteristics of padded surfaces impacted depend upon the padding stiffness and thickness. Using simple calculations and graphs, it is possible to determine the padding stiffness and thickness necessary to insure that specified body pressure or human tolerances are not exceeded during impact. Impact tolerances to various parts of the body are discussed in Human Tolerance, Section 8.3 and a summary of the body pressure limits are presented in Table 6-2.

TABLE 6-2. HUMAN PRESSURE TOLERANCES

| Part of the Body | Pressure Required to Fracture (lb/sq in.) | Design Limits (lb/sq in.) |
|---|---|---|
| Skull | 400 | 200 |
| Facial Bone | 70 | 40 |
| Chest (Rib) | 40 | 30 |
| Knee, Thigh, and Pelvis Complex | 190 | 125 |

In order to determine the required padding properties, the impacting body's kinetic energy and the body contact area must be known. The velocity of the body at impact and the masses of the body segments for a 156-pound occupant are given in Figure 6-10; from these the kinetic energy can be calculated. The body contact area is estimated by the designer. From the kinetic energy and the padding contact area, the kinetic energy density, $\mu$ defined as the kinetic energy, per body padding contact area (inch-pounds per square inch), is determined. Assuming a padding thickness, and with the previously calculated kinetic energy density, $\mu$, a minimum padding stiffness value can be obtained (Figure 6-11). With the known body pressure tolerance (Table 6-2) and the kinetic energy density, $\mu$ (Figure 6-12), the maximum allowable cushion stiffness is obtained, the designer can then select a suitable padding material within the range of these stiffness values.

Example

Determine the required padding for a chest buffer 10 inches from the locomotive engineman's chest. An arbitrary padding thickness of three inches is used.

- Step 1 - Calculate Kinetic Energy

$$K.E. = 1/2M\ V^2$$

a. With the known impact distance of 10 inches, the impact speed is found to be 128 in./sec on the locomotive curve (Figure 6-10).

| BODY SEGMENT | MASS DISTRIBUTION FOR 156-LB OCCUPANT | EQUIVALENT WEIGHT DISTRIBUTION FOR 156-LB OCCUPANT |
|---|---|---|
| HEAD | 0.05176 LB SEC$^2$/IN. | 20.0 LB |
| CHEST | 0.12008 LB SEC$^2$/IN. | 46.4 LB |
| PELVIS | 0.13200 LB SEC$^2$/IN. | 51.1 LB |
| UPPER LEG | 0.06640 LB SEC$^2$/IN. | 25.7 LB |
| LOWER LEG | 0.03312 LB SEC$^2$/IN. | 12.8 LB |

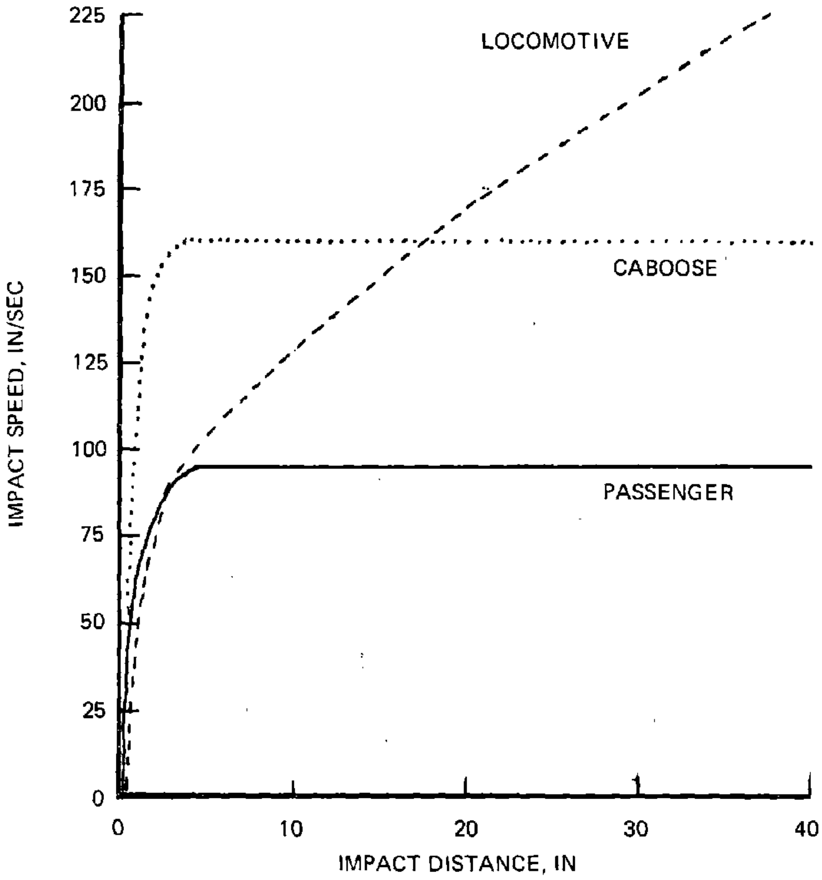


*Figure 6—10. Body Impact Velocity vs Distance Traveled*

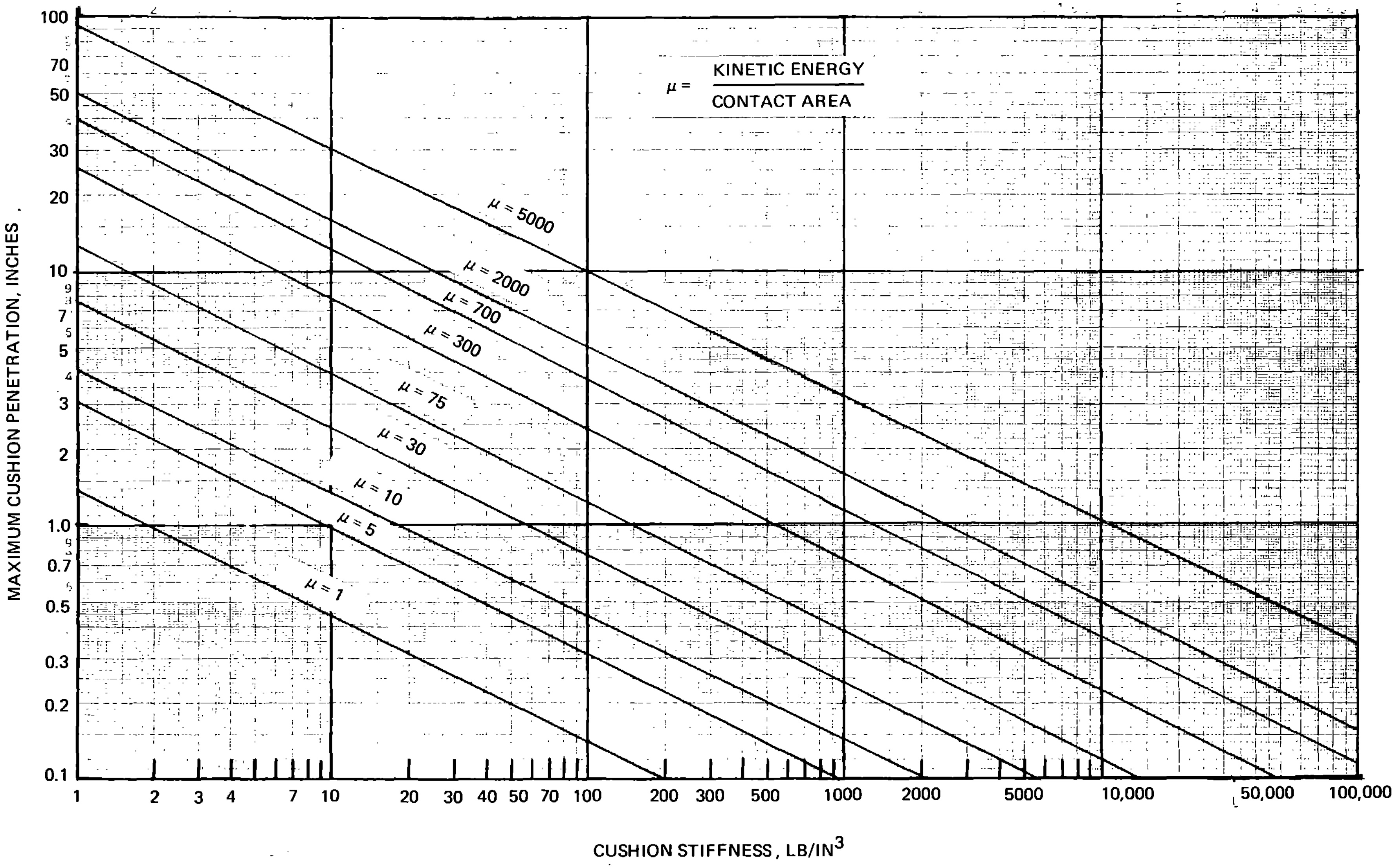


Figure 6–11. Cushion Penetration vs Cushion Stiffness

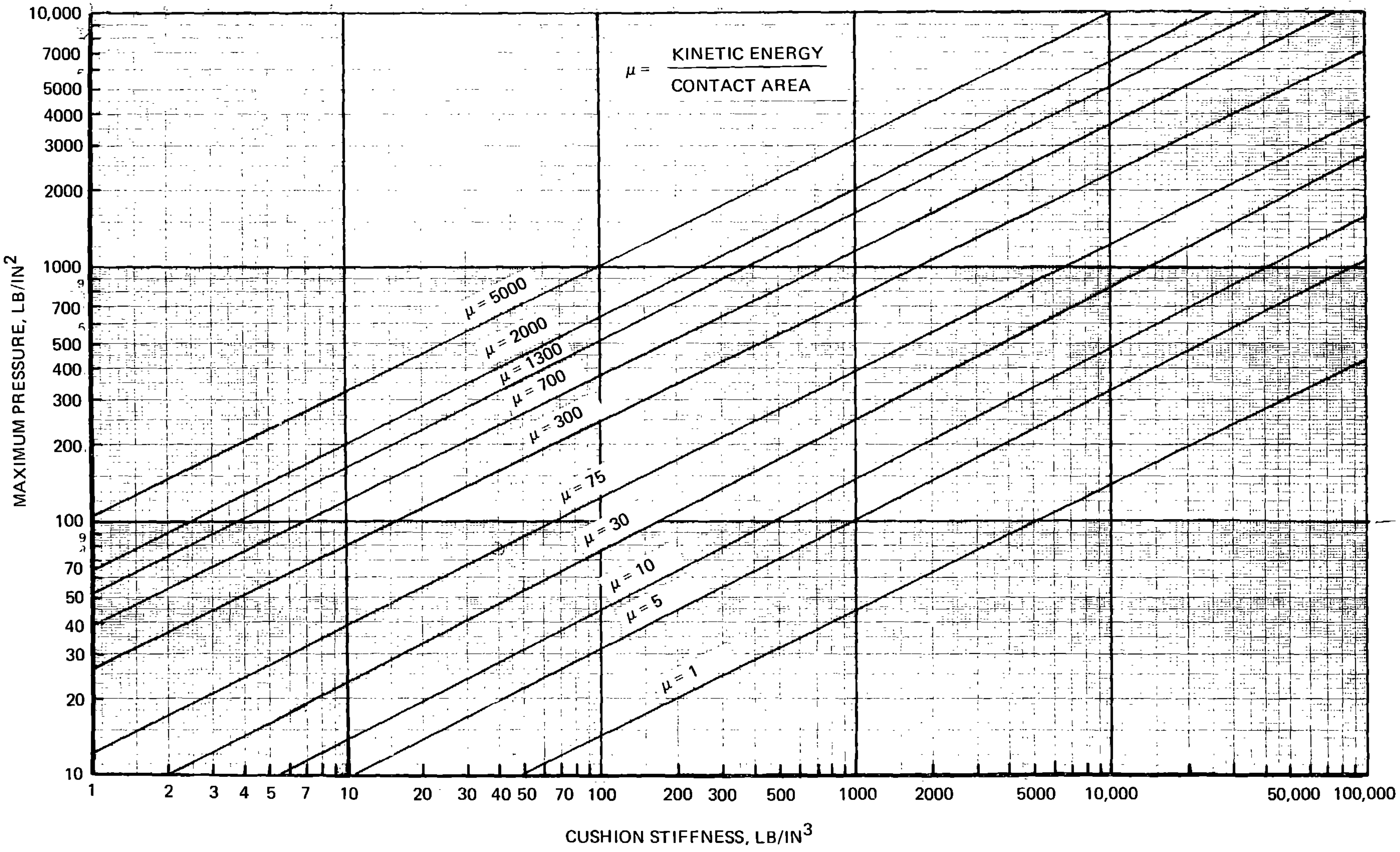


Figure 6–12. Impact Pressure vs Cushion Stiffness

b. From Figure 6-12, the chest mass is found to be 0.12008

c. Therefore the kinetic energy = $1/2\ (0.12008)(128)^2 =$ 983.7 in.-lb.

- Step 2 - Determine the Contact Area

  a. The chest/cushion contact area is assumed to be 36 square inches. The designer will base his assumption on design geometry, occupant position, area of the body likely to impact the surface, etc.

- Step 3 - Calculate the Kinetic Energy Density, $\mu$

$$\mu = \frac{983.7 \text{ in.-lb}}{36 \text{ in.}^2} = 27.3 \text{ in.-lb/in.}^2$$

- Step 4 - Determine Minimum Padding Stiffness

  a. Using the assumed padding thickness of 3 inches and kinetic energy density or, $\mu$, of 27.3, the minimum padding stiffness value is determined from Figure 6-11.

$$K_{\text{minimum}} = 6.6 \text{ lb/in.}^3$$

  This minimum stiffness value is controlled by padding thickness. For the padding to be effective, the occupant must be decelerated within the working range of the padding.

- Step 5 - Determine the Maximum Padding Stiffness

  a. From Table 6-2 the chest pressure tolerance is found to be 40 pounds per square inch.

  b. Knowing that $\mu$, the kinetic energy density, is 27.3 in.-lb/in.$^2$, the maximum padding is determined from Figure 6-12.

$$K_{\text{maximum}} = 29 \text{ lb/in.}^3$$

  The maximum value of the stiffness is controlled by the body pressure tolerance. Stiffer padding values would exceed human tolerances.

- Note: If the value calculated in Step 4 exceeds the value calculated in Step 5, this indicates a greater padding thickness is necessary. A greater padding thickness is estimated and Steps 4 and 5 must be repeated.

### 6.3.2.3 HIC Index Determination

The HIC Index can be determined for head injury by using the following equation:

$$HIC = (t_2 - t_1) \left[ \left| \frac{V}{g_c \cdot t_1} \cdot \cos \sqrt{\frac{K}{M}} \cdot (t_2 - t_1) \ \mathrm{RAD} \right| \right]^{2.5}$$

where $M$ = effective mass, lb-sec$^2$/in.

$K$ = effective cushion or structural stiffness, lb/in.

$V$ = head impact velocity, in./sec

$gc$ = gravitational constant, 386.4 in./sec$^2$

$t_2 = \frac{2\pi \sqrt{KM}}{4K}$ seconds

$t_1$ = time seconds

The designer simply selects values for $t_1$ between 0 and $t_2$ and determines the $t_1$ value which maximizes the HIC Index.

# 7 INJURY MINIMIZATION CONSIDERATIONS

With the determination of the basic causal factors which produce injury, as discussed previously, consideration can now be taken in identifying the approach to minimizing the injurious effects of accidents. Several approaches can be considered for the minimization of occupant injury as follows:

- Occupant restraint to prevent impact with hostile surfaces
- Removal of or cushioning hostile surfaces
- Retention of loose objects to prevent impact with occupants

## 7.1 OCCUPANT RESTRAINT

Occupant injury can be prevented or minimized by restraining the occupants to their seated positions. A restraint system will prevent the occupant from being accelerated into a hostile surface. Active or passive restraint systems can be used. An active system requires a willful effort on the part of the occupant to fasten the restraint system about them. A passive restraint system requires no effort on the part of the occupant and will limit the motion of the occupant if accelerated due to an accident. Passive restraints are more suited to passenger use while active as well as passive restraint systems can be considered for railway personnel.

In the selection of a restraint system, consideration must be given to the probability of an occupant using the system provided. Active restraint systems, although generally less costly than other types, are the least likely to be used because a willful effort is required to fasten them. For this reason active restraints should be considered for passengers. Active restraint systems are presently being used by some railroads for their trainmen. Statistics on their use by the trainmen is not available, nor is the data on injuries prevented by their use during accidents.

If economically feasible and practical, preference should be given to the use of a passive restraint system. Buffers and containment provisions can also be considered. A buffer is a fixed padded surface in close proximity to the occupant which limits motion of the occupant. Ingress and egress to a seat with buffer restraint is accomplished by adjusting the seat position. Containment systems utilize the existing furnishings around a seated occupant to limit occupant motion such as a seat back or bulkhead in front of the occupant.

## 7.2 SURFACE DELETHALIZATION

Surfaces can be prepared to make them safe for impact by occupants in a number of ways. Protruding objects on surfaces or rigid nonyielding surfaced objects can be removed, softened, or relocated away from the occupants environment. Surfaces should be designed as flat as possible or with large corner radii. They should be constructed to yield under impact or be padded with sufficient thickness and density material to absorb the impact energy and reduce forces to within human tolerances.

## 7.3 RETENTION OF LOOSE OBJECTS

Injury by being struck with loose objects or objects torn loose due to inadequate attachments can be prevented. Luggage the principal loose object in passenger cars can be restrained by installing doors on luggage racks. Portable equipment such as fire extinguishers, water bottles, lanterns, etc., should be provided with attachments adequate to withstand loads due to accelerations experienced in collisions and rollover.

## 7.4 INJURY MINIMIZATION APPROACH SELECTION

Selection of one or more of the approaches discussed above will depend upon the type of railcar considered and the rail property for which the system is being designed. As an example, higher utilization of an active restraint system could be expected by employers of a property which would deny medical benefits for injuries sustained in a collision while not wearing the restraint. A similar penalty is employed by some automobile insurance companies against drivers injured in accidents while not wearing the restraint system. Other factors such as frequency of getting in and out of a seat for normal rail vehicle operation, multi-position of the seat required for operation and cost will have a bearing on the approach to be taken in the selection of a system for collision injury minimization.

## 8. REVIEW OF RELATED CRASHWORTHINESS TECHNOLOGY

### 8.1 STATE-OF-THE-ART

Government requirements have been established for crashworthiness of passenger cars, trucks and buses, and for military aircraft. As a result, the development of crashworthy features has been principally for these vehicles. The Department of Transportation National Highway Traffic Safety Administration and the United States Army have issued regulations, standards and guides for crashworthiness provisions. DOT has issued 26 safety standards and 20 crashworthiness standards. The following crashworthiness standards are currently effective and are being incorporated in the manufacture of highway vehicles:

Standard No. 201 - Occupant Protection in Interior Impact -
Specifies requirements for padded instrument panels, seat backs, sun visors and armrests

Standard No. 202 - Head Restraints -
Specifies requirements for a head rest to reduce frequency and severity of "whiplash" type neck injuries from rear-end collisions

Standard No. 203 - Impact Protection For The Driver From The Steering Control System -
Specifies requirements for minimizing chest, neck and facial injuries by providing a steering system that yields forward, absorbing much of the driver's impact energy in forward collisions

Standard No. 204 - Steering Control Rearward Displacement -
Specifies requirement for limiting penetration of the control column into passenger compartment from forward collisions

Standard No. 205 - Glazing Materials - Passenger Cars, Trucks, Buses -
Specifies requirements for glazing materials to reduce the likelihood of lacerations to face, scalp and neck, and minimize penetration into the windshield during collision

Standard No. 206 - Door Locks and Door Retention Components -
Specifies load requirements for door latches for forces encountered during vehicle impact

Standard No. 207 - Seating Systems -
Establishes load requirements for seats, attachment assemblies, and installations for forces experienced during vehicle impact

Standard No. 208 - Occupant Crash Protection -
Specifies requirements for active or passive crash protection systems for occupant restraint

Standard No. 209 - Seat Belt Assemblies -
Specifies requirements for straps or webbing and hardware fitting materials

Standard No. 210 - Seat Belt Assembly Anchorages -
Specifies the requirements for seat belt and shoulder strap anchorage strength

Standard No. 211 - Wheel Nuts, Wheel Disks and Hub Caps -
Specifies requirements for delethalization of wheel protrusions for the protection of pedestrians and cyclists

Standard No. 212 - Windshield Mounting -
Specifies windshield load retention requirements for impact by two 95th percentile male occupants during a crash

Standard No. 213 - Child Seating Systems -
Specifies requirements for protection and restraint of child occupants in a crash

Standard No. 214 - Side Door Strength -
Specifies side door strength requirements to minimize intrusion into the passenger compartment in a side impact collision

Standard No. 215 - Exterior Protection -
Specifies strength and deformation requirements and damage limitations for crash impact into a barrier

Standard No. 216 - Roof Crush Resistance -
Specifies minimum strength requirements for roofs in rollover accidents

Standard No. 217 - Bus Window Retention and Release -
Establishes requirements for window retention and release to minimize passenger ejection in accidents and to facilitate passenger exit in emergencies

Standard No. 218 - Motorcycle Helmets -
Establishes requirement for impact attenuation, retention and penetration minimization

Standard No. 301 - Fuel System Integrity -
Specifies fuel retention requirements for 20 mph impacts and rollover

Standard No. 302 - Flammability of Interior Materials -
Specifies burn resistance requirements for materials used in the occupant compartment

The United States Army has issued the following documents dealing with aircraft crash safety standards:

| | |
|---|---|
| TR71-22 | Crash Survival Design Guide |
| MIL-STD-1290 | Light Fixed - and Rotary-Wing Aircraft Crashworthiness |
| ADS-11 | Aeronautical Design Standard Survivability/Vulnerability |

The Crash Survival Design Guide presents crashworthiness design data for potentially survivable aircraft crashes. Given in the document are impact velocities, pulses and accelerations for various impact attitudes and the human tolerances at these accelerations. Structural design principles are given for balancing strength and deformation and ensuring retention of living space within the collapsed structure. Techniques for minimizing rapid deceleration due to earth gouging and structural rigidity are discussed. Design criteria are specified for the design of crashworthy seats and restraint systems. Techniques for the delethalization of the occupied area are discussed. Strike envelopes of occupants using various type restraint systems are illustrated. Head impact tolerances and stress strain properties of padding materials are shown. Fire resulting from crash impacts is discussed and techniques are recommended to minimize fuel spillage from line and tank ruptures. Requirements for emergency exists and lighting are specified. The requirements include provisions for emergency egress while the vehicle is on its side or inverted.

MIL-STD-1290 is essentially a condensed version of the Crash Survival Design in military standard format. The crashworthy design techniques and analytical approaches discussed in the Design Guide were omitted and only the required results were retained.

The crashworthiness portion of ADS-11 is similar in scope to MIL-STD-1290 but is not so detailed or definitive. This document is devoted primarily to a procedure for evaluating the crashworthiness provisions.

Federal regulations for rail vehicle collision or accident safety provisions are minimal. The Department of Transportation

Federal Railroad Administration document of regulations contains several pertaining to safety requirements. Requirements are established for shatterproof glass in the locomotive cab, non-skid floor surfaces and proper protection to avoid contact with fan blades. Guards and protective devices are specified for hand-operated electrical controls and switches to avoid hazards to the operator. Exposed moving parts of mechanisms and pipes carrying hot gases are required to be isolated or guarded against personnel contact. Safety regulations for passenger cars and cabooses pertain only to handrails, steps and ladders.

The specification for AMTRAK locomotive propelled passenger cars specifies a few collision safety requirements. These include requirements for safety glass, fire-retardant materials, emergency escape sash units, seat attachments capable of 6000-pound force on each fitting and car collision load test requirements.

## 8.2 CONCEPTS APPLICABLE TO RAIL VEHICLES

Of the existing regulations and standards pertaining to crash safety, some can be considered to be applicable in whole or in part for use in locomotives, passenger railcars or cabooses. The applicable concepts or data and their source are summarized as follows:

### U.S. Department of Transportation National Highway Traffic Safety Administration Crash Safety Standards

Standard No. 201 - Padding requirements are specified which are applicable to locomotive bulkheads, control pedestal, sun visor and other equipment such as heater, radio, etc. The padding requirements are applicable to passenger car bulkheads, seat backs, armrests, wainscot and luggage rack. Applicable areas for padding in the caboose would also be the bulkheads, and furnishings such as ice chest, heater, etc.

Standard No. 202 - Head restraint requirements are specified to reduce whiplash type neck injuries from rear-end collisions, by providing head rests on all seats in locomotives, passenger cars and cabooses.

Standard No. 205 - Glazing material properties are specified which are applicable for reduction of lacerations to face, scalp and neck and for penetration during collision.

Standard No. 207 - Seating system design load requirements are specified which are applicable for forces experienced during collision.

Standard No. 208 - Active or passive restraint requirements are specified which are applicable for railroad crewmen.

Standard No. 209 - Restraint system material properties are specified which are applicable for crewmen restraints.

Standard No. 210 - Restraint system anchorage strength is specified which is applicable for rail vehicle collision loads.

Standard No. 212 - Window mounting requirements are specified which are applicable for retention of occupants who impact windows during collision.

Standard No. 217 - Window retention and release requirements are specified which are applicable for egress after collision.

Standard No. 301 - Fuel system integrity requirements are specified for collision and rollover which are applicable for railcars having fuel systems.

Standard No. 302 - Burn-resistance requirements are specified for interior materials, and are applicable for railcars.

## U.S. Army Crash Safety Standards

Of the several Army documents pertaining to crash safety, the principal document with data and concepts applicable to rail vehicle collision safety is the Crash Survival Design Guide. A portion of the guide particularly applicable is the section on interior delethalization. Data is given on head impact tolerances and stress strain properties of padding materials. Also of particular importance is the section on emergency exits and egress when the vehicle is on its side or inverted. Data on energy attenuating seats and restraint systems may be applicable for use in locomotives and cabooses. Techniques for minimizing fuel leakage and fire resulting from collisions would also be applicable to fuel systems used in locomotives and cabooses.

## 8.3 HUMAN TOLERANCE TO IMPACT

Human tolerance is difficult to establish because of the obvious impracticability of subjecting humans to impact at serious injury levels. The main classifications of human tolerance are:

1. Voluntary
2. Injury threshold
3. Minor injury
4. Severe injury

The voluntary tolerance level is established by subjecting human volunteers to the environment being studied. Generally, the approach is to subject the volunteers to a very low level exposure with the exposure severity increased until the volunteer refuses to go further for fear of injury. In a few cases volunteers have been injured, but in general, the voluntary level is well below the injury level. Nevertheless, the voluntary tolerance threshold is beneficial since it is the only tolerance value that is based upon results from carefully controlled human experiments where the physical parameters are known accurately.

The injury threshold is defined as the impact conditions at or just below the point at which injury occurs. The injury threshold has been achieved or exceeded in some volunteer experiments since there have been some minor injuries. However, the general voluntary levels are well below the injury threshold.

Minor injury is usually defined as injury resulting in bruises, abrasions, contusions, or other minor recoverable injuries that are acceptable to the occupant. The minor injury threshold has been reached by some volunteers and in general is probably acceptable in the design of intercity rail vehicles. In establishing the minor injury category, it is necessary to realize that what might be considered a minor injury, insofar as danger to life is concerned, might not be considered a minor injury in the general sense of an injury that is acceptable to an individual. In this respect a fractured rib is considered to be a minor injury form a life-threatening standpoint, while the same fractured rib will generally not be considered a minor injury by the riding public.

Severe injuries include serious injuries up to fatal injuries. These often require surgical intervention and long recovery times. The severe injury level is obviously not acceptable for the tolerance level for intercity railcars.

When establishing human tolerance levels, the resistance of the "average" individual is the basis for the tolerance level. It has been established[3,4] that age, sex, and physical conditions are only a few of the variables that effect the tolerance of humans to impact. Age is of particular importance with the degree of injury for a given impact increasing markedly at the higher age level. In some exposures the tolerance is low for young people. Burdi and Huelke[5] point out the differences in anatomy between children and adults. With the variation from individual to individual in the ability to sustain impact without injury, it should be realized that in any given environment those least able to withstand the impact will be injured at a low severity of collision, while the more resistant individual will sustain no injury whatsoever under the same conditions.

Methods of establishing human tolerance to impact range from the exposure of human volunteers to the environment in question to reproducing accidents in which the collision severity and degree of injury are known. For some types of injuries, the volunteer program can be extended to more severe exposures by substituting unembalmed human cadavers to the impact environment. Bruising, bone fractures, and internal injuries have all been observed in cadavers with results that are similar to those observed in collisions.

Before tolerance levels can be specified, it is necessary to have a uniform method of describing injuries. The Abbreviated Injury Scale (AIS) has been established for use in automobile injury studies[6] and is recommended for application to railcar injuries in order to maintain uniformity and to permit the results from the more numerous automobile injuries to be applied to railcar design. The nine injury categories of

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[3] Patrick, L.M., Bohlin, N., and Anderson, A., "Three-Point Harness Accident and Laboratory Data Comparison", SAE Paper No. 741181.

[4] Yamada, H. (Edited by Evans), "Strength of Biological Materials", Williams and Wilkins, 1970.

[5] Burdi, A.R., and Huelke, D.F., "Infants and Children in the Adult World of Automobile Safety Design: Pediatric and Anatomical Considerations for Design of Child Restraints", Journal of Biomechanics.

[6] Abbreviated Injury Scale: Zero to nine (fatal)

the AIS cover the range from essentially zero injuries to fatals. For railcar application it may be desirable to use only the first three AIS categories and to enlarge on the definitions of the injuries within each of these categories. It is recommended that the AIS-3 level be the maximum acceptable injury with a design goal of AIS-0 injury for all rail occupants in collisions up to the 20 mph severity.

Injury criteria which have been established and are in general use, including those of Motor Vehicle Safety Standards (MVSS) 208[7], are:

1. The Head Injury Criteria (HIC)
2. The Gadd Severity Index (GSI)
3. The 80-g, three-millisecond exclusion parameter for head impact.
4. The 60-g three-millisecond exclusion chest impact criterion.
5. The 1700-pound femur load for dummy knee impact.
6. Torque at the occipital condyles.

The injury criteria of MVSS 208 are not all inclusive. Therefore, additional injury criteria will be suggested for the specific injury conditions. (A list of terms pertaining to injury is presented in Table 8-1).

## HEAD IMPACT

- Injury Type: brain injury, skull fracture, and/or scalp laceration
- Human Tolerance: HIC = 1000

Head injury is considered to be injury to the skull, scalp, and/or brain and does not include the facial injury.

Melvin and Evans[8] summarized the fracture forces from different investigators with a skull fracture range of 500 to

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[7] Title 49, Code of Federal Regulations, Part 571 - Federal Motor Vehicle Safety Standards, National Highway Traffic Safety Administration, Department of Transportation, Washington, D.C.

[8] Melvin, J.W., and Evans, F.G., "A Strain Energy Approach to the Mechanics of Skull Fracture," Proceedings of the Fifteenth Stapp Car Crash Conference, November, 1971, SAE No. 710871.

## TABLE 8-1. INJURY TERMS

| | |
|---|---|
| AIS | Abbreviated Injury Scale; zero to nine (fatal) |
| AP Mandible | Anterior posterior on jam |
| Basil | Base |
| Caudal | Posteriorly (opposed to cephalad) |
| Caudal Cephalad Direction | Loads transmitted vertically through the spine |
| Caudal Cephalad Loading | Vertically along the spine |
| Cephalad | Anterior part of body (opposed to caudal) |
| Cervical Vertebra | The seven vertebra in the neck region |
| Coccyx | A small bone at the lower end of the vertebral column |
| Condyles | Ball and socket joints |
| Contusion | Injury in which skin is not broken |
| Distal | Terminal |
| Dorsal | Of, on or near the back |
| Femur | Thigh bone |
| Fibula | Leg calf bone |
| Frontal Bone | Convex front portion of skull |
| GSI | Gadd Severity Index |
| HIC | Head Injury Criteria |
| Hyperextension | Extreme rearward rotation of head |
| Hyperflexion | Head striking chest |
| Ilium | Upper portion of the hip bone |
| Intervertebral Discs | Elastic discs interposed between the centra of adjoining vertebrae |
| Ischia | Lower portion of the hip bone |
| Laceration | Jaggedly torn flesh |
| Lateral Mandible | Sideways on jam |
| Ligaments | Tissue connecting the bones |
| Lumbar | Lower part of the back |
| Mandible | The jaw |
| Maxilla | Jaw bone |
| Occipital | Posterior part of the skull bone |
| Patella | The knee cap |
| Pelvis | A basin like cavity formed by a ring of bones supporting the spine |
| Sternum | The breastbone |
| Tibia | The lower leg (shin) bone |
| Thorax | The chest (between the neck and abdomen) |
| Torso | The trunk of the human body |
| Vertebra | The articulating bones of the spinal column |
| Viscera | The inner parts of the body especially of the thorax and abdomen |
| Zygoma | The anterior portion of the upper jaw bone |

2200 pounds depending upon the impact conditions. A small area of impact resulted in the 500-pound fracture level while a 2200-pound fracture force resulted from a large area impact without padding. A flat surface impact to the frontal bone with approximately 3/4 inch of padding shows no fracture at forces up to 2640 pounds in another study.[16]

Nahum[9] quotes a minimum fracture force of 900 pounds and an average of 1100 pounds from impact to the frontal bone with a one-square-inch impactor.

With the human volunteer runs on the Holloman sled with the GM air cushion, Smith et al[10] reached a maximum HIC of 380 and a maximum acceleration of 71 g's in the head at a 30 mph barrier equivalent impact. These did not result in injury, and did have a greater stopping distance than feasible from a seat back impact.

Hodgson et al[11] reported on probably the most significant study with regard to impacting a grab rail. He impacted cadavers with cylindrical steel unpadded impactors of 5/16-inch radius and one inch radius. The average fracture level was 1250 pounds with a range of 700 to 1730 pounds.

A well-designed helmet provides an excellent example of the impact attenuation that can be achieved under ideal conditions with approximately 0.8-inch deceleration distance available. A helmet impact at 12 to 16 mph to a rigid surface often does not result in head injury. At an impact of 12 mph a helmeted head does not exceed 80 g's if the helmet is adequately designed.

For a seat back designed with a three-inch decelerating distance from a head impact of 20 mph, the maximum head acceleration should not exceed 80 g's and the HIC will be approximately 400. These values are extremely conservative and should cause no brain injury or skull fracture. Adequate padding to distribute the force will eliminate soft tissue or scalp injury with the exception, perhaps, of a bruise.

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9. Nahum, A.M., Gatts, J.D., Gadd, C.W., and Danforth, J., "Impact Tolerance of the Skull and Face", Proceedings of the Twelfth Stapp Car Crash Conference, October, 1968, SAE Paper No. 680785.

10. Smith, G.R., Gulash, E.C., and Baker, R.G., "Human Volunteer and Anthropomorphic Dummy Tests of General Motors Driver Air Cushion System", 3rd International Conference on Occupant Protection, Troy, Michigan, July, 1974, SAE Paper No. 740578.

11. Hodgson, V.R., Brinn, J., Thomas, L.M., and Greenberg, S.W., "Fracture Behavior of the Skull Frontal Bone Against Cylindrical Surfaces", Proceedings of the Fourteenth Stapp Car Crash Conference, November, 1970, SAE Paper No. 700909.

FACE IMPACTS

- Injury Type: Facial bone fracture, soft tissue injury and eye injury

- Human Tolerance: Zygomatic arch 200 pounds minimum, 648 pounds maximum; maxilla, 150 pounds minimum, lateral mandible 200 pounds, AP mandible 400 pounds.

Facial bone fractures are sensitive to the area and hardness of the impactor. The minimum force levels as recommended by Schneider[12] and Nahum[9] are based upon an impact by a one-inch diameter impactor covered with a 0.1 inch layer of crushable nickel foam. With such a small impactor the force is concentrated on the bone in question. If the impact is to a large padded surface, the force is distributed over several facial bones and the tolerance level increases dramatically. For example, the minimum fracture level, as reported by Hodgson[13], for impact to the Zygoma is 360 pounds or almost twice that reported by Schneider. Hodgson used an impactor of 5.2 square inches covered with a one-inch urethane pad. Similarly, the mandible fracture level was considerably higher with the padded impactor.

The effectiveness of padding is illustrated in Reference 12. For a given impact, the head acceleration was reduced from over 400 g's to about 10 g's with two inches of padding.

Injuries to soft tissues can occur from impacting glass[14], small knobs, or hard surfaces, where the injury appears as a laceration but is actually a compression or explosion type of injury. Soft tissue injury to the upper lip, nose, and chin can be eliminated by adequate padding to distribute the force, especially over the facial bones.

Fracture of the nose occurs at low levels. A very soft padding of one inch or more in thickness will protect the nose by permitting the nose to sink into the padding and the major force then to be taken on other parts of the face.

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[12] Schneider, D.C., and Nahum, A.M., "Impact Studies of Facial Bones and Skull," Proceedings of the Sixteenth Stapp Car Crash Conference, Detroit, Michigan, November, 1972.

[13] Hodgson, V.R., "Tolerance of the Facial Bones to Impact," The American Journal of Anatomy, Dempster Memorial Issue, Vol. 120, No. 1, pp. 113-122, January, 1967.

[14] Patrick, L.M., Lange, W.A., and Hodgson, V.R., "Facial Injuries - Causes and Prevention", Proceedings of the Seventh Stapp Car Crash Conference, Charles C. Thomas, Springfield, Illinois, 1965.

## KNEE-THIGH-HIP COMPLEX IMPACT TO SEATS

- Injury Type: fracture of the patella, fracture of the femur, fracture of the pelvis, and/or joint injury.
- Human Tolerance: femur 1500 to 3800 pounds with a recommended value of 2000 pounds (MVSS 208 is 1700 pounds), patella 2000 pounds with padded surface, pelvis 2000 pounds with padded surface.
- Injury Source: knee impact to the back of the front seat, bulkhead, or other equipment.

King[15] has developed a femur load injury criterion based upon knee impacts and duration of impact. He feels that the 1700-pound femur criterion of MVSS 208 is conservative. This agrees with the data that Patrick generated which results in a load of 2000 pounds as being a reasonable value for the femur. Patrick[16,17] reports on impacts to a rigid padded surface with cadavers in a normal seated position. The load cells measured the force at the knee. Since the intact cadaver was used, the force applied to the knee could result in fracture to the patella, femur and/or pelvis. With a deformable structure that will deform at 1800 to 2000 pounds, there is little likelihood that fractures will occur except to individuals who are extremely weak in regard to knee impact.

## FLEXION OR EXTENSION NECK INJURIES

- Injury Type: Soft tissue, cervical vertebra fracture or basilar skull fracture.
- Human Tolerance: Extension 35 foot-pounds around the occipital condyles produced no injury in a volunteer, and 42 foot-pounds is a threshold of injury from cadaver experiments. The equivalent torque at the occipital condyles in flexion is 65 foot-pounds for voluntary minor injury and 140 foot-pounds to cadavers. Compres-

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[15] King, J.J., Fan, W.R.S., and Vargovick, R.J., "Femur Load Injury Criteria - A Realistic Approach", Proceedings of Seventeenth Stapp Car Crash Conference, Oklahoma City, Oklahoma, November, 1973, SAE Paper No. 730984.

[16] Patrick, L.M., and Mertz, H.J., "Cadaver Knee, Chest and Head Impact Loads", Proceedings of the Eleventh Stapp Car Crash Conference, October, 1967, Anaheim, California, SAE Paper No. 670913.

[17] Patrick, L.M., Kroell, C.K., and Mertz, H.J., "Forces on the Human Body in Simulated Crashes", Proceedings of the Ninth Stapp Car Crash Conference, Nolte Center for Continuing Education, University of Minnesota, 1966.

sion or tension and bending tolerance is unknown, but is lower than the inertia tolerances for flexion and extension.

Research has shown that the torque at the occipital condyles is the best measure of injury potential as a result of inertia loading in flexion or extension[18,19,20]. In addition to the torque at the occipital condyles from the inertial loading, there is a shear and axial load applied at the occipital condyles. Experimental results indicate that these loads are well below the voluntary static limit when the torque exceeds the injury limit. Therefore, the shear and axial load under inertial loading conditions are not limiting factors.

During the extension of the head and neck during inertia loading (the so-called whiplash syndrome), soft tissue is injured more often than bone. Ligaments, muscles, and complex tissue attachments between the cervical vertebra are vulnerable to injury. Experimental programs with volunteers and cadavers indicate that there are no injuries until the angle between the head and neck reaches or exceeds a critical value. Consequently, hyperextension and hyperflexion injuries can be avoided by providing a suitable support to keep the head from rotating more than a predetermined amount with respect to the torso. The limiting angle appears to be approximately 80 degrees between the head and the torso, measuring from the normal head position.

In a volunteer program[18,19,20] the static torque at the occipital condyles in extension was 17.5 foot-pounds maximum and was limited by the strength of the volunteers' neck muscles. No injury resulted at 35 foot-pounds at the occipital condyles and approximately 80 degrees between the torso and the head. Under the same conditions, ligamentous damage was observed in embalmed cadavers at 42 foot-pounds.

Under conditions producing flexion of the head and neck, the chin strikes the chest in hyperflexion. The external force applied to the chin is not easily measured without modifying the angle through which the head and neck can travel. Therefore, Mertz[18] has calculated an equivalent torque in which the force on the chin is assumed to produce a change in the head acceleration equivalent to a given torque at the

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18. Mertz, H.J., "The Kinematics and Kinetics of Whiplash," Ph.D. Dissertation, Wayne State University, 1967.

19. Mertz, H.J., and Patrick, L.M., "Investigation of the Kinematics and Kinetics of Whiplash", Proceedings of the Eleventh Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, 1967.

20. Mertz, J.J., and Patrick, L.M., "Strength and Response of the Human Neck", Fifteenth Stapp Car Crash Conference, Coronado, California, November 17-19, 1971, SAE Paper No. 710020.

occipital condyles. Under these conditions, the static torque for a human volunteer is 26 foot-pounds. Under dynamic conditions the pain threshold is 44 foot-pounds and the maximum dynamic torque sustained by a volunteer was 65 foot-pounds. At the 65 foot-pound level, the volunteer had considerable pain in the neck and upper torso area for approximately one week with no permanent injury.

In both extension and flexion, the neck muscles play a role in minimizing the torque at the occipital condyles in low-level collision simulations. At the higher levels, the neck muscles cannot reduce the torque at the occipital condyles to a sub-injury level.

STANDEES STRIKING STANCHIONS OR BULKHEADS

- Injury Types: Whole body deceleration injuries from striking a stanchion with deflection around the stanchion and concentrated loads and whole body deceleration from striking a bulkhead.

- Human Tolerance: The tolerance for head impact, knee impact and face impact will be the same as provided under the main headings herein for those body components. Little is known about the tolerance to concentrated loads from impact to a stanchion except for the head for which the tolerances are listed under that heading. For short duration impacts to the chest, a 60 g for 3 milliseconds exclusion has been recommended for automotive use as has a Gadd Severity Index of 1000 maximum. These values probably represent a greater injury than is acceptable for intercity railcars. Therefore, a 40 g for 3 milliseconds exclusion is suggested.

When striking a bulkhead, the force will probably be distributed over a large part of the body; consequently, with suitable padding to prevent localized forces in the injurious range, the occupants should survive the 20 mph velocity impact with no more than minor injury. It is proposed that the bulkheads be designed with sufficient padding and/or deformation to permit a 20 mph impact of the occupant with a maximum of 40 g's measured at the cg of the thorax. With the bulkhead so designed, the head impact should be well under the maximum allowable HIC 1000.

The stanchion or grab bar impact is more critical and must be deformable to obtain additional stopping distance over that required for the 40 g whole body deceleration into the bulkhead. Local area impacts would have tolerances similar to those described for that particular area.

## FLAILING LIMBS

- Injury Types: Fracture of the long bones of the arm and legs and injury to joints.
- Human Tolerance: Impacts to the tibia with a hard surface from a cylindrical pendulum with the axis of the cylinder perpendicular to the long axis of the tibia resulted in impact ranging from 225 pounds to 1330 pounds causing fracture according to one investigator, and 1000 to 1500 pounds applied at the distal 1/3 of the tibia reported by a second investigator.

Kramer[21] conducted tests on the lower limbs of 200 cadavers. He used a dual pendulum in which the cadaver, lying on its side, was swung in an arc and made contact at the bottom of the arc with a second pendulum consisting of cylinders 5.7 or 8.5 inches in diameter. The forces measured ranged from 225 to 1330 pounds at fracture. The impact site varied from just below the knee to the distal end of the tibia. The maximum values were lower for females than for males.

Young[22] found a range of 1000 to 1500 pounds when impacting the tibia at the distal third. His value corresponds to the upper end of the fracture range found by Kramer.[21]

Flailing limbs coming in contact with a hard surface that concentrates the force near the center of the long bone will produce bending plus concentrated loads at the point of impact. When the force exceeds the fracture level, including the effect of the concentrated load on the bone, fractures will occur. The danger of fracture can be reduced by distributing the force over a substantial length of the bone and by padding the contact areas to avoid the concentrated loads at point of contact.

Information on the forces which cause fracture in bending of the long bones of the arm was not available. To minimize the danger of fracture of the long bones of the limbs, it is suggested that the tolerance level be established at the midrange of the data presented by Kramer, approximately 750 pounds. At the 20-mph collision condition, it is anticipated that the forces can be reduced to a value below the fracture level by a reasonable amount of padding, the required thickness of which will decrease as the radius of the rigid component increases.

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[21] Kramer, M., Burow, K., and Heger, A., "Fracture Mechanism of Lower Legs Under Impact Load," Proceedings of Seventeenth Stapp Car Crash Conference, November 12-13, Oklahoma City, Oklahoma, SAE Paper No. 730966.

[22] Young, J.W., "Threshold Value for Tibia Fracture, Male Cadavers (aged 29-57)", 1967 (unpublished).

## BACK INJURIES FROM FLEXION, EXTENSION, AND/OR CAUDAL CEPHALAD LOADING INCLUDING FALLS

- Injury Type: Bone fracture, intervertebral disc damage, injury to connecting tissues.

- Human Tolerance: Caudal cephalad direction with optimal restraints (pilot ejection seats), 20 g's for lower dorsal or lumbar vertebra fracture. Average 600 pounds for fracture of the endplate for excised vertebra. Tolerance is very low for individuals with weak backs or those with previous injuries. For flexion with a lap belt only, the tolerance is approximately 2000 pounds.

Ejection seats designed for a maximum of 20 g acceleration have been successful in saving lives, but have caused several fractured vertebrae. Consequently, the 20 g limit is probably too great for the average individual. In a fall from 4 feet, assuming a half sine deceleration pulse and a direct impact on the buttocks, a 3.6-inch decelerating distance is required if the peak acceleration is not to exceed 20 g's. From a 2-foot fall under the same conditions, a 2.3-inch decelerating distance is required. This explains the numerous injuries that occur when people fall in a seated position to a hard surface. Furthermore, the average unrestrained individual is not able to withstand the 20 g's that the fully restrained military pilot can sustain with only occasional fractures. It is obvious that the average individual falling in awkward positions and landing on his buttocks can and does receive serious back injuries in many cases in falls from low heights. Since it is impossible to put sufficient padding on the floor and approaches to the railcar, the prevention of such injuries must be relegated to preventing the falls.

Human volunteers have been subjected to deceleration conditions with lap belts at forces of 2000 pounds or greater, without injury. Again, these were young males in good physical condition and do not represent the average population. The lap belt flexion or jackknifing comes the closest to the jackknifing over a seat back, armrest, table, etc. for which the force measurements have been made.

Extension of the back over an object of small cross sectional area will produce a concentrated load on the back and can produce injuries at comparably low forces. While quantitative data is unavailable on the forces required, they are thought to be small for producing injury.

## THORAX IMPACT

- Injury Types: Injuries to the thorax from striking the seat back in front during forward force collisions. The injuries include rib fractures, sternal fractures, and thoracic viscera injuries.

- Human Tolerance: The human tolerance to chest impact is dependent upon the area of contact. Patrick[16] reports approximately 1000 pounds for rib fracture from impact to a 6-inch diameter padded target. Kroell[23] reports about 800 pounds as the fracture limit with a 6-inch diameter unpadded impactor. Kroell further notes that force is not as good a criterion as deflection of the chest for indicating injury potential. If the force is distributed over a substantial part of the thorax the recommended tolerance is 40 g for 3 millisecond exclusion.

Chest impact with a well-padded surface should result in a distributed force which will minimize the danger of rib fractures or other injury from concentrated forces. If the force is distributed over the rib cage without concentrated forces, the 40 g for 3 millisecond tolerance level is recommended as a conservative value. For automotive collisions with the chest, impact to the steering assembly or the instrument panel is 60 g for 3 milliseconds. However, for the 20-mph low injury level requirements of the rail cars the 40 g value is recommended.

Patrick,[16] with a limited number of cadavers impacting a 6-inch diameter target with 15/16 of an inch padding, found a fracture level at about 1000 pounds. Kroell,[21] with a 6-inch diameter unpadded impactor, found fractures at approximately an 800-pound plateau.

## BENDING FRACTURE AND/OR SPRAIN TO LOWER LIMBS FROM AN ENTRAPMENT OF THE LOWER LEG BETWEEN THE FLOOR AND THE BOTTOM OF THE SEAT IN FRONT OF THE OCCUPANT

Tolerance for this specific condition is unknown. The only tolerance that can be applied is the force to the tibia that was reported under the heading of flailing limbs. If the 1000-pound tolerance is assumed at the midpoint of the tibia or approximately 8 inches above the floor, and the cg of the occupant is assumed to be 40 inches above the floor with the

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[23] Kroell, C.H., Schneider, D.C., and Nahum, A.M., "Impact Tolerance and Response of the Human Thorax II", Proceedings of Eighteenth Stapp Car Crash Conference, Ann Arbor, Michigan, December 4-5, 1974, SAE Paper No. 741187.

legs straight, a simple calculation shows that a force of 167 pounds applied at the 40-inch cg height will produce 1000 pounds at the 8-inch height of the tibia. This corresponds to approximately 1 g applied to the occupant. With several g's expected in a 20 mph collision, the only mitigation for this type of injury is to prevent the leg from being trapped beneath the seat.

## OCCUPANT-TO-OCCUPANT IMPACT WHEN PASSENGER SEATS FACE EACH OTHER

Huelke[24] reports on occupant-to-occupant injuries in automobile collisions. He found that occupant-to-occupant contact is a frequent cause of injury occurring in about 22 percent of the cars in injury crashes in which there was more than one occupant. The injuries from occupant-to-occupant contact are frequently worse than minor on the Abbreviated Injury Scale. It should be noted that in automobile collisions, the occupants are seated side-by-side or in front and rear seats. In all cases they move in the same direction during impact. In the railcar with seats facing each other, the occupant on the impact side will be retained by the seat and will be impacted against the seat by the facing passenger. They will probably be subjected to more serious injuries than those in which the occupants are free to move in the same direction. The exception in the case of the automobile is a side impact in which the side-by-side occupants move together with the occupant on the impact side being crushed between the occupant and the side of the vehicle.

Elimination of occupant-to-occupant injuries can be achieved by eliminating the facing seats.

Table 8-2 summarizes the injury data presented in this section. As will be noted, there are gaps in the table where tolerance levels are unknown for the particular exposure. Further research with cadavers and/or human volunteers is necessary to obtain this data.

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[24] Huelke, D.F., Sherman, H.W., and O'Day, J., "The Hazard of the Unrestrained Occupant", Proceedings of the Eighteenth Conference of the American Association for Automotive Medicine, Toronto, Ontario, September 12-14, 1974.

TABLE 8-2. HUMAN TOLERANCE SUMMARY

| INJURY SOURCE | INJURY TYPE | HUMAN TOLERANCE | INJURY MECHANISM | INJURY MITIGATION |
|---|---|---|---|---|
| HEAD IMPACT | BRAIN INJURY, SKULL FRACTURE, SCALP LACERATION | HIC=1000 WITH A GOAL OF 500 | HUMAN IMPACT TO BACK OF SEAT OR GRAB RAIL | PADDING AND CONTROLLED DEFORMATION |
| FACE IMPACT | FACIAL BONE FRACTURE, SOFT TISSUE AND EYE INJURY | APPROXIMATELY 200 LBS TO INDIVIDUAL FACIAL BONES | FACE IMPACT TO BACK OF SEAT OR GRAB RAIL | PADDING AND CONTROLLED DEFORMATION |
| KNEE IMPACTS | FRACTURE OF PATELLA, FEMUR OR PELVIS, AND JOINT INJURY | KNEE IMPACT OF 2,000 POUNDS | KNEE IMPACT TO BACK OF SEAT | PADDING AND CONTROLLED DEFORMATION |
| FLEXION OR EXTENSION NECK INJURIES | SOFT TISSUE DAMAGE, CERVICAL VERTEBRAE, OR BASILAR SKULL FRACTURE | EXTENSION 42 LB-FT, FLEXION-EQUIVALENT OF 65 LB-FT. | FLEXION OR EXTENSION OVER SEAT BACK | HIGH SEAT BACK, HEAD SUPPORT OR CONTROLLED MOVEMENT |
| STANDEES STRIKING STANCHION OR BULKHEADS | WHOLE BODY DECELERATION | 40g RECOMMENDED FOR WHOLE BODY WITH HEAD, FACE, AND KNEES AS REPORTED UNDER SEAT IMPACTS | IMPACT TO STANCHION OR BULKHEAD | PADDING OR CONTROLLED DEFORMATION |
| FLAILING LIMBS | FRACTURE OF LONG BONES AND JOINT INJURY | TIBIA IMPACT 1000 LB, UPPER LIMBS UNKNOWN | FLAILING LIMBS STRIKING STANCHION OR OTHER SMALL DIAMETER OBJECTS | PADDING AND CONTROLLED DEFORMATION |
| BACK INJURIES FROM FALLS OR BENDING | VERTEBRAE FRACTURE, DISC DAMAGE, CONNECTING TISSUE INJURY | CAUDO-CEPHALAD-20g's ENDPLATE FRACTURE – 600 LBS FLEXION 2000 APPLIED TO LAP BELT EXTENSION-UNKNOWN | FALLS OR BENDING OVER SEAT BACK | NONSKID FLOORS, HAND GRIPS AND HIGH SEAT BACKS |

TABLE 8-2 - Continued

| INJURY SOURCE | INJURY TYPE | HUMAN TOLERANCE | INJURY MECHANISM | INJURY MITIGATION |
|---|---|---|---|---|
| THORAX IMPACT | RIB FRACTURE, STERNAL FRACTURE, THORACIC VISCERA INJURIES | 1000 LB FOR 6-INCH DIA PADDED IMPACT AREA, 40g/3ms FOR DISTRIBUTED LOAD | IMPACT TO SEAT BACK | PADDING AND CONTROLLED |
| CRUSHING FROM PEOPLE PILING INTO BULKHEADS | CRUSHING OF BODY AND/OR JOINT DISLOCATION | UNKNOWN | CRUSHING | ELIMINATION OF STANDEES OR SEGREGATION TO PREVENT SEVERAL OCCUPANTS PILING INTO A BULKHEAD |
| BENDING FRACTURE OR SPRAINS FROM LOWER LIMB ENTRAPMENT | BENDING FRACTURE OF LONG BONES OR JOINT DISTORTION | UNKNOWN | BENDING OF LOWER LIMBS DUE TO ENTRAPMENT OF LOWER PART OF LOWER LIMB UNDER SEAT | ELIMINATE OR LIMIT SPACE BETWEEN BOTTOM OF SEAT AND FLOOR SO FOOT CANNOT BECOME ENTRAPPED |
| OCCUPANT-TO-OCCUPANT IMPACT | IMPACT INJURY FROM HEAD OR OTHER BODY PART IMPACTING ANOTHER OCCUPANT | UNKNOWN | ONE OCCUPANT HITTING ANOTHER DURING COLLISION MOVEMENT. MAJOR PROBLEM IS WITH FACING SEATS | ELIMINATE FACING SEAT DESIGN |

# 9. CANDIDATE INJURY MINIMIZATION TECHNIQUES

The injury mechanisms causing the greatest number of injuries and those causing the greatest severity of injuries are discussed in Section 5.4. Using this data candidate techniques for minimizing the injuries can be presented. The mechanisms and the severity is peculiar to the type of rail vehicle in which the injury occurs. Therefore the techniques will be presented for specific types of rail vehicles.

## 9.1 LOCOMOTIVE INJURY MINIMIZATION TECHNIQUES

Injuries due to impact with the bulkhead, door and window frame produced the greatest number of injuries and the magnitude of the injuries were more severe than all other injuries (Figure 5-13). Calculations for impact of the engineman or helper into the front bulkhead or door glass can produce fatal head injuries during a collision. Retention of the locomotive trainmen to their seated area is essential to their safety during a collision. An active restraint system using a lap belt and shoulder harness can be considered however, the low probability of use may warrant use of a passive system. A padded buffer placed in front of the trainmen's chest and abdomen in a fixed position would provide containment during a collision and would prevent impacts with the front bulkhead, door, window, heater, control console, miscellaneous equipment, etc. during a forward collision. Many of the injuries due to being thrown to the floor would be prevented by the seat containment provision.

Injuries by being thrown to the floor was the second highest in frequency and the injuries were severe. Minimization of injuries due to impact with the floor is not practical due to the thick padding necessary. Therefore, means of preventing falls to the floor must be considered. Along with adequate retention in the seated position, adequate hand grabs recessed along the rear bulkhead should be provided for standing trainmen. Operational procedures should also be developed to minimize the chance that a trainman be standing during periods of coupling when slack action is likely and when collisions can be foreseen.

A high percentage of injuries were due to the seats. The resulting injuries were moderate in severity. Inadequancy of the seat contributed to many of the injuries. Low seat backs and lack of headrests caused back injuries and whiplash during rearward accelerations. Inadequate anchorage of the seat caused the seat to come loose from the wall attachment or from the mounting frame. Seat backs should extend to shoulder height. A headrest either part of the seat back or a separate attachment should extend above the seat back to prevent rearward rotation of the head. The seat should be track mounted with positive locks retaining the seat against vertical as well as horizontal accelerations.

The water cooler caused a high frequency of injuries however, the injuries were minor. Consideration should be given to placement of the water cooler behind a partition. Other equipments such as fire extinguishers, first aid kits, etc. should also be recessed with the bulkhead or partition.

## 9.2 CABOOSE INJURY MINIMIZATION TECHNIQUES

The injury mechanisms most frequently involved in caboose trainmen injuries were impact with bulkheads, doors, table/desks and railing (Figure 5-15) with moderate injuries resulting. At least half of all injuries occurred from a seated position. These seated position injuries could be prevented by providing adequated restraint or containment in the seated position. A lap belt and shoulder harness restraint can be employed. Containment with padded buffers in front of seats or on table/desks can also be considered. They would contain the occupants and distribute the impact force over a large portion of the abdomen and chest.

Falls to the floor was the next most frequent cause of injury and resulted in moderate to severe injury. Adequate padding on the floors to minimize injury is not practical therefore, prevention of falls must be considered. Restraint and containment in the seated positions will eliminate many falls to the floor. Recessed hand grabs along the sides of the aisle to supplement the overhead longitudinal hand rail should reduce the number of falls.

Impact with stoves and other equipment and appliances occurred next in the order of frequency and produced moderate injuries. Injuries would be reduced if these items were placed behind a partition and the partitions designed to absorb the impact energy, reducing forces below the injury level.

Seats were a cause of an average amount of injuries which were minor to moderate. Inadequate seat back height caused whiplash injuries. Lack of adequate padding on seat back and armrests caused injuries to standing trainmen. Adequate seat back height and sufficient padding on back and armrest would substantially reduce these injuries.

Impacts with small protrusions such as control valves and fire extinguishers were less frequent than the above but the resulting injuries were of a more serious nature. Such injuries can be reduced by providing adequate covers over them or recessing them in flush panels.

## 9.3 PASSENGER RAILCAR INJURY MINIMIZATION TECHNIQUES

The most frequently occurring mechanisms in passenger railcar occupant injuries are, bulkheads, doors, window frames and miscellaneous equipment (Figure 5-14). Minor to moderate injuries are produced. The rigidity of these surfaces produced the injuries. Padding on the surfaces or design for deflection would reduce the injuries.

Seats were the next most frequent cause of injury. Armrests were the predominant factor in seat caused injuries. The rigidity of these surfaces produce injuries. Sufficient padding would reduce the injuries.

The floor was next in order of frequency as the cause of injury and the injuries produced were generally serious. Sufficient padding on the floor to prevent injury is not practical; therefore, means of preventing occupants from being thrown to the floor such as better containment in the seated areas and more surface on the seat backs on which to grab. Padded shoulder buffers on the seats would provide such additional surface as well as provide additional containment.

Breaking window glass injuries occurred as frequently as impacts with the floor. However, these injuries usually were very minor. Improved shatter proofing of glass would reduce these injuries.

Impact with tables, counters and bars was next in order of frequency and produced minor to moderate injuries. Increasing the surface area of these items and designing for deformation or padding would reduce the injuries.

Injuries due to impact with hand rails occurred infrequently; however, generally produced serious injuries. Recessing of hand rails into bulkheads or partitions would produce a larger surface to distribute impact loads and would reduce these injuries.

## 9.4 COST OF THE INJURY MINIMIZING DEVICES

The cost effectiveness of the proposed railcar equipment and furnishings modifications for crashworthiness is not within the scope of this study. Work has been done by the J.H. Wiggins

Company on risks and cost benefits of improved railcar crashworthiness and is discussed in report number 76-1264/65-1 titled Rail Vehicle Occupant Protection - Risk Analysis and Assessment of Research Needs, dated June 1976. It was prepared by J. Hrzina et al, for the Department of Transportation, Transportation Systems Center.

Costs for proposed crashworthiness modifications of locomotives, cabooses and passenger railcars for new construction and retrofit are presented in this section. These costs can be used in conjunction with the above risk analysis.

### 9.4.1 Locomotive Collision Safety Provisions Cost

A typical intercity freight locomotive the EMD GP-40 was used for design modifications of proposed collision safety features. Features selected for costing are as follows:

- Improved enginemans control console with padded guards
- Engineman and helper containment buffer
- Improved seats with high back, headrest and track adjustment.
- Delethalization of cab interior equipment.

#### 9.4.1.1 Control Console

For the conventional oblique angled engineman's console which has control handles projecting horizontally from the side, protection is needed to prevent impact with the handles. A padded shroud is provided above the handles to prevent impact with the handles. Installation of the shroud requires regrouping of the handles. Rearrangement of switches and indicators was necessary for better visible reference using the eye level of the 50th percentile man (seated) as a basis.

Necessary alterations in the controls, from their original position, are as follows:

- Move train and locomotive brake valves down 4 inches.
- Relocate whistle valve handle below engine brake and rotate 90 degrees counterclockwise.
- Move indicators and power reduction lever from center to upper left portion of console.
- Move indicators from right-hand edge toward engineman.
- Move pressure gage name plates to location above gage face from below.

Costs for these modifications are listed in Table 9-1 for new build and retrofit.

### 9.4.1.2 Containment Buffer

A padded buffer is provided in front of the engineman and helper to serve as a passive containment system. The buffers are mounted on the side wall of the cab in a fixed position. Cost is listed in Table 9-1.

### 9.4.1.3 Improved Seats

The conventional locomotive trainman seats are proposed to be completely replaced with seats having a back which extends up to shoulder height and a headrest to prevent whiplash. Armrests and shoulder buffers are added to improve lateral retention. The seat is track mounted with adjustments that can be controlled from a seated or standing position. The seat is fixed to the track in a manner which will prevent disengagement during rollover. Costs are listed in Table 9-1.

### 9.4.1.4 Interior Delethalization

Equipment and furnishings surch as fire extinguishers, first aid kits, fusee holders, etc. normally hung on the bulkhead and the water cooler normally located on the floor in the cab are proposed to be located behind or recessed with a flush partition. Covers are provided over such items as windshield wiper motors, valves, etc. Exposed instruments and radio equipment are mounted flush in the console. Padding is added to the back of the console and vulnerable areas of bulkheads. Costs are listed in Table 9-1.

### 9.4.2 Caboose Collision Safety Equipment Costs

A typical bay window caboose was used for design modifications of proposed collision safety features. Features selected for costing are as follows:

- Caboose trainmen restraint system
- Crashworthy seats
- Containment for bunks
- Interior delethalization to include the following:
    a. Recessed knobs, handles, gages, valves, etc.

    b. Flush partitions covering oil tank, water tank, water cooler, refrigerator, heater, pipes, etc.

TABLE 9-1. LOCOMOTIVE INJURY MINIMIZING PROVISION COSTS

| ITEM | BASIC REVISIONS | COST PER SYSTEM-$ NEW BUILD | COST PER SYSTEM-$ RETROFIT | NUMBER OF SYSTEMS PER LOCOMOTIVE |
|---|---|---|---|---|
| Control Console | Relocate Instruments and Handles<br>Add Padded Guard | 86 | 1,975 | 1 |
| Containment Buffer | Side Wall Structure<br>Add Padded Buffer | 115 | 352 | 2 |
| Crashworthy Seat | High Back-Arm Rests-Shoulder Pads-Track | 300 | 350 | 2 |
| Cab Delethalization | Recess Handles, Knobs, Small Equip., Water Cooler-<br>Add Padding | 800 | 2,000 | 1 |
| Total Cost per Locomotive All Systems | | 1,716 | 5,379 | |

<u>NOTE</u>: Costs include installation

c. Recessed hand grabs along longitudinal aisle.

d. Padding on front and rear bulkheads and doors.

### 9.4.2.1 Restraint System

A restraint system is provided for each seat station in the caboose. The system consists of a lap belt and a two strap shoulder harness. A retractor would be provided for the shoulder harness which allows the conductor to lean forward to work at a desk or the brakeman to operate brake valves, the windshield wiper control, etc. Costs are listed in Table 9-2 for new build and retrofit.

### 9.4.2.2 Crashworthy Seats

For the seats to be crashworthy they must have high seat backs to shoulder height plus an extension for anti whiplash head support. The seat must also have provisions for lap belt and shoulder harness attachments and must be strong enough to withstand the restraint system loads. Seats on some of the newer model cabooses are fitted with high backs and retraint systems. Those that do not would require the replacement of the entire seat. Costs are listed in Table 9-2.

### 9.4.2.3 Containment for Bunks

Longitudinal bunks with open ends require a resiliant barrier to prevent ejection from the ends. Ends against bulkheads will require padding. Webbing straps are required on the inboard side for lateral retention. Costs for these provisions are listed in Table 9-2.

### 9.4.2.4 Interior Delethalization

Interior delethalization required in most cabooses is extensive. Much of the large equipment and appliances should be protected against by the use of paneling. Small protrusions such as knobs and handles require replacing with flush hardware. Exposed controls, valves, plumbing, etc. should be covered. Recessed hand grabs should be incorporated in the longitudinal panels. Rigid bulkheads and doors at both ends of the caboose require padding. Costs for delethalization are listed in Table 9-2 for new build and retrofit.

### 9.4.3 Passenger Railcar Collision Safety Provisions Cost

A typical passenger railcar having double seats on each side of a central aisle and lavatory partitions or bulkheads at each end was used for design modifications of proposed collision safety features. Features selected for costing are as follows:

TABLE 9-2. CABOOSE INJURY MINIMIZATION PROVISION COSTS

| ITEM | BASIC REVISIONS | COST PER SYSTEM-$ NEW BUILD | COST PER SYSTEM-$ RETROFIT | NUMBER OF SYSTEMS PER CABOOSE |
|---|---|---|---|---|
| Restraint System | Double Shoulder Straps with Retractor Reel - Lap Belt | 100* | 100* | 3 |
| Crashworthy Seats | Track Mounted Swivel Seat - High Back - Arm Rests - High Strength | 300 | 350 | 3 |
| Bunk Containment | Padded Back - End Containment - Side Retention Straps | 175 | 200 | 2 |
| Interior Delethalization | Flush Partitions - Recessed Protrusions - Recessed Hand Grabs | 2,000 | 4,000 | 1 |
| Padding | Padded Doors and End Bulkheads | 385 | 430 | 2 |
| Total Cost Per Caboose All Systems | | 4,320 | 6,610 | |

NOTE: Costs include installation

*Cost assumes seat replacement

- Passenger seat improvements
- Partition and bulkhead padding
- Luggage rack doors

### 9.4.3.1 Passenger Seat Improvements

Passenger seats in the more modern passenger railcars have seat backs of adequate height to prevent whiplash and are adequately padded to prevent head and knee injury from impact from behind. Those seats which have inadequate high backs should be replaced in existing cars. Modifications required to existing seats or for newly designed seats are the addition of skirts below the seat back to prevent leg entrapment, the addition of a locking device to prevent inadvertant seat rotation, padded armrests and shoulder buffers. When inadequate padding is provided in the seat back top or knee area of the seat back additional padding must be added. To provide all of these features to an existing seat on a retrofit basis would cost more than replacing the entire seat. Therefore, a new seat is recommended. Cost is listed in Table 9-3.

### 9.4.3.2 Partition, Bulkhead and Door Padding

Partitions adjacent to passenger seats in existing cars may require padding to prevent injury to seated passengers accelerated into them. Partitions in newly constructed cars may be padded or constructed of an energy absorbing material. The bulkhead and entrance door to the car will require padding in both existing and newly constructed cars. The rigidity of the construction necessitates that padding be used. Approximately 100 square feet of padding is required on partitions bulkheads and door at each end of the car. Padding is estimated at $5.00 per square foot installed. Padding in lavatories is not recommended for existing cars and newly designed cars should be provided with compartments to limit the occupant travel distance in a collision. Cost is listed in Table 9-3.

### 9.4.3.3 Luggage Rack Doors

Occupants of passenger railcars are injured in a collision by unrestrained luggage particularly in derailments where lateral accelerations are experienced. Installation of doors on the luggage compartment similar to those used in the new commercial aircraft is recommended for newly constructed cars as well as retrofit. Cost is listed in Table 9-3.

TABLE 9-3. PASSENGER RAILCAR INJURY MINIMIZATION PROVISION COSTS

| ITEM | BASIC REVISIONS | COST PER SYSTEM-$ NEW BUILD | COST PER SYSTEM-$ RETROFIT | NUMBER OF SYSTEMS PER PASSENGER CAR |
|---|---|---|---|---|
| Passenger Seats (New Seats) | High Back with Shoulder Pads - Padded Armrests - Leg Skirt - Lock | 100* | 500 | 30 |
| Passenger Seats (Modified) | Padded Armrest Leg Skirt - Rotation Lock | - | 150 | 30 |
| Padding | End Partitions Bulkhead and Door | 350 | 400 | 2 |
| Luggage Rack | Hinged Door with Latch | 25 | 35 | 32 |
| Total Cost per Car All Systems | | 4,500 | 21,420** | |

NOTE: Costs include installation

* Additional cost over standard seat
**Using new crashworthy seats

## 10. CONCLUSIONS

The conclusions reached in this study are based on data obtained from accident investigation reports and T-Forms, visual surveys of rail vehicle interiors, analytical determi- of occupant impact forces and logical assumptions. Accident data, in the majority of incidents, reported the initiating factors of the accident, the type of vehicle the occupant was injured in and the nature of the injuries. The area of minimal information was on the injury mechanism or object contacted by the occupant. Conclusions as to the items requiring improvement to reduce injuries was based to a great extent on the visual surveys to determine the likely object to cause injury in a collision. This was particularly true for passenger rail vehicle occupants where collision injury mechanism data was practically non existent. The severity of injuries, based on the assumptions from the visual survey, was determined by the use of mathematical analysis to obtain force levels.

Severity of injuries was found to be less pronounced for passenger railcar occupants than locomotive and caboose occupants. This is assuming that the passenger car does not telescope or become penetrated by another car. Calculations show that acceleration pulses experienced in passenger cars, regardless of the velocity at collision, will not cause occupants to impact interior furnishings at a velocity sufficient to cause fatal injuries. Injuries experienced in passenger cars fell into the minor to moderate level range. Modifications to passenger cars for collision safety will be for the purpose of eliminating or reducing injuries rather than so much to prevent fatalities. The principal modifications to passenger railcars are as follows:

- Prevent double seats from swiveling by providing a positive lock to improve occupant containment
- Prevent leg entrapment under setts by adding a back skirt to reduce high frequency of leg injury in collisions
- Provide padded armrests, headrests and shoulder wings to improve containment
- Provide padding on rigid bulkheads, doors and nonyielding partitions
- Compartment lounge and lavatory areas to minimize distance occupant can be thrown

- Delethalize food preparation areas
- Secure dining car seats or provide compartmentation.

Collision safety provisions in locomotives is of prime importance. Locomotive occupants in a collision have a higher probability of fatal or serious injury than those in any other rail vehicle. Lethal control surfaces in front of the engineman and rugged unyielding bulkhead and door in front of the helper are the principal causes of injury.

To protect the locomotive occupants from injury, they must be prevented from being thrown into these injury producing surfaces. A padded buffer or lap belt shoulder harness can be used to restrain the occupants and are about equal in cost. The buffer is passive and would be more effective than a lap belt shoulder harness system which requires a willful act on the part of the occupant to put it on. Seats should be improved by providing high seat backs, headrests and padded armrests. Other areas of improvement to protect standing locomotive occupants are as follow:

- Recessed water cooler
- Equipment normally hung on rear bulkhead placed on cabinets
- Padding added to rear bulkhead and back of control console.

Accelerations experienced by caboose occupants are three times as great as those in locomotives and passenger railcars. Due to the light weight of the caboose, high accelerations are also experienced in non collision operations such as hard coupling and slack action. Restraint of caboose occupants is a necessity in preventing injury. Padded buffers or webbing restraint systems can be used. Due to the frequent accelerations and decelerations experienced by caboose occupants, the webbing restraint system can be considered and a high frequency of use can be expected. Many of the new cabooses being produced are equipped with lap belts and shoulder harnessed for the trainmen.

Cabooses are equipped with many irregular shaped items of equipment which can produce serious injury if impacted. These items of equipment should be covered by flat surfaced partitions which are padded or sufficiently resiliant to absorb impact energy, reducing forces to a tolerable level.

Cost effectiveness of incorporation of some or all of the features recommended in this study in new build or retrofit rail vehicles is the subject of much debate. The number of occupants killed or seriously injured in rail vehicle accidents where structural crushing does not occur is relatively low. The cost of incorporating the crashworthy features on a retrofit basis is many times higher than on a new build basis. It is therefore recommended that crashworthy features be incorporated only in new build rail vehicles.

# APPENDIX A - PROMETHEUS COMPUTER PROGRAM

## A.1 SYNOPSIS OF PROGRAM INPUT

This section provides information about program input in abbreviated form. It is intended to provide quickly accessible information to the experienced user, who usually does not require a detailed explanation. Detailed descriptions of PROMETHEUS 2 input are found in Reference A-1.

Variable names are capitalized. Lower case letters within a variable name are to be replaced by numerals. This provides a shorthand for representing a class of variables. Thus AMmn is shorthand for the variables AM23, AM24, AM45, AM56, AM57 and AM78. (The numerals which may be substituted are always described in the text.)

This section is divided into five major subsections:

- 4.1 Victim
- 4.2 Vehicle Structure and Cushions
- 4.3 Seat Belt and Shoulder Harness
- 4.4 Motion of Vehicle Frame
- 4.5 Miscellaneous Parameters

An alphabetical listing of variables which indicates in which section the variable description is to be found is given in Reference A-1.

## 4.1 Victim

There are six subsections:

- Properties of Limbs (4.1.1)
- Joint Properties (4.1.2)
- Forces Between Feet and Floor (4.1.3)
- Interference Between Limbs (4.1.4)
- Initial Position and Velocity of Victim (4.1.5)
- Limb Semi-Thicknesses at Joints (4.1.6)

### 4.1.1 Properties of Limbs

Physical properties of each segment of the occupant/pedestrian are required. The properties are summarized below and illustrated in Figure A-1. The segment number (k) is defined in Table A-1.

Reference A-1

NTIS Report PB269-305/9, Prometheus II, A User Orientation Program for Human Crash Dynamics, Technical Report Number BCS/6 0802, U.S. Department of Transportation, National Highway Traffic Safety Administration, David Twigg, August, 1976.

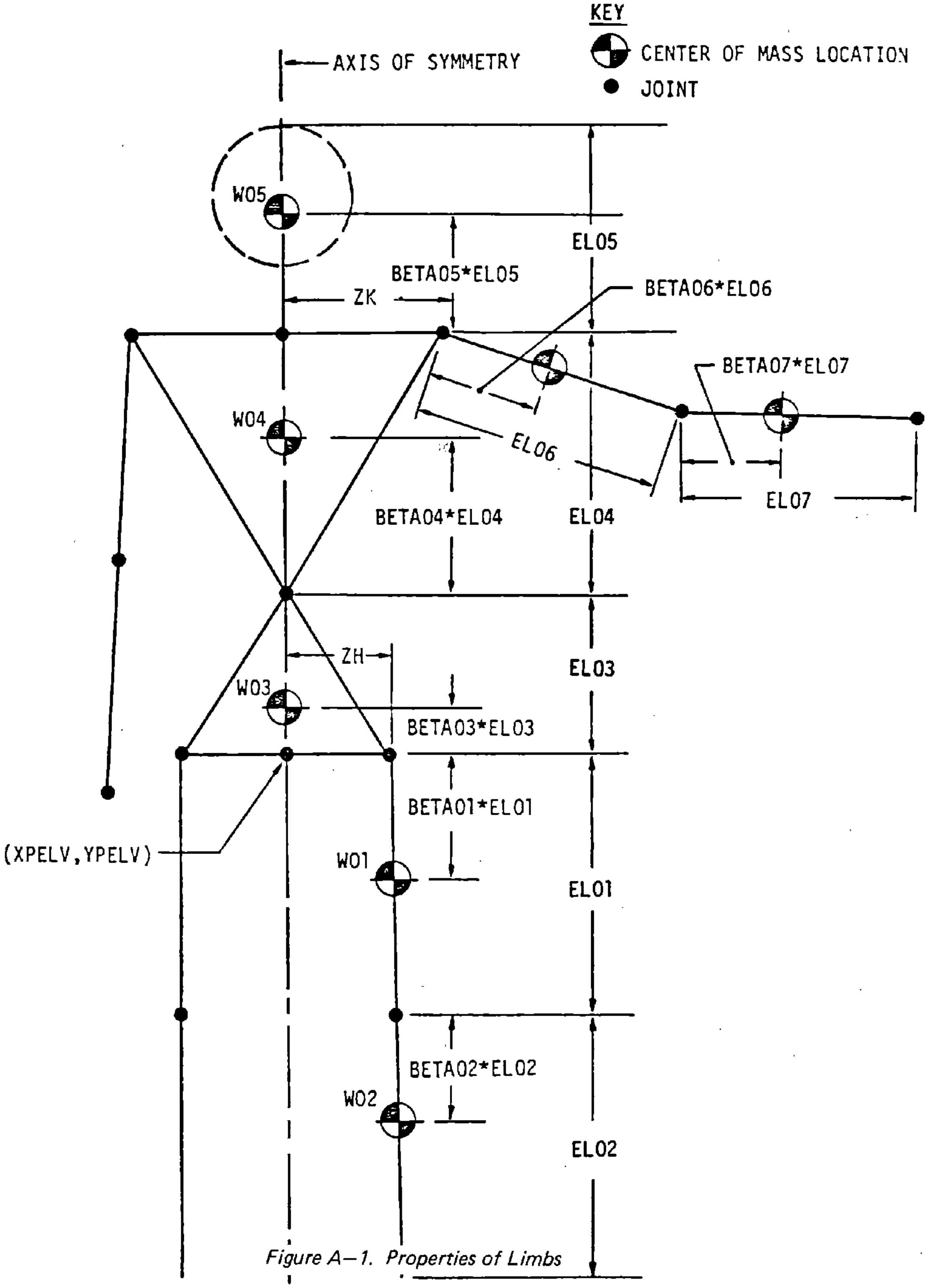

*Figure A—1. Properties of Limbs*

TABLE A-1. DESCRIPTION OF BODY SEGMENTS

| k | Description |
|---|---|
| 1 | Upper Legs (Thighs) |
| 2 | Lower Legs and Feet |
| 3 | Pelvis |
| 4 | Chest |
| 5 | Neck and Head |
| 6 | Upper Arms |
| 7 | Forearms |

| | |
|---|---|
| BETAOk | Dimensionless ratio defining location of segment center of mass of segment k |
| ELOk | Length of segment h (inches) |
| ERTOk | Polar moment of inertia of segment k about center of mass (slug-in.$^2$) |
| WOk | Weight of segment k (lb) |
| ZH | Half width of hips |
| ZK | Half width of shoulders |

The following properties may also be specified for each segment.

| | |
|---|---|
| SFRCMk | Coefficient of friction of segment k (Table A-1); This value, if specified, will override the cushion coefficient of friction (SFRCmn). |
| KLIMBk | Cushion curve number to be used when body segment k strikes <u>any</u> cushion (the cushion parameter KCSHmn is overriden) |
| SKIPmn | Body segment mn is transparent with respect to the vehicle structure if and only if SKIPmn$\neq$0. (See Table A-2 for definition of mn.) |

### 4.1.2 Joint Properties

| | |
|---|---|
| AMmn | Magnitude of Coulomb torque (in.-lb) |
| AMLmn | Damping constant for viscous damper which opposes joint motion (in.-lb sec/radian) |
| BMmn | Spring constant (in.-lb/radian) for the inelastic joint stop spring in the elastic regime. The joint stop spring is active when the joint angle is outside the range specified by the joint stops. |
| CMLmn, CMUmn | Lower and upper joint stop angles. These parameters define the algebraically smallest and largest value which can be achieved by the joint angle in "free" rotation (degrees). For the arm and leg joints (hips, knee, shoulder, elbow) the parameters refer to the pedestrian's left joint, assuming that the occupant/pedestrian is facing out of the paper. The joint stops for the right side are taken equal to the left side properties |

## TABLE A-2. DESCRIPTION OF BODY SEGMENTS FOR PARAMETERS WHICH CAN BE SPECIFIED ASYMMETRICALLY

| mn | Limb |
|---|---|
| 01 | Left Thigh |
| 02 | Left Calf and Foot |
| 03 | Pelvis |
| 04 | Chest |
| 05 | Neck/Head |
| 06 | Left Upper Arm |
| 07 | Left Forearm |
| 08 | Right Upper Arm |
| 09 | Right Forearm |
| 10 | Right Thigh |
| 11 | Right Calf and Foot |

## TABLE A-3. DESCRIPTION OF BODY JOINTS

| mn | Description of Body Joint |
|---|---|
| 23 | Hips |
| 24 | Knees |
| 45 | Waist |
| 56 | Neck |
| 57 | Shoulders |
| 78 | Elbows |

if the symmetry indication is turned off (i.e. if SYMM≠0), and mirror symmetry is assumed if SYMM=0, i.e.

CML (right) = (360-CMU(left) ) mod 360
CMU (right) = (360-CML(left) ) mod 360

| | |
|---|---|
| RMLmn | Spring constant (in.-lb/radian) for linear elastic torque spring which tries to restore the limb to a position midway between the joint stop angles. RMLmn is used to model a rubber joint in an anthromorphic dummy. |
| SYMM | Joint symmetry indicator. If SYMM = 0 (default), the right side joint stop angles are mirror symmetric with respect to the left side angles. If SYMM≠0, the right side joint stops are taken equal to the left side joint stops. |
| TORMmn | Maximum torque (in.-lb) which can be exerted by the inelastic joint stop torque spring. TORMmn is also the elastic limit for this spring. |

### 4.1.3 Forces Between Feet and Ground or Floor

| | |
|---|---|
| CK1, CK2 | Spring constant and viscous damping coefficient resisting vertical motion of feet (when in contact with ground or floor). |
| CK3, CK4 | Same as CK1, CK2, except applied to horizontal motion. |
| U1 | Coefficient of friction between feet and ground or floor. |
| FLOOR | Floor/ground switch. If FLOOR=0, the victim's feet contact the ground; if FLOOR≠0, the victim's feet contact the vehicle floor. |

### 4.1.4 Inteference Between Limbs

Interference between various pairs of limbs can be modeled by PROMETHEUS 2. The interference is controlled by the variables SEGjk.

| | |
|---|---|
| SEGjk | If SEGjk=m, where m>0, then the interference described in Table A-4 is modeled, using cushion curve m for the interference force calculation. If m=0 the interference is not modeled. |

TABLE A-4. PERMITTED INTERACTIONS

| Variable | Interaction |
|---|---|
| SEG01 | Head - Left Lower Arm |
| SEG02 | Head - Left Upper Arm |
| SEG03 | Head - Left Lower Leg |
| SEG04 | Head - Left Upper Leg |
| SEG05 | Head - Right Lower Leg |
| SEG06 | Head - Right Upper Leg |
| SEG07 | Chest - Left Lower Arm |
| SEG08 | Chest - Left Upper Arm |
| SEG09 | Chest - Head |
| SEG10 | Chest - Right Upper Arm |
| SEG11 | Chest - Left Lower Leg |
| SEG12 | Chest - Left Upper Leg |
| SEG13 | Chest - Right Lower Leg |
| SEG14 | Chest - Right Upper Leg |
| SEG15 | Pelvis - Left Lower Arm |
| SEG16 | Pelvis - Left Upper Arm |
| SEG17 | Pelvis - Right Lower Arm |
| SEG18 | Pelvis - Right Upper Arm |
| SEG19 | Left Lower Leg - Left Lower Arm |
| SEG20 | Left Lower Leg - Right Lower Arm |
| SEG21 | Left Lower Leg - Right Lower Leg |
| SEG22 | Left Upper Leg - Left Lower Arm |
| SEG23 | Left Upper Leg - Right Lower Arm |
| SEG24 | Left Upper Leg - Right Upper Leg |
| SEG25 | Right Lower Leg - Left Lower Arm |
| SEG26 | Right Lower Leg - Right Lower Arm |
| SEG27 | Right Upper Leg - Left Lower Arm |
| SEG28 | Right Upper Leg - Right Lower Arm |

### 4.1.5 Initial Position and Velocity of Victim

| | |
|---|---|
| XPELV, YPELV | Initial position of the pelvis (the point midway between the hip sockets). |
| THnI | Initial value of generalized coordinate $q_n$ (degrees counterclockwise from the x axis). The generalized coordinates $q_n, n=03, \ldots 13$, represent the orientation angles of the segments, and are defined in Table A-5. |
| ZXDPEL, ZYDPEL | Horizontal and vertical components of the initial (translational) velocity of the occupant/pedestrian measured in the inertial coordinate system (in./sec). |

### 4.1.6 Limb Semi-Thicknesses at Joints

Limb semi-thicknesses may be supplied at various joints to model the interaction between the occupant and the seat cushions. (These parameters are optional.)

| | |
|---|---|
| OSNDjk | Semi-thickness at joint k of the occupant (see Table A-6) - inches. jk=01,...,16 |

## 4.2 Vehicle Structure and Cushions

There are six major subsections:

- Nodal Data (4.2.1)
- Elastic Spring Properties (4.2.2)
- Viscous Damper Properties (4.2.3)
- Inelastic Spring Peroperties (4.2.4)
- Element Definition (4.2.5)
- Cushion Properties (4.2.6)

### 4.2.1 Nodal Data (Maximum of 40 Nodes)

| | |
|---|---|
| SXjk, SYjk | Coordinates of the initial position of node jk (jk = 01,02,...,40.) |
| NPSEAT | Number of nodes in seat. |
| FIXjk | Code indicating how node jk is restrained (jk = 01,...,40). FIXjk $\le 0$ if node jk is free. FIXjk = 4 if node jk is constrained to lie in a vertical line. FIXjk = 5 if node jk is constrained to lie in a horizontal line. FIXjk =100+n if node jk is constrained to lie on a line connecting the initial positions of nodes n and jk. |

TABLE A-5. SEGMENT NUMBERS FOR INITIAL POSITION SPECIFICATIONS

| n | Segment whose orientation angle is $q_n$ |
|---|---|
| 3 | Pelvis |
| 4 | Chest |
| 5 | Head |
| 6 | Left Thigh |
| 7 | Left Calf |
| 8 | Right Thigh |
| 9 | Right Calf |
| 10 | Left Upper Arm |
| 11 | Left Forearm |
| 12 | Right Upper Arm |
| 13 | Right Forearm |

TABLE A-6. NODES AT WHICH SEMI-THICKNESSES CAN BE SPECIFIED

| n | Node/Joint |
|---|---|
| 1 | Midpoint of Line Segment Joining Hip Sockets |
| 2 | Left Knee |
| 3 | Left Foot |
| 4 | Mid Torso Joint |
| 5 | Neck/Shoulder Joint |
| 6 | Top of Head |
| 7 | Left Elbow |
| 8 | Left Hand |
| 9 | Right Elbow |
| 10 | Right Hand |
| 11 | Right Knee |
| 12 | Right Foot |
| 13 | Left Hip Socket |
| 14 | Right Hip Socket |
| 15 | Left Shoulder Socket |
| 16 | Right Shoulder Socket |

### 4.2.2 Elastic Spring Properties

(Maximum of 5 Different Property Sets)

| | |
|---|---|
| CVFnjk, CVDnjk | Points on the force-deflection (or stress-strain) curve for nonlinear elastic spring property set n (jk = 01,02,...,10; n = 1,...,5). |
| NCRVn | Number of force-deflection points specified for spring property set n. |

### 4.2.3 Viscous Damper Properties (maximum of 5)

| | |
|---|---|
| SHCn | Viscous coefficient |
| STROKCn | Maximum stroke in compression |
| STROKTn | Maximum stroke in tension |

### 4.2.4 Inelastic Spring Properties

| | |
|---|---|
| AkLPmn, AkLDmn | Points describing the force-deflection or stress-strain loading curve for inelastic spring property set k. (mn = 01, 02,...,10 and k = 1,2, or 3.). The interpretation of the curve is determined by the cross sectional area parameter AREAjk of each element to which the curve is applied. |
| AkUPmn, AkUDmn | Points describing the force-deflection or stress-strain unloading curve for inelastic spring property set k. (mn = 01,...,10 and k = 1,2 or 3.) |
| NATENk | Total number of points and loading and unloading curve for inelastic spring property set k. (k = 1,2,3.) |
| ELASTk | Elastic limit for inelastic spring property set k. (k = 1,2,3.) |

### 4.2.5 Element Defintion

The following information is required to define seat elements (maximum of 40 elements):

| | |
|---|---|
| WTELjk | Weight of element jk (jk = 01,...,40). |
| JELjk, KELjk | Nodes to which element jk is connected (jk = 01,...,40). |
| TYPEjk | Element category for element jk. |

TYPEjk = 1 if element jk is an elastic spring.
= 2 if element jk is a viscous damper.
= 3 if element jk is a tension-only inelastic spring (e.g., an extruder).
= 4 if element jk is a compression-only inelastic spring.

| | |
|---|---|
| NSEAT | Number of seat elements (seat elements must be numbered 1,2,...,NSEAT). |
| CURVjk | Element property selector. The definition of an element requires both CURVjk and TYPEjk. TYPEjk gives the element type, and CURVjk references the properties which element TYPEjk possesses. For example, TYPE01 = 2, CURV01 = 3 means that element 1 is a viscous damper (TYPE01 = 2), with properties of property set 3 (i.e., SHC3, STRØKC3 and STRØKT3). |
| AREAjk | Cross sectional area of element jk. AREAjk is ignored if element jk is a viscous damper (i.e., TYPEjk = 2). Otherwise, AREAjk serves as a switch which determines whether the (elastic or inelastic) spring property curve defining element jk is interpreted as a force deflection curve or a stress strain curve. If AREAjk is not specified (i.e., AREAjk = 0.0) the curve selected by TYPE01 and CURV01 is interpreted as a force deflection curve. When AREAjk is specified, the curve is interpreted as a stress strain curve, with AREAjk used as cross sectional area to convert the axial force in element jk to stress. |

### 4.2.6 Cushion Properties

The following data are needed to describe cushions (maximum) of 20 cushioned elements):

| | |
|---|---|
| CUSHjk | Structural element number to which cushion k is attached (jk = 01,...,20.) |
| OSJLjk<br>OSKLjk | Seat cushion offsets for cushion jk, attached to node j = CUSHjk. OSJLjk is the offset associated with node JELjk, and OSKLjk is the offset associated with node KELjk. |
| KCSHjk | Number of curve defining properties of cushion jk. (Let j = KCSHjk. Then curve j defined by points CUDjmn, CUFjmn is used to describe cushion jk.) |

| | |
|---|---|
| SFRCjk | Coefficient of friction for cushion jk. |
| ORXjk<br>ORYjk | Coordinates of orientation node for cushion jk. The cushion will be oriented so that the orientation node is behind the cushion surface. |

Polynomical representation of force-deflection curves. (Omit unless the selector switch CABISW (CAHISW) is set to 1.)

| | |
|---|---|
| CABO<br>(CAHO)<br>CAB01-CAB10<br>(CAH01-CAH10) | Let F be the belt force, let X be the elongation of the seat belt (or shoulder harness), and X be the rate of elongation. The loading curve is defined as follows: |

If $0 < X \le CAB06$,

$$F = CABO + CAB01 \cdot X + CAB02 \cdot X^2 + CAB03 \cdot X^3 + CAB04 \cdot X^4 + CAB05 \cdot \dot{X}$$

If $X > CAB06$,

$$F = CAB08 + CAB07 \cdot X + CAB05 \cdot \dot{X}$$

If $X \le 0$,

$$F = 0$$

The unloading curve is defined thusly?

If $X > 0$,

$$F = CAB09\ (X-T) + CAB10\ (X-T)^2.$$

where the translation term T is calculated by PROMETHEUS.

If $X \le 0$,

$$F = 0.$$

Tabular representation of the force-deflection curves. (Omit unless the selector switch CABISW (CAHISW) is set to 2.)

| | |
|---|---|
| ZORX, ZORY | Default orientation node, which is used if neither ORXjk nor ORYjk is specified. |

Force-deflection curves for cushions are defined as follows:

| | |
|---|---|
| CUFjmn<br>CUDjmn | Points on force-deflection curve j for cushions. (mn = 01,...,10; j = 1,...,5). |
| NCUSHj | Number of points on force-deflection curve j. |

## 4.3 Seat Belt and Shoulder Harness

The following variables are required to define the properties of the seat belt or shoulder harness. The seat belt variable name is given in the description, with the corresponding shoulder harness variable name in parentheses. The seat belt and shoulder harness exist if and only if the appropriate attachment point to the seat or vehicle has been defined (see description of seat nodes, variable FIXmn).

| | |
|---|---|
| BATCHM<br>(HATCHM) | Node on the man to which the seat belt is attached. |
| BATCHS<br>(HATCHS) | Node on the seat to which the seat belt is attached. |
| CABISL<br>(CAHISL) | Initial slack in seat belt (inches). (Alternatively, CAHISL is initial slack in shoulder harness.) |
| CABEL<br>(CAHEL) | Elastic limit for seat belt material (lbs). (CAHEL is limit for shoulder harness.) |
| CABISW<br>(CAHISW) | Selector switch - set to 1 if polynomial representation of force-deflection curves is to be used; set to 2 for tabular representation. |
| CABLPk, CABLDk<br>(CAHLPk, CAHLDk) | Points describing tabular force-deflection loading curve ($k = 0, 1, \ldots, 9$). |
| CABUPk, CABUDk<br>(CAHUPk, CAHUDk) | Points describing tabular force-deflection unloading curve ($k = 0, 1, \ldots, 9$). |
| NCAB<br>(NCAH) | Number of points in either the tabular loading curve or unloading curve (must be the same). |

## 4.4 Motion of Vehicle Frame

| | |
|---|---|
| Tmn<br>ACCmn | The magnitude of the acceleration applied to the vehicle as a function of time is given by the points Tmn, ACmn. (mn = 01,...,20). |
| LL | Number of points (Tmn, ACCmn) in acceleration pulse description. ($1 \leq LL \leq 20$). |
| DV | Velocity increment. If DV is non-zero, the curve of acceleration values (ACCmn) vs. Time (Tmn) is scaled so that the area under the curve is DV. |

| | |
|---|---|
| QU0 | The angle (degrees) which the acceleration vector makes with the positive X-axis of the coordinate system of the vehicle. |
| ZVVEHX, ZVVEHY | Components of initial (translational velocity of vehicle (in./sec). |

## 4.5 Miscellaneous Parameters

This section includes the following subsections:

Integration Controls (4.5.1)
Accelerometer Simulation (4.5.2)
Output Controls (4.5.3)
Cockpit Outline (4.5.4)
Severity Indices (4.5.5)

### 4.5.1 Integration Controls

These parameters control the numerical integration process in PROMETHEUS.

| | |
|---|---|
| DTI | Minimum time step (seconds). This value is also used for the initial step size. |
| TMAX | Time at which integration stops (seconds). |
| TEST1 | Tolerance governing accuracy of integration. If the maximum relative error in the computed accelerations is greater than TEST1, then the step size is reduced. The default value is 0.1. |
| TEST2 | Target error (should be less than TEST1). PROMETHEUS attempts to adjust each integration step so that the error for each step is TEST2. The default value is 0.632 (TEST1). |

### 4.5.2 Accelerometer Simulation (Maximum of 15)

To specify accelerometer location, the segment number and per cent distance from one of the segment nodes are required.

| | |
|---|---|
| ACRNjk | The segment number to which the $jk^{th}$ accelerometer is to be affixed (see Table A-7 for segment number). |
| ACRBjk | The distance, measured as a fraction of the distance between nodes, of the accelerometer from one node (see Table A-7). |
| NATEN | Number of accelerometers specified. |

## TABLE A-7. ACCELEROMETER DEFINITION

| Segment No. (jk) | Segment Name | ACRBjk Measured From |
|---|---|---|
| 1 | Left Thigh | Hip Socket |
| 2 | Left Calf | Knee |
| 3 | Pelvis | Midpoint of Hip Sockets |
| 4 | Chest | Solar Plexis |
| 5 | Neck/Head | Midpoint of Shoulder Sockets |
| 6 | Left Upper Arm | Shoulder Socket |
| 7 | Left Forearm | Elbow |
| 8 | Right Upper Arm | Shoulder Socket |
| 9 | Right Forearm | Elbow |
| 10 | Right Thigh | Hip Socket |
| 11 | Right Calf | Knee |

### 4.5.3 Output Controls

(These parameters control the output tables.)

| | |
|---|---|
| TPT | Time of initial printout (seconds). No values in the output tables are printed before time TPT. |
| PI | Print interval (seconds). The lines in the tables are printed at approximate times TPT, TPT+PI, TPT+2PI, etc. |
| PMAN | Print switch for tables of time history of motion of pedestrian nodes. If $\text{PMAN} \neq 0$, the tables are not printed. |
| PRACC | Print switch for tables of time history of accelerometers. If $\text{PRACC} \neq 0$, the accelerometer tables are not printed. |
| PRCUSH | Print switch for tables of cushion forces. If $\text{PRCUSH} \neq 0$, the cushion force history tables are not printed. |
| PREL | Print switch for tables of time history of structural element forces. If $\text{PREL} \neq 0$, the tables are not printed. |
| PRFRAC | Print switch for table of time history of forces and accelerations. If $\text{PRFRAC} \neq 0$, the table is not printed. |
| PRNOD | Print switch for tables of time history of structural nodes. If $\text{PRNOD} \neq 0$, the tables are not printed. |
| PRPIC | Print switch for graphic displays, produced on the printers, which depict the position of the occupant/pedestrian at various times. If $\text{PRPIC} \neq 0$, the displays are not generated. |
| PRPLT | Print switch for printer generated x-y plots of position, velocity, and acceleration of head/chest/pelvis as a function of time. If $\text{PRPLT} \neq 0$, the x-y plots are not generated. |
| ZSLOT | Time step history switch. If $\text{ZSLOT} > 0$, the time step history plots are generated. ZSLOT is also the number of time intervals in the time step summary histogram ($\text{ZSLOT} \leq 50$). |

### 4.5.4 Cockpit Outline

(Optional, for CRT terminal and post processor only)

| | |
|---|---|
| XPITmn, YPITmn | x and y coordinates of points outlining cockpit interior or other auxiliary structure. (mn = 01,...,15) |
| YPITN | Number of points in cockpit outline. ($0 \leq \text{YPITN} \leq 15$) |

### 4.5.5 Severity Indices

| | | |
|---|---|---|
| ZEXP1 | Severity index exponent for | head |
| ZEXP2 | Severity index exponent for | chest |
| ZEXP3 | Severity index exponent for | pelvis |

## A.2 PROMETHEUS INPUT VARIABLES

```
                           TABLE OF INPUT VARIABLES - * INDICATES DEFAULTED VALUE                              PAGE  1

 AC001  =  .0                       AML23  =  .0                       AREA39 =  .0            *      A2LD09 =  .0            *
 AC002  =  2.51800E+03              AML25  =  .0                       AREA40 =  .0            *      A2LD10 =  .0            *
 AC003  =  2.26200E+03              AML45  =  6.00000E+01              A1LD01 =  .0            *      A2LP01 =  .0            *
 AC004  =  .0                       AML56  =  6.00000E+01              A1LD02 =  .0            *      A2LP02 =  .0            *
 AC005  =  .0                       AML57  =  .0                       A1LD03 =  .0            *      A2LP03 =  .0            *
 AC006  =  .0            *          AML78  =  .0                       A1LD04 =  .0            *      A2LP04 =  .0            *
 AC007  =  .0            *          AM23   =  4.23000E+02              A1LD05 =  .0            *      A2LP05 =  .0            *
 AC008  =  .0            *          AM25   =  1.19800E+02              A1LD06 =  .0            *      A2LP06 =  .0            *
 AC009  =  .0            *          AM45   =  .0                       A1LD07 =  .0            *      A2LP07 =  .0            *
 AC010  =  .0            *          AM56   =  .0                       A1LD08 =  .0            *      A2LP08 =  .0            *
 AC011  =  .0            *          AM57   =  1.08700E+02              A1LD09 =  .0            *      A2LP09 =  .0            *
 AC012  =  .0            *          AM78   =  2.71000E+01              A1LD10 =  .0            *      A2LP10 =  .0            *
 AC013  =  .0            *          AREA01 =  .0            *          A1LP01 =  .0            *      A2UD01 =  .0            *
 AC014  =  .0            *          AREA02 =  .0            *          A1LP02 =  .0            *      A2UD02 =  .0            *
 AC015  =  .0            *          AREA03 =  .0            *          A1LP03 =  .0            *      A2UD03 =  .0            *
 AC016  =  .0            *          AREA04 =  .0            *          A1LP04 =  .0            *      A2UD04 =  .0            *
 AC017  =  .0            *          AREA05 =  .0            *          A1LP05 =  .0            *      A2UD05 =  .0            *
 AC018  =  .0            *          AREA06 =  .0            *          A1LP06 =  .0            *      A2UD06 =  .0            *
 AC019  =  .0            *          AREA07 =  .0            *          A1LP07 =  .0            *      A2UD07 =  .0            *
 AC020  =  .0            *          AREA08 =  .0            *          A1LP08 =  .0            *      A2UD08 =  .0            *
 ACFB01 =  4.95000E-01              AREA09 =  .0            *          A1LP09 =  .0            *      A2UD09 =  .0            *
 ACFB02 =  4.37000E-01              AREA10 =  .0            *          A1LP10 =  .0            *      A2UD10 =  .0            *
 ACFB03 =  1.00000E-02              AREA11 =  .0            *          A1UD01 =  .0            *      A2UP01 =  .0            *
 ACFB04 =  .0            *          AREA12 =  .0            *          A1UD02 =  .0            *      A2UP02 =  .0            *
 ACFB05 =  .0            *          AREA13 =  .0            *          A1UD03 =  .0            *      A2UP03 =  .0            *
 ACFB06 =  .0            *          AREA14 =  .0            *          A1UD04 =  .0            *      A2UP04 =  .0            *
 ACFB07 =  .0            *          AREA15 =  .0            *          A1UD05 =  .0            *      A2UP05 =  .0            *
 ACFB08 =  .0            *          AREA16 =  .0            *          A1UD06 =  .0            *      A2UP06 =  .0            *
 ACFB09 =  .0            *          AREA17 =  .0            *          A1UD07 =  .0            *      A2UP07 =  .0            *
 ACFB10 =  .0            *          AREA18 =  .0            *          A1UD08 =  .0            *      A2UP08 =  .0            *
 ACFB11 =  .0            *          AREA19 =  .0            *          A1UD09 =  .0            *      A2UP09 =  .0            *
 ACFB12 =  .0            *          AREA20 =  .0            *          A1UD10 =  .0            *      A2UP10 =  .0            *
 ACFB13 =  .0            *          AREA21 =  .0            *          A1UP01 =  .0            *      A3LD01 =  .0            *
 ACFB14 =  .0            *          AREA22 =  .0            *          A1UP02 =  .0            *      A3LD02 =  .0            *
 ACFB15 =  .0            *          AREA23 =  .0            *          A1UP03 =  .0            *      A3LD03 =  .0            *
 ACFA01 =  5.00000E+00              AREA24 =  .0            *          A1UP04 =  .0            *      A3LD04 =  .0            *
 ACFA02 =  4.00000E+00              AREA25 =  .0            *          A1UP05 =  .0            *      A3LD05 =  .0            *
 ACFA03 =  1.00000E+00              AREA26 =  .0            *          A1UP06 =  .0            *      A3LD06 =  .0            *
 ACFA04 =  .0            *          AREA27 =  .0            *          A1UP07 =  .0            *      A3LD07 =  .0            *
 ACFA05 =  .0            *          AREA28 =  .0            *          A1UP08 =  .0            *      A3LD08 =  .0            *
 ACFA06 =  .0            *          AREA29 =  .0            *          A1UP09 =  .0            *      A3LD09 =  .0            *
 ACFA07 =  .0            *          AREA30 =  .0            *          A1UP10 =  .0            *      A3LD10 =  .0            *
 ACFA08 =  .0            *          AREA31 =  .0            *          A2LD01 =  .0            *      A3LP01 =  .0            *
 ACFA09 =  .0            *          AREA32 =  .0            *          A2LD02 =  .0            *      A3LP02 =  .0            *
 ACFA10 =  .0            *          AREA33 =  .0            *          A2LD03 =  .0            *      A3LP03 =  .0            *
 ACFA11 =  .0            *          AREA34 =  .0            *          A2LD04 =  .0            *      A3LP04 =  .0            *
 ACFA12 =  .0            *          AREA35 =  .0            *          A2LD05 =  .0            *      A3LP05 =  .0            *
 ACFA13 =  .0            *          AREA36 =  .0            *          A2LD06 =  .0            *      A3LP06 =  .0            *
 ACFA14 =  .0            *          AREA37 =  .0            *          A2LD07 =  .0            *      A3LP07 =  .0            *
 ACFA15 =  .0            *          AREA38 =  .0            *          A2LD08 =  .0            *      A3LP08 =  .0            *
```

```
                           TABLE OF INPUT VARIABLES - * INDICATES DEFAULTED VALUE                              PAGE  2

 A3LP09 =  .0            *          CABLP0 =  .0            *          CAHLD6 =  .0            *      CML24  =  2.29000E+02
 A3LP10 =  .0            *          CABLP1 =  .0            *          CAHLD7 =  .0            *      CML45  = -1.00000E+01
 A3UD01 =  .0            *          CABLP2 =  .0            *          CAHLD8 =  .0            *      CML56  = -6.00000E+01
 A3UD02 =  .0            *          CABLP3 =  .0            *          CAHLD9 =  .0            *      CML57  =  1.20000E+02
 A3UD03 =  .0            *          CABLP4 =  .0            *          CAHLP0 =  .0            *      CML78  =  .0
 A3UD04 =  .0            *          CABLP5 =  .0            *          CAHLP1 =  .0            *      CMU23  =  1.33000E+02
 A3UD05 =  .0            *          CABLP6 =  .0            *          CAHLP2 =  .0            *      CMU24  =  1.60000E+02
 A3UD06 =  .0            *          CABLP7 =  .0            *          CAHLP3 =  .0            *      CMU45  =  3.00000E+01
 A3UD07 =  .0            *          CABLP8 =  .0            *          CAHLP4 =  .0            *      CMU56  =  6.00000E+01
 A3UD08 =  .0            *          CABLP9 =  .0            *          CAHLP5 =  .0            *      CMU57  =  1.60000E+02
 A3UD09 =  .0            *          CABUD0 =  .0            *          CAHLP6 =  .0            *      CMU78  =  4.50000E+01
 A3UD10 =  .0            *          CABUD1 =  .0            *          CAHLP7 =  .0            *      CUC101 =  .0
 A3UP01 =  .0            *          CABUD2 =  .0            *          CAHLP8 =  .0            *      CUC102 =  2.50000E+00
 A3UP02 =  .0            *          CABUD3 =  .0            *          CAHLP9 =  .0            *      CUC103 =  1.00000E+00
 A3UP03 =  .0            *          CABUD4 =  .0            *          CAHUD0 =  .0            *      CUC104 =  .0            *
 A3UP04 =  .0            *          CABUD5 =  .0            *          CAHUD1 =  .0            *      CUD105 =  .0            *
 A3UP05 =  .0            *          CABUD6 =  .0            *          CAHUD2 =  .0            *      CUC106 =  .0            *
 A3UP06 =  .0            *          CABUD7 =  .0            *          CAHUD3 =  .0            *      CUC107 =  .0            *
 A3UP07 =  .0            *          CABUD8 =  .0            *          CAHUD4 =  .0            *      CUD108 =  .0            *
 A3UP08 =  .0            *          CABUD9 =  .0            *          CAHUD5 =  .0            *      CUC109 =  .0            *
 A3UP09 =  .0            *          CABUP0 =  .0            *          CAHUD6 =  .0            *      CUC110 =  .0            *
 A3UP10 =  .0            *          CABUP1 =  .0            *          CAHUD7 =  .0            *      CUC201 =  .0
 BATCHM =  .0            *          CABUP2 =  .0            *          CAHUD8 =  .0            *      CUC202 =  2.00000E+00
 BATCHS =  .0            *          CABUP3 =  .0            *          CAHUD9 =  .0            *      CUC203 =  1.20000E+01
 BETA01 =  5.71000E-01              CABUP4 =  .0            *          CAHUP0 =  .0            *      CUC204 =  .0            *
 BETA02 =  6.04000E-01              CABUP5 =  .0            *          CAHUP1 =  .0            *      CUC205 =  .0            *
 BETA03 =  1.19000E-01              CABUP6 =  .0            *          CAHUP2 =  .0            *      CUC206 =  .0            *
 BETA04 =  4.37000E-01              CABUP7 =  .0            *          CAHUP3 =  .0            *      CUC207 =  .0            *
 BETA05 =  4.95000E-01              CABUP8 =  .0            *          CAHUP4 =  .0            *      CUC208 =  .0            *
 BETA06 =  4.11000E-01              CABUP9 =  .0            *          CAHUP5 =  .0            *      CUC209 =  .0            *
 BETA07 =  5.00000E-01              CAB0   =  .0            *          CAHUP6 =  .0            *      CUC210 =  .0            *
 B723   =  2.00000E+04              CAB01  =  .0            *          CAHUP7 =  .0            *      CUC301 =  .0
 B724   =  2.00000E+04              CAB02  =  .0            *          CAHUP8 =  .0            *      CUC302 =  2.00000E+00
 B745   =  4.00000E+03              CAB03  =  .0            *          CAHUP9 =  .0            *      CUC303 =  1.20000E+01
 B756   =  4.00000E+03              CAB04  =  .0            *          CAH0   =  .0            *      CUC304 =  .0            *
 B757   =  2.00000E+04              CAB05  =  .0            *          CAH01  =  .0            *      CUC305 =  .0            *
 B778   =  1.00000E+04              CAB06  =  .0            *          CAH02  =  .0            *      CUD306 =  .0            *
 CABEL  =  .0            *          CAB07  =  .0            *          CAH03  =  .0            *      CUC307 =  .0            *
 CAB1SL =  .0            *          CAB08  =  .0            *          CAH04  =  .0            *      CUC308 =  .0            *
 CAB1SW =  .0            *          CAB09  =  .0            *          CAH05  =  .0            *      CUC309 =  .0            *
 CABLD0 =  .0            *          CAB10  =  .0            *          CAH06  =  .0            *      CUC310 =  .0            *
 CABLD1 =  .0            *          CAHEL  =  .0            *          CAH07  =  .0            *      CUD401 =  .0            *
 CABLD2 =  .0            *          CAH1SL =  .0            *          CAH08  =  .0            *      CUD402 =  .0            *
 CABLD3 =  .0            *          CAH2SL =  .0            *          CAH09  =  .0            *      CUD403 =  .0            *
 CABLD4 =  .0            *          CAHLD0 =  .0            *          CAH10  =  .0            *      CUD404 =  .0            *
 CABLD5 =  .0            *          CAHLD1 =  .0            *          CK1    =  1.00000E+09              CUD405 =  .0            *
 CABLD6 =  .0            *          CAHLD2 =  .0            *          CK2    =  .0                       CUD406 =  .0            *
 CABLD7 =  .0            *          CAHLD3 =  .0            *          CK3    =  1.00000E+04              CUD407 =  .0            *
 CABLD8 =  .0            *          CAHLD4 =  .0            *          CK4    =  .0                       CUD408 =  .0            *
 CABLD9 =  .0            *          CAHLD5 =  .0            *          CML23  =  1.35000E+02              CUD409 =  .0            *
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                    TABLE OF INPUT VARIABLES - * INDICATES DEFAULTED VALUE                        PAGE  3

CUD410 =  .0               *    CUF410 =  .0           *    CURV40 =  .0              *    CVD310 =  .0        *
CUD501 =  .0               *    CUF501 =  .0           *    CUSH01 =  1.00000E+00          CVD401 =  .0        *
CUD502 =  .0               *    CUF502 =  .0           *    CUSH02 =  2.00000E+00          CVD402 =  .0        *
CUD503 =  .0               *    CUF503 =  .0           *    CUSH03 =  3.00000E+00          CVD403 =  .0        *
CUD504 =  .0               *    CUF504 =  .0           *    CUSH04 =  4.00000E+00          CVD404 =  .0        *
CUD505 =  .0               *    CUF505 =  .0           *    CUSH05 =  5.00000E+00          CVD405 =  .0        *
CUD506 =  .0               *    CUF506 =  .0           *    CUSH06 =  6.00000E+00          CVD406 =  .0        *
CUD507 =  .0               *    CUF507 =  .0           *    CUSH07 =  .0                   CVD407 =  .0        *
CUD508 =  .0               *    CUF508 =  .0           *    CUSH08 =  .0              *    CVD408 =  .0        *
CUD509 =  .0               *    CUF509 =  .0           *    CUSH09 =  .0              *    CVD409 =  .0        *
CUD510 =  .0               *    CUF510 =  .0           *    CUSH10 =  .0              *    CVD410 =  .0        *
CUF101 =  .0                    CURV01 =  .0           *    CUSH11 =  .0              *    CVD501 =  .0        *
CUF102 =  3.00000E+01           CURV02 =  .0           *    CUSH12 =  .0              *    CVD502 =  .0        *
CUF103 =  1.00000E+02           CURV03 =  .0           *    CUSH13 =  .0              *    CVD503 =  .0        *
CUF104 =  .0               *    CURV04 =  .0           *    CUSH14 =  .0              *    CVD504 =  .0        *
CUF105 =  .0               *    CURV05 =  .0           *    CUSH15 =  .0              *    CVD505 =  .0        *
CUF106 =  .0               *    CURV06 =  .0           *    CUSH16 =  .0              *    CVD506 =  .0        *
CUF107 =  .0               *    CURV07 =  .0           *    CUSH17 =  .0              *    CVD507 =  .0        *
CUF108 =  .0               *    CURV08 =  .0           *    CUSH18 =  .0              *    CVD508 =  .0        *
CUF109 =  .0               *    CURV09 =  .0           *    CUSH19 =  .0              *    CVD509 =  .0        *
CUF110 =  .0               *    CURV10 =  .0           *    CUSH20 =  .0              *    CVD510 =  .0        *
CUF201 =  .0                    CURV11 =  .0           *    CVD101 =  .0              *    CVF101 =  .0        *
CUF202 =  4.50000E+01           CURV12 =  .0           *    CVD102 =  .0              *    CVF102 =  .0        *
CUF203 =  5.00000E+02           CURV13 =  .0           *    CVD103 =  .0              *    CVF103 =  .0        *
CUF204 =  .0               *    CURV14 =  .0           *    CVD104 =  .0              *    CVF104 =  .0        *
CUF205 =  .0               *    CURV15 =  .0           *    CVD105 =  .0              *    CVF105 =  .0        *
CUF206 =  .0               *    CURV16 =  .0           *    CVD106 =  .0              *    CVF106 =  .0        *
CUF207 =  .0               *    CURV17 =  .0           *    CVD107 =  .0              *    CVF107 =  .0        *
CUF208 =  .0               *    CURV18 =  .0           *    CVD108 =  .0              *    CVF108 =  .0        *
CUF209 =  .0               *    CURV19 =  .0           *    CVD109 =  .0              *    CVF109 =  .0        *
CUF210 =  .0               *    CURV20 =  .0           *    CVD110 =  .0              *    CVF110 =  .0        *
CUF301 =  .0                    CURV21 =  .0           *    CVD201 =  .0              *    CVF201 =  .0        *
CUF302 =  2.41000E+01           CURV22 =  .0           *    CVD202 =  .0              *    CVF202 =  .0        *
CUF303 =  5.00000E+02           CURV23 =  .0           *    CVD203 =  .0              *    CVF203 =  .0        *
CUF304 =  .0               *    CURV24 =  .0           *    CVD204 =  .0              *    CVF204 =  .0        *
CUF305 =  .0               *    CURV25 =  .0           *    CVD205 =  .0              *    CVF205 =  .0        *
CUF306 =  .0               *    CURV26 =  .0           *    CVD206 =  .0              *    CVF206 =  .0        *
CUF307 =  .0               *    CURV27 =  .0           *    CVD207 =  .0              *    CVF207 =  .0        *
CUF308 =  .0               *    CURV28 =  .0           *    CVD208 =  .0              *    CVF208 =  .0        *
CUF309 =  .0               *    CURV29 =  .0           *    CVD209 =  .0              *    CVF209 =  .0        *
CUF310 =  .0               *    CURV30 =  .0           *    CVD210 =  .0              *    CVF210 =  .0        *
CUF401 =  .0               *    CURV31 =  .0           *    CVD301 =  .0              *    CVF301 =  .0        *
CUF402 =  .0               *    CURV32 =  .0           *    CVD302 =  .0              *    CVF302 =  .0        *
CUF403 =  .0               *    CURV33 =  .0           *    CVD303 =  .0              *    CVF303 =  .0        *
CUF404 =  .0               *    CURV34 =  .0           *    CVD304 =  .0              *    CVF304 =  .0        *
CUF405 =  .0               *    CURV35 =  .0           *    CVD305 =  .0              *    CVF305 =  .0        *
CUF406 =  .0               *    CURV36 =  .0           *    CVD306 =  .0              *    CVF306 =  .0        *
CUF407 =  .0               *    CURV37 =  .0           *    CVD307 =  .0              *    CVF307 =  .0        *
CUF408 =  .0               *    CURV38 =  .0           *    CVD308 =  .0              *    CVF308 =  .0        *
CUF409 =  .0               *    CURV39 =  .0           *    CVD309 =  .0              *    CVF309 =  .0        *
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                    TABLE OF INPUT VARIABLES - * INDICATES DEFAULTED VALUE                        PAGE  4

CVF310 =  .0               *    FIX11  =  3.00000E+00       JEL18  =  .0              *    KEL08  =  1.00000E+01
CVF401 =  .0               *    FIX12  =  .0           *    JEL19  =  .0              *    KEL09  =  1.10000E+01
CVF402 =  .0               *    FIX13  =  .0           *    JEL20  =  .0              *    KEL10  =  2.00000E+00
CVF403 =  .0               *    FIX14  =  .0           *    JEL21  =  .0              *    KEL11  =  .0           *
CVF404 =  .0               *    FIX15  =  .0           *    JEL22  =  .0              *    KEL12  =  .0           *
CVF405 =  .0               *    FIX16  =  .0           *    JEL23  =  .0              *    KEL13  =  .0           *
CVF406 =  .0               *    FIX17  =  .0           *    JEL24  =  .0              *    KEL14  =  .0           *
CVF407 =  .0               *    FIX18  =  .0           *    JEL25  =  .0              *    KEL15  =  .0           *
CVF408 =  .0               *    FIX19  =  .0           *    JEL26  =  .0              *    KEL16  =  .0           *
CVF409 =  .0               *    FIX20  =  .0           *    JEL27  =  .0              *    KEL17  =  .0           *
CVF410 =  .0               *    FIX21  =  .0           *    JEL28  =  .0              *    KEL18  =  .0           *
CVF501 =  .0               *    FIX22  =  .0           *    JEL29  =  .0              *    KEL19  =  .0           *
CVF502 =  .0               *    FIX23  =  .0           *    JEL30  =  .0              *    KEL20  =  .0           *
CVF503 =  .0               *    FIX24  =  .0           *    JEL31  =  .0              *    KEL21  =  .0           *
CVF504 =  .0               *    FIX25  =  .0           *    JEL32  =  .0              *    KEL22  =  .0           *
CVF505 =  .0               *    FIX26  =  .0           *    JEL33  =  .0              *    KEL23  =  .0           *
CVF506 =  .0               *    FIX27  =  .0           *    JEL34  =  .0              *    KEL24  =  .0           *
CVF507 =  .0               *    FIX28  =  .0           *    JEL35  =  .0              *    KEL25  =  .0           *
CVF508 =  .0               *    FIX29  =  .0           *    JEL36  =  .0              *    KEL26  =  .0           *
CVF509 =  .0               *    FIX30  =  .0           *    JEL37  =  .0              *    KEL27  =  .0           *
CVF510 =  .0               *    FIX31  =  .0           *    JEL38  =  .0              *    KEL28  =  .0           *
DTI    =  1.00000E-04           FIX32  =  .0           *    JEL39  =  .0              *    KEL29  =  .0           *
DY     =  .0                    FIX33  =  .0           *    JEL40  =  .0              *    KEL30  =  .0           *
ELAST1 =  .0               *    FIX34  =  .0           *    KCSH01 =  1.00000E+00          KEL31  =  .0           *
ELAST2 =  .0               *    FIX35  =  .0           *    KCSH02 =  1.00000E+00          KEL32  =  .0           *
ELAST3 =  .0               *    FIX36  =  .0           *    KCSH03 =  2.00000E+00          KEL33  =  .0           *
EL01   =  1.56000E+01           FIX37  =  .0           *    KCSH04 =  2.00000E+00          KEL34  =  .0           *
EL02   =  1.96000E+01           FIX38  =  .0           *    KCSH05 =  3.00000E+00          KEL35  =  .0           *
EL03   =  6.70000E+00           FIX39  =  .0           *    KCSH06 =  3.00000E+00          KEL36  =  .0           *
EL04   =  1.55000E+01           FIX40  =  .0           *    KCSH07 =  1.00000E+00          KEL37  =  .0           *
EL05   =  9.30000E+00           FLOOR  =  1.00000E+00       KCSH08 =  .0              *    KEL38  =  .0           *
EL06   =  1.20000E+01           HATCHB =  .0           *    KCSH09 =  .0              *    KEL39  =  .0           *
EL07   =  1.13000E+01           HATCH5 =  .0           *    KCSH10 =  .0              *    KEL40  =  .0           *
EFT01  =  1.27000E-01           JEL01  =  1.00000E+00       KCSH11 =  .0              *    KLIMB1 =  .0           *
EFT02  =  1.85000E+00           JEL02  =  2.00000E+00       KCSH12 =  .0              *    KLIMB2 =  .0           *
EFT03  =  2.32000E+00           JEL03  =  4.00000E+00       KCSH13 =  .0              *    KLIMB3 =  .0           *
EFT04  =  2.18000E+00           JEL04  =  5.00000E+00       KCSH14 =  .0              *    KLIMB4 =  .0           *
EFT05  =  3.10000E-01           JEL05  =  6.00000E+00       KCSH15 =  .0              *    KLIMB5 =  .0           *
EFT06  =  1.34000E-01           JEL06  =  7.00000E+00       KCSH16 =  .0              *    KLIMB6 =  .0           *
EFT07  =  1.25000E-01           JEL07  =  1.00000E+01       KCSH17 =  .0              *    KLIMB7 =  .0           *
FIX01  =  1.00000E+00           JEL08  =  1.00000E+00       KCSH18 =  .0              *    LL     =  5.00000E+00
FIX02  =  3.00000E+00           JEL09  =  1.00000E+01       KCSH19 =  .0              *    MACEL  =  3.00000E+00
FIX03  =  3.00000E+00           JEL10  =  1.10000E+01       KCSH20 =  .0              *    MATER1 =  .0           *
FIX04  =  1.00000E+00           JEL11  =  .0           *    KEL01  =  2.00000E+00          MATER2 =  .0           *
FIX05  =  3.00000E+00           JEL12  =  .0           *    KEL02  =  3.00000E+00          MATER3 =  .0           *
FIX06  =  3.00000E+00           JEL13  =  .0           *    KEL03  =  5.00000E+00          MCAB   =  .0           *
FIX07  =  1.00000E+00           JEL14  =  .0           *    KEL04  =  6.00000E+00          MCAH   =  .0           *
FIX08  =  3.00000E+00           JEL15  =  .0           *    KEL05  =  7.00000E+00          MCRV1  =  .0           *
FIX09  =  3.00000E+00           JEL16  =  .0           *    KEL06  =  8.00000E+00          MCRV2  =  .0           *
FIX10  =  3.00000E+00           JEL17  =  .0           *    KEL07  =  9.00000E+00          MCRV3  =  .0           *
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                         TABLE OF INPUT VARIABLES - * INDICATES DEFAULTED VALUE                          PAGE  5

NCRVN  =  .0           *    OSJL02 =  1.00000E-03          OSND12 =  1.00000E+00          SFRCM2 =  .0           *
NCRV5  =  .0           *    OSJL03 =  1.00000E-03          OSND13 =  2.50000E+00          SFRCM3 =  .0           *
NCUSH1 =  3.00000E+00       OSJL04 =  1.00000E-03          OSND14 =  2.50000E+00          SFRCM4 =  .0           *
NCUSH2 =  3.00000E+00       OSJL05 =  1.00000E-03          OSND15 =  1.00000E+00          SFRCM5 =  .0           *
NCUSH3 =  3.00000E+02       OSJL06 =  1.00000E-03          OSND16 =  1.00000E+00          SFRCM6 =  .0           *
NCUSH4 =  .0           *    OSJL07 =  1.00000E-03          PI     =  1.00000E-03          SFRCM7 =  .0           *
NCUSH5 =  .0           *    OSJL08 =  .0           *       PMAN   =  .0           *       SFRC01 =  2.00000E-01
NFSEG  =  1.10000E+01       OSJL09 =  .0           *       PRACC  =  .0           *       SFRC02 =  2.00000E-01
NSEA   =  .0                OSJL10 =  .0           *       PRCUSH =  1.00000E+00          SFRC03 =  2.00000E-01
ORX01  =  1.00000E+01       OSJL11 =  .0           *       PREL   =  .0           *       SFRC04 =  2.00000E-01
ORX02  =  1.00000E+01       OSJL12 =  .0           *       PREFAC =  .0           *       SFRC05 =  2.00000E-01
ORX03  =  6.00000E+01  *    OSJL13 =  .0           *       PRNOD  =  .0           *       SFRC06 =  .0           *
ORX04  =  6.00000E+01  *    OSJL14 =  .0           *       PRPIC  =  .0           *       SFRC07 =  .0           *
ORX05  =  6.00000E+01  *    OSJL15 =  .0           *       PRPLT  =  .0           *       SFRC08 =  .0           *
ORX06  =  6.00000E+01  *    OSJL16 =  .0           *       QUO    =  1.80000E+02          SFRC09 =  .0           *
ORX07  =  .0                OSJL17 =  .0           *       RML23  =  .0                   SFRC10 =  .0           *
ORX08  =  .0           *    OSJL18 =  .0           *       RML24  =  .0                   SFRC11 =  .0           *
ORX09  =  .0           *    OSJL19 =  .0           *       RML45  =  1.50000E+03          SFRC12 =  .0           *
ORX10  =  .0           *    OSJL20 =  .0           *       RML56  =  2.50000E+03          SFRC13 =  .0           *
ORX11  =  .0           *    OSKL01 =  9.00000E+00          RML57  =  .0                   SFRC14 =  .0           *
ORX12  =  .0           *    OSKL02 =  1.00000E-03          RML78  =  .0                   SFRC15 =  .0           *
ORX13  =  .0           *    OSKL03 =  1.00000E-03          SEG01  =  .0           *       SFRC16 =  .0           *
ORX14  =  .0           *    OSKL04 =  1.00000E-03          SEG02  =  .0           *       SFRC17 =  .0           *
ORX15  =  .0           *    OSKL05 =  1.00000E-03          SEG03  =  .0           *       SFRC18 =  .0           *
ORX16  =  .0           *    OSKL06 =  1.00000E-03          SEG04  =  .0           *       SFRC19 =  .0           *
ORX17  =  .0           *    OSKL07 =  1.00000E-03          SEG05  =  .0           *       SFRC20 =  .0           *
ORX18  =  .0           *    OSKL08 =  .0           *       SEG06  =  .0           *       SHC1   =  .0           *
ORX19  =  .0           *    OSKL09 =  .0           *       SEG07  =  .0           *       SHC2   =  .0           *
ORX20  =  .0           *    OSKL10 =  .0           *       SEG08  =  .0           *       SHC3   =  .0           *
ORY01  =  1.00000E+00       OSKL11 =  .0           *       SEG09  =  .0           *       SHC4   =  .0           *
ORY02  =  1.00000E+00       OSKL12 =  .0           *       SEG10  =  .0           *       SHC5   =  .0           *
ORY03  =  1.00000E+01  *    OSKL13 =  .0           *       SEG11  =  .0           *       SKIP01 =  .0           *
ORY04  =  3.00000E+01  *    OSKL14 =  .0           *       SEG12  =  .0           *       SKIP02 =  .0           *
ORY05  =  3.00000E+01  *    OSKL15 =  .0           *       SEG13  =  .0           *       SKIP03 =  .0           *
ORY06  =  3.00000E+01  *    OSKL16 =  .0           *       SEG14  =  .0           *       SKIP04 =  .0           *
ORY07  =  1.00000E+01       OSKL17 =  .0           *       SEG15  =  .0           *       SKIP05 =  .0           *
ORY08  =  .0           *    OSKL18 =  .0           *       SEG16  =  .0           *       SKIP06 =  1.00000E+00
ORY09  =  .0           *    OSKL19 =  .0           *       SEG17  =  .0           *       SKIP07 =  1.00000E+00
ORY10  =  .0           *    OSKL20 =  .0           *       SEG18  =  .0           *       SKIP08 =  1.00000E+00
ORY11  =  .0           *    OSND01 =  2.50000E+00          SEG19  =  .0           *       SKIP09 =  1.00000E+00
ORY12  =  .0           *    OSND02 =  1.00000E+00          SEG20  =  .0           *       SKIP10 =  .0           *
ORY13  =  .0           *    OSND03 =  1.00000E+00          SEG21  =  .0           *       SKIP11 =  .0           *
ORY14  =  .0           *    OSND04 =  1.00000E+00          SEG22  =  .0           *       STROKC1=  .0           *
ORY15  =  .0           *    OSND05 =  1.00000E+00          SEG23  =  .0           *       STROKC2=  .0           *
ORY16  =  .0           *    OSND06 =  3.00000E+00          SEG24  =  .0           *       STROKC3=  .0           *
ORY17  =  .0           *    OSND07 =  1.00000E+00          SEG25  =  .0           *       STROKC4=  .0           *
ORY18  =  .0           *    OSND08 =  1.00000E+00          SEG26  =  .0           *       STROKC5=  .0           *
ORY19  =  .0           *    OSND09 =  1.00000E+00          SEG27  =  .0           *       STROKT1=  .0           *
ORY20  =  .0           *    OSND10 =  1.00000E+00          SEG28  =  .0           *       STROKT2=  .0           *
OSJL01 =  1.50000E+00       OSND11 =  1.00000E+00          SFRCM1 =  .0           *       STROKT3=  .0           *
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                         TABLE OF INPUT VARIABLES - * INDICATES DEFAULTED VALUE                          PAGE  6

STROKT4=  .0           *    SY08   =  5.29700E+01          TORM36 =  1.00000E+04          T07    =  .0           *
STROKT5=  .0           *    SY09   =  4.25700E+01          TORM57 =  9.00000E+01          T08    =  .0           *
SX01   =  1.00000E+01       SY10   =  1.45000E+01          TORM78 =  5.00000E+02          T09    =  .0           *
SX02   =  3.00000E+01       SY11   =  1.70000E+01          TPI    =  .0           *       T10    =  .0           *
SX03   =  3.05000E+01       SY12   =  .0           *       TYPE01 =  .0           *       T11    =  .0           *
SX04   =  4.30000E+01       SY13   =  .0           *       TYPE02 =  .0           *       T12    =  .0           *
SX05   =  4.30000E+01       SY14   =  .0           *       TYPE03 =  .0           *       T13    =  .0           *
SX06   =  4.16600E+01       SY15   =  .0           *       TYPE04 =  .0           *       T14    =  .0           *
SX07   =  3.80900E+01       SY16   =  .0           *       TYPE05 =  .0           *       T15    =  .0           *
SX08   =  3.60900E+01       SY17   =  .0           *       TYPE06 =  .0           *       T16    =  .0           *
SX09   =  5.09000E+00       SY18   =  .0           *       TYPE07 =  .0           *       T17    =  .0           *
SX10   =  1.00000E+01       SY19   =  .0           *       TYPE08 =  .0           *       T18    =  .0           *
SX11   =  3.00000E+01       SY20   =  .0           *       TYPE09 =  .0           *       T19    =  .0           *
SX12   =  .0           *    SY21   =  .0           *       TYPE10 =  .0           *       T20    =  .0           *
SX13   =  .0           *    SY22   =  .0           *       TYPE11 =  .0           *       UI     =  4.00000E-01
SX14   =  .0           *    SY23   =  .0           *       TYPE12 =  .0           *       WTEL01 =  .0           *
SX15   =  .0           *    SY24   =  .0           *       TYPE13 =  .0           *       WTEL02 =  .0           *
SX16   =  .0           *    SY25   =  .0           *       TYPE14 =  .0           *       WTEL03 =  .0           *
SX17   =  .0           *    SY26   =  .0           *       TYPE15 =  .0           *       WTEL04 =  .0           *
SX18   =  .0           *    SY27   =  .0           *       TYPE16 =  .0           *       WTEL05 =  .0           *
SX19   =  .0           *    SY28   =  .0           *       TYPE17 =  .0           *       WTEL06 =  .0           *
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SX21   =  .0           *    SY30   =  .0           *       TYPE19 =  .0           *       WTEL08 =  .0           *
SX22   =  .0           *    SY31   =  .0           *       TYPE20 =  .0           *       WTEL09 =  .0           *
SX23   =  .0           *    SY32   =  .0           *       TYPE21 =  .0           *       WTEL10 =  .0           *
SX24   =  .0           *    SY33   =  .0           *       TYPE22 =  .0           *       WTEL11 =  .0           *
SX25   =  .0           *    SY34   =  .0           *       TYPE23 =  .0           *       WTEL12 =  .0           *
SX26   =  .0           *    SY35   =  .0           *       TYPE24 =  .0           *       WTEL13 =  .0           *
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SX28   =  .0           *    SY37   =  .0           *       TYPE26 =  .0           *       WTEL15 =  .0           *
SX29   =  .0           *    SY38   =  .0           *       TYPE27 =  .0           *       WTEL16 =  .0           *
SX30   =  .0           *    SY39   =  .0           *       TYPE28 =  .0           *       WTEL17 =  .0           *
SX31   =  .0           *    SY40   =  .0           *       TYPE29 =  .0           *       WTEL18 =  .0           *
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SX33   =  .0           *    TEST2  =  1.00000E-02          TYPE31 =  .0           *       WTEL20 =  .0           *
SX34   =  .0           *    TH03I  =  1.11000E+02          TYPE32 =  .0           *       WTEL21 =  .0           *
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SX36   =  .0           *    TH05I  =  1.11000E+02          TYPE34 =  .0           *       WTEL23 =  .0           *
SX37   =  .0           *    TH06I  =  9.90000E+00          TYPE35 =  .0           *       WTEL24 =  .0           *
SX38   =  .0           *    TH07I  =  2.70000E+02          TYPE36 =  .0           *       WTEL25 =  .0           *
SX39   =  .0           *    TH08I  =  9.90000E+00          TYPE37 =  .0           *       WTEL26 =  .0           *
SX40   =  .0           *    TH09I  =  2.70000E+02          TYPE38 =  .0           *       WTEL27 =  .0           *
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SY01   =  6.00000E+00       TH11I  = -9.00000E+01          TYPE40 =  .0           *       WTEL29 =  .0           *
SY02   =  6.00000E+00       TH12I  = -9.00000E+01          T01    =  .0                   WTEL30 =  .0           *
SY03   =  .0                TH13I  = -9.00000E+01          T02    =  8.00000E-03          WTEL31 =  .0           *
SY04   =  .0                TOAX   =  4.25000E+01          T03    =  2.70000E-02          WTEL32 =  .0           *
SY05   =  1.45000E+01       TORM23 =  4.00000E+03          T04    =  7.00000E-02          WTEL33 =  .0           *
SY06   =  2.20000E+01       TORM24 =  5.00000E+03          T05    =  5.00000E-01          WTEL34 =  .0           *
SY07   =  4.25700E+01       TORM35 =  2.00000E+04          T06    =  .0           *       WTEL35 =  .0           *
```

```
                          TABLE OF INPUT VARIABLES - * INDICATES DEFAULTED VALUE                          PAGE  7

[illegible] =  .0           *    XPELY  =  1.64000E+01       XPIT15 =   .0           *    YPIT13 =   .0           *
[illegible] =  .0           *    XPIT01 =   .0           *    YPELY  =  1.69200E+01       YPIT14 =   .0           *
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[illegible] =  .0           *    XPIT03 =   .0           *    YPIT01 =   .0           *    ZEXP1  =  2.50000E+00
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[illegible] =  .0           *
```
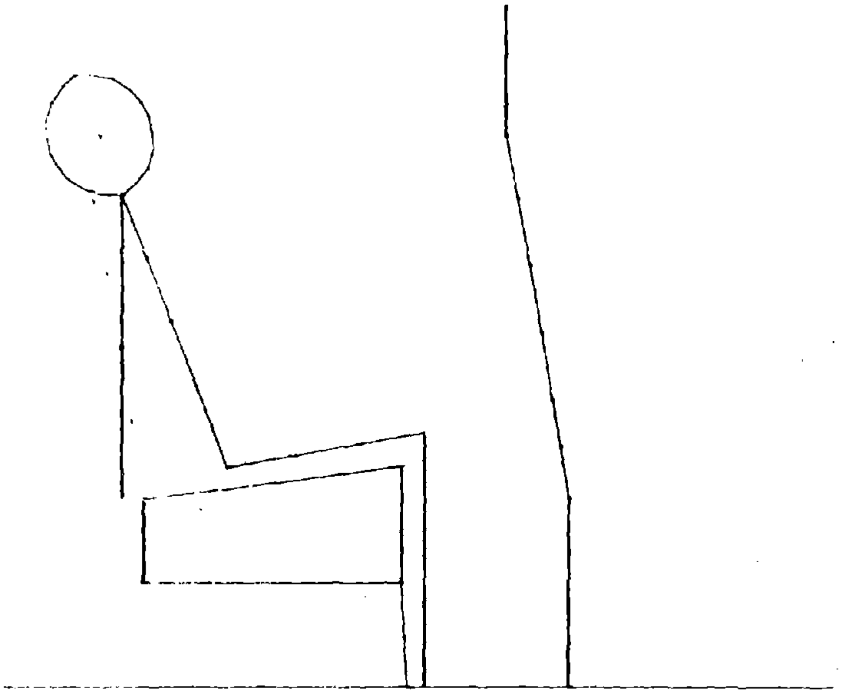

## A.3 PROMETHEUS GRAPHIC PRINTOUT

IDENTIFICATION NAME:  BIG SYSTEM USER PLOTS   EKS - KIT

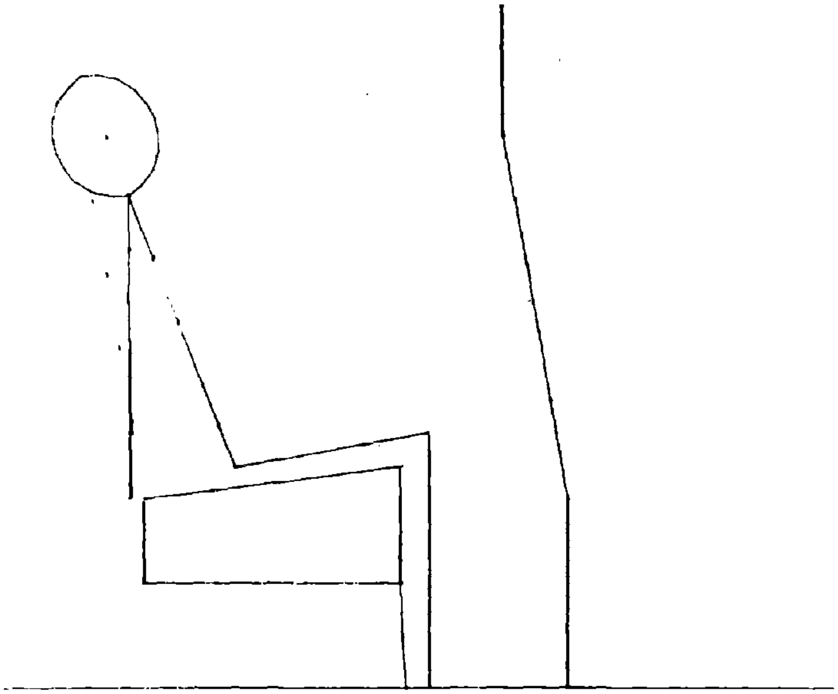
DATE 07/JUL/76 _ TIME 17.02.12.

RAIL CAR CRASH - DEMONSTRATION RUN



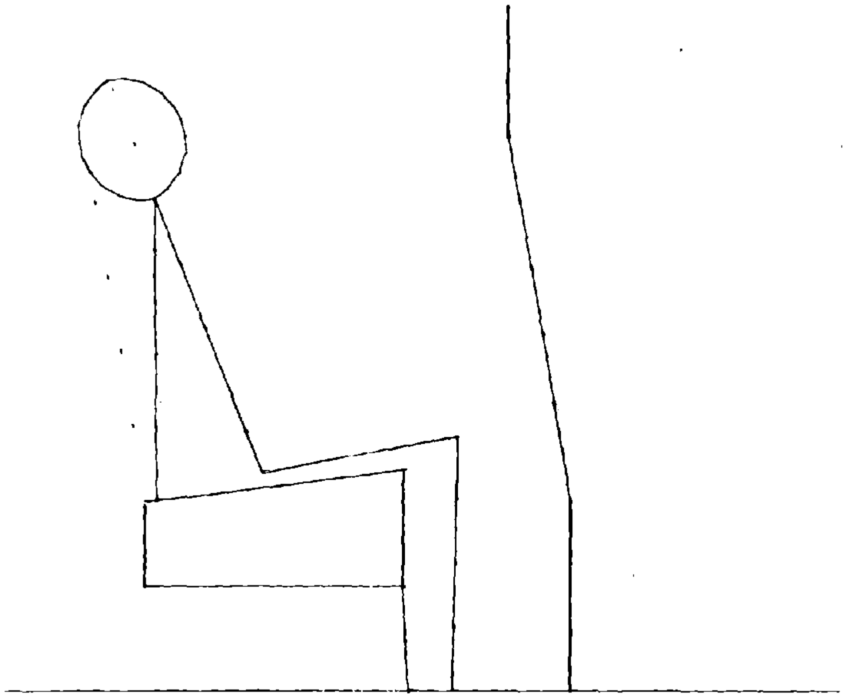
T = 0 MS

RAIL CAR CRASH - DEMONSTRATION RUN



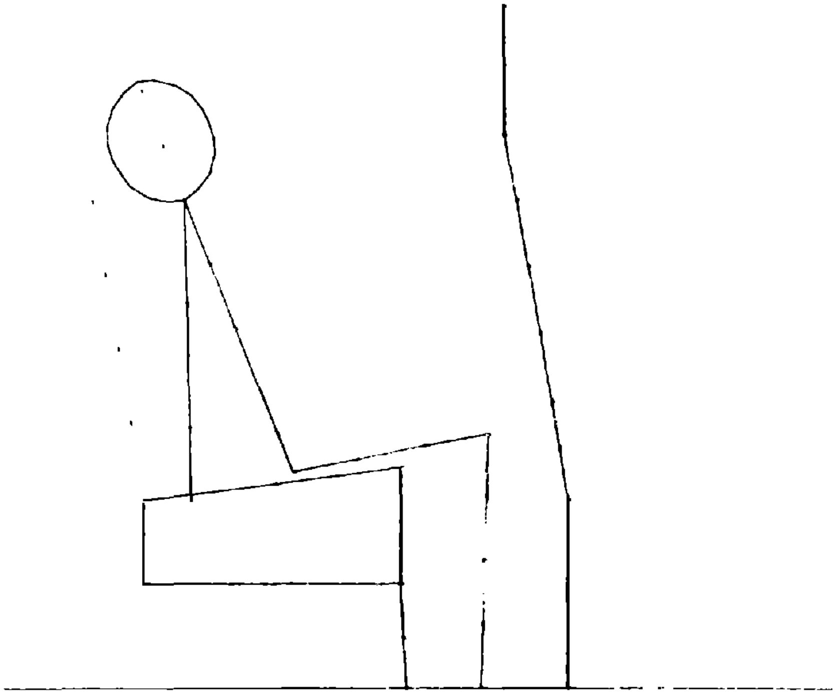
T = 25 MS

RAIL CAR CRASH - DEMONSTRATION RUN



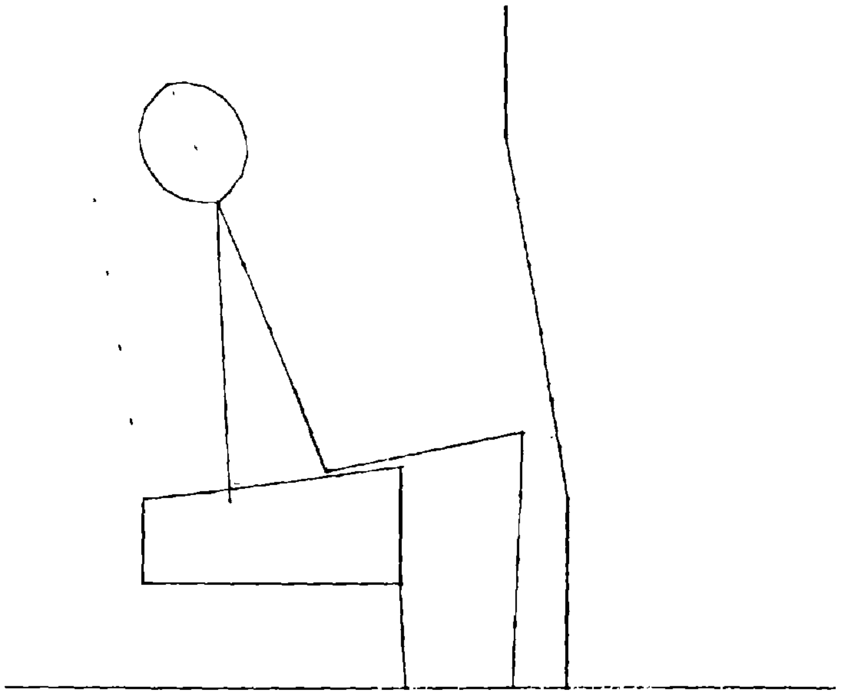
T = 49 MS

RAIL CAR CRASH - DEMONSTRATION RUN



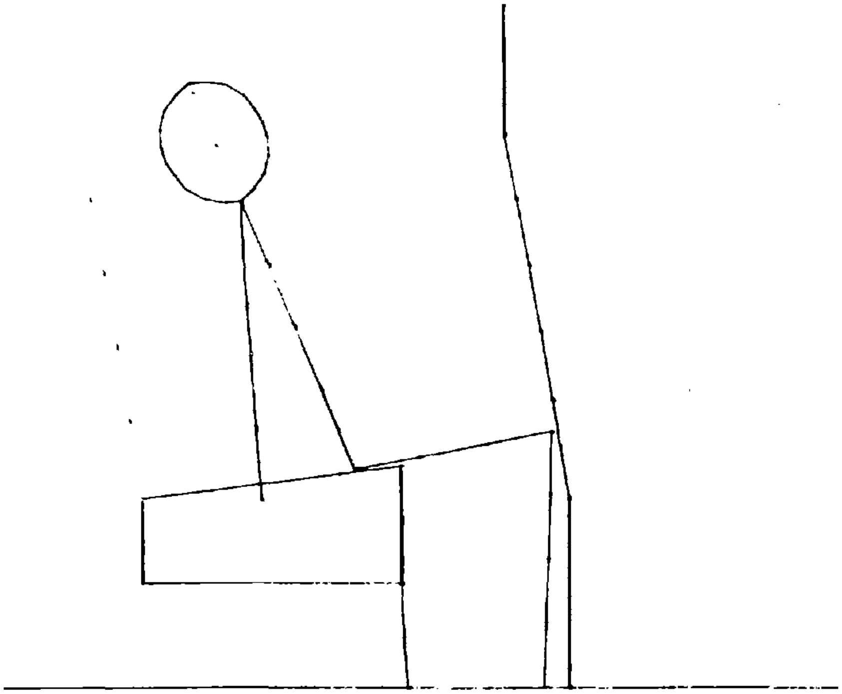
T = 75 MS

RAIL CAR CRASH - DEMONSTRATION RUN



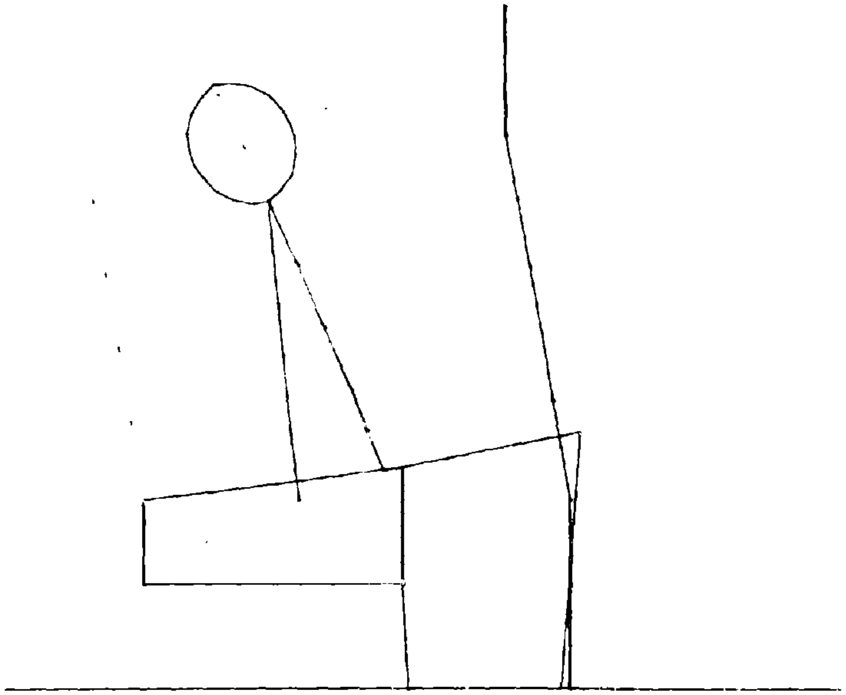
T = 102 MS

RAIL CAR CRASH - DEMONSTRATION RUN



T = 124 MS

RAIL CAR CRASH - DEMONSTRATION RUN



T = 149 MS

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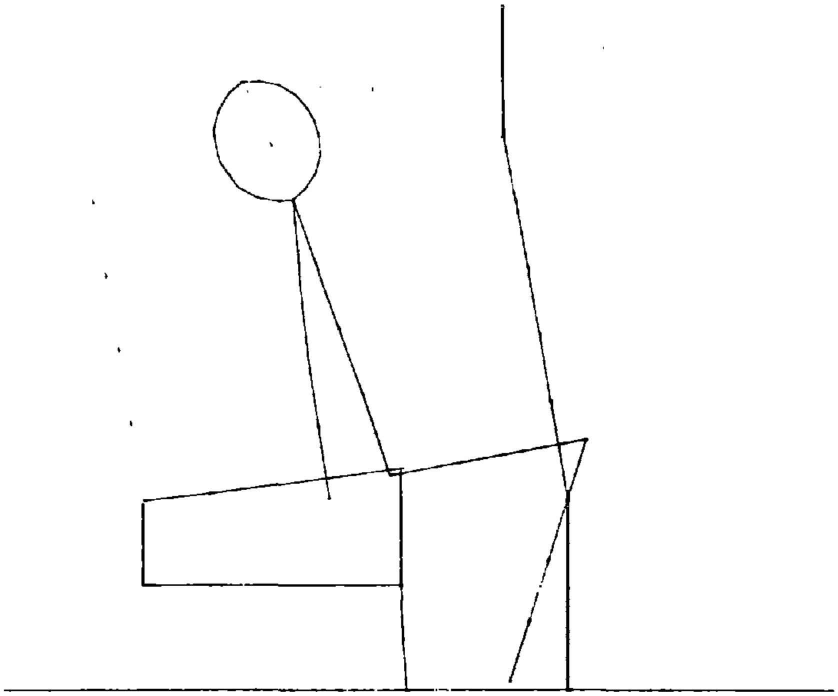

T = 174 MS

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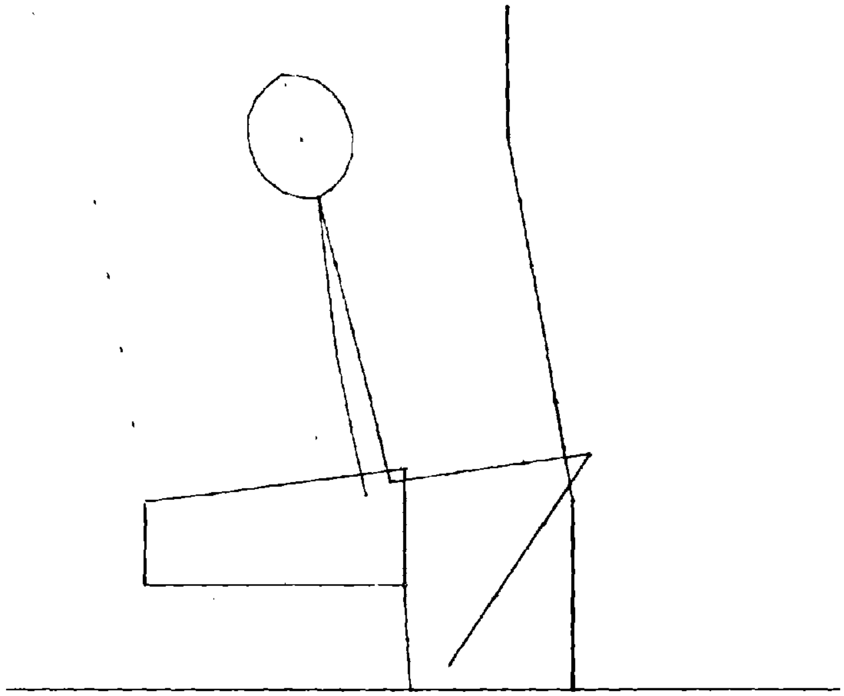

T = 199 MS

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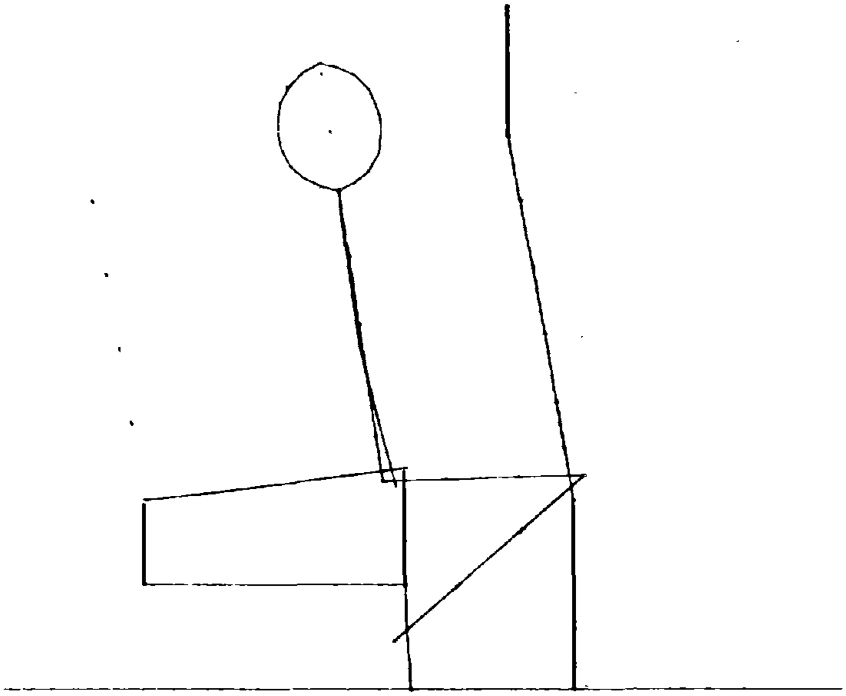
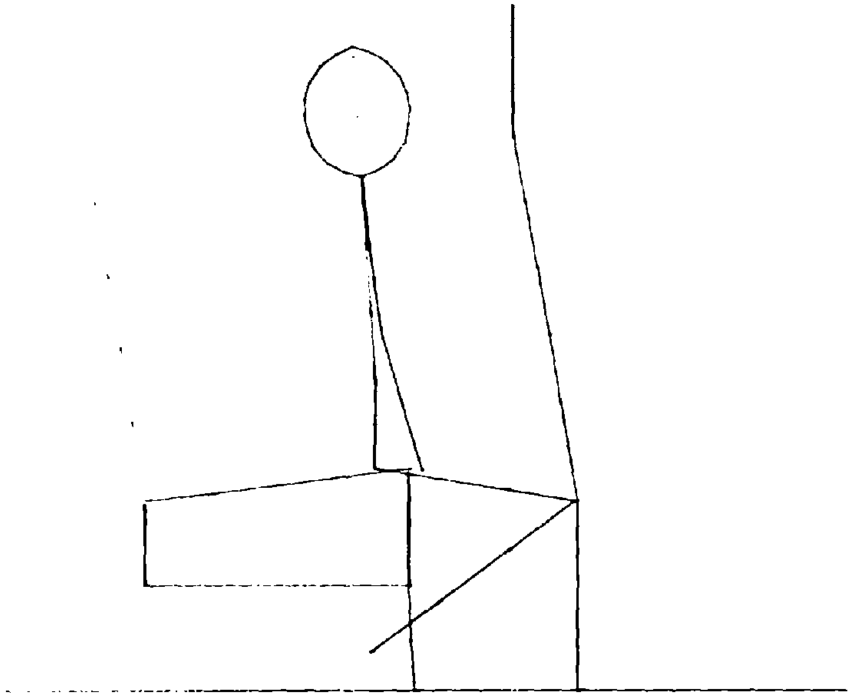


T = 226 MS

RAIL CAR CRASH - DEMONSTRATION RUN



T = 249 MS

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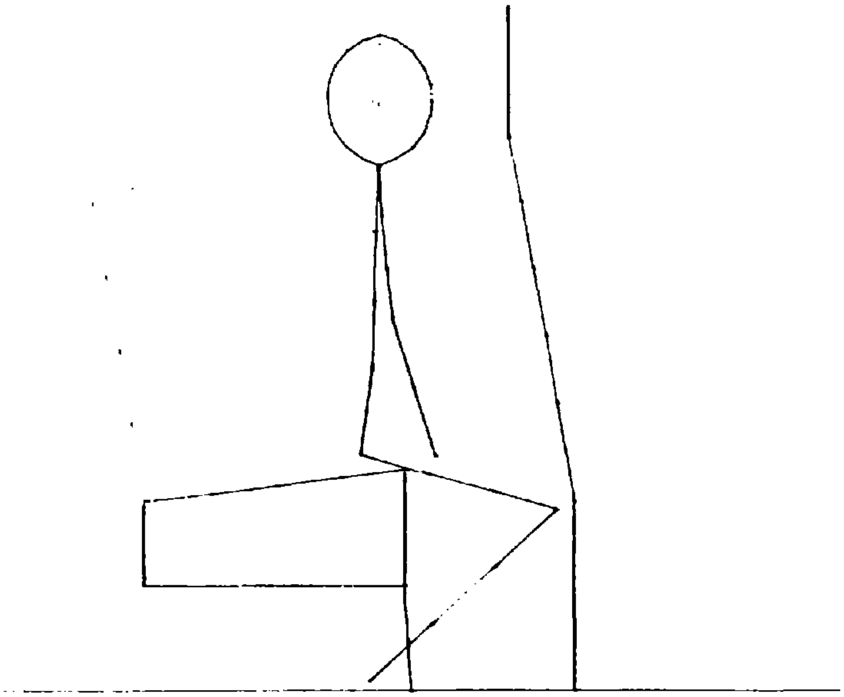

T = 275 MS

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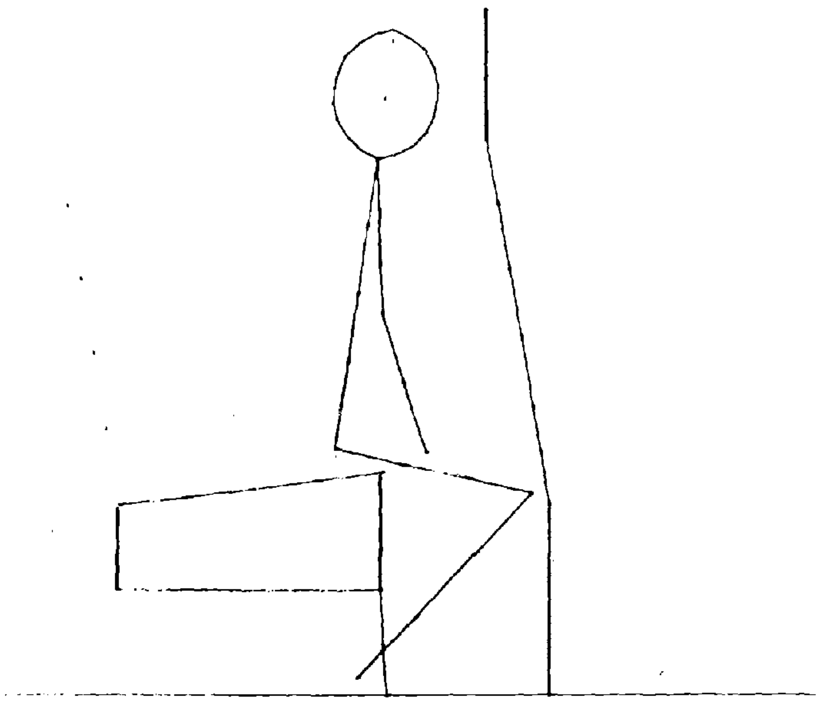
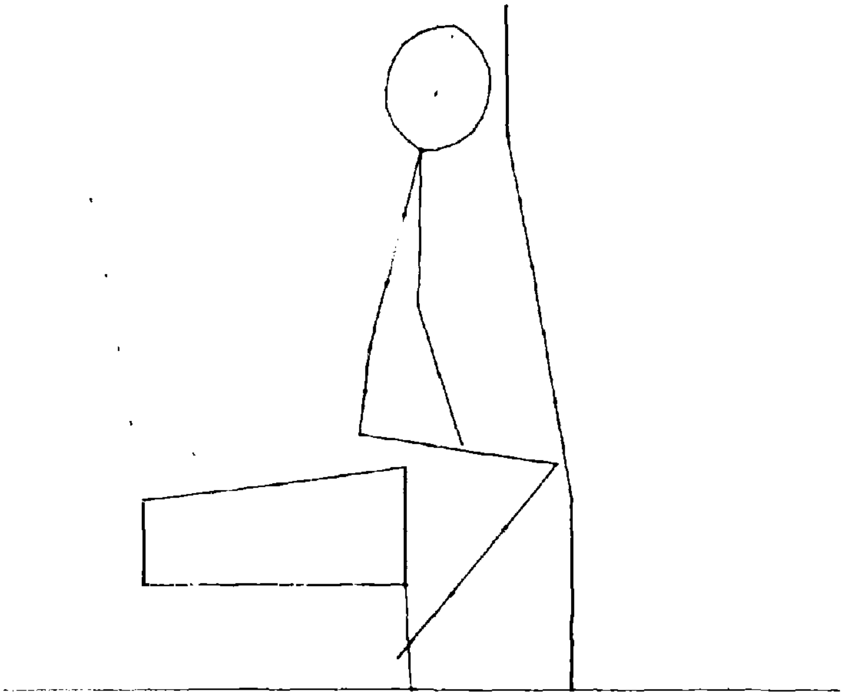


T = 301 MS

RAIL CAR CRASH - DEMONSTRATION RUN



T = 328 MS

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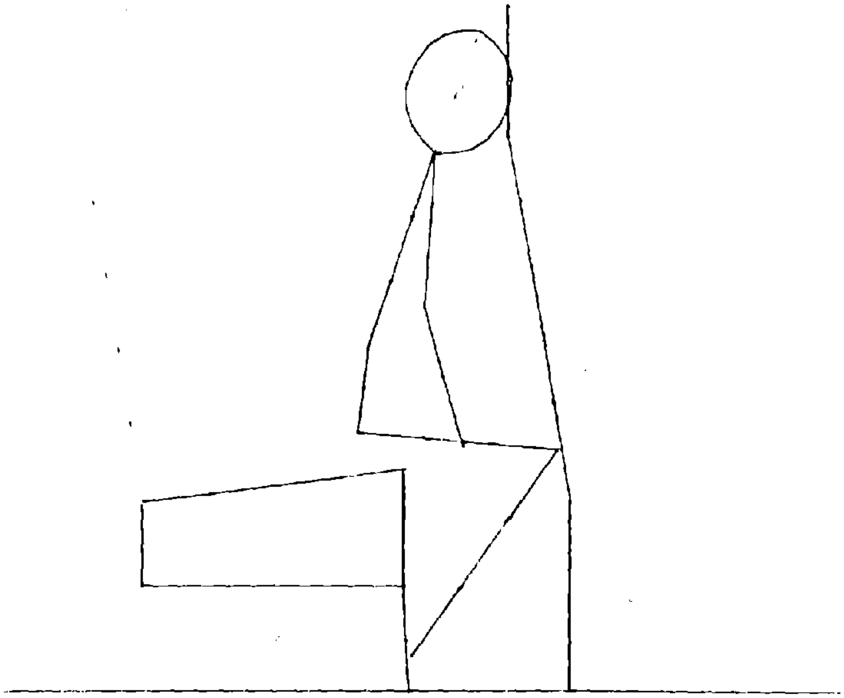
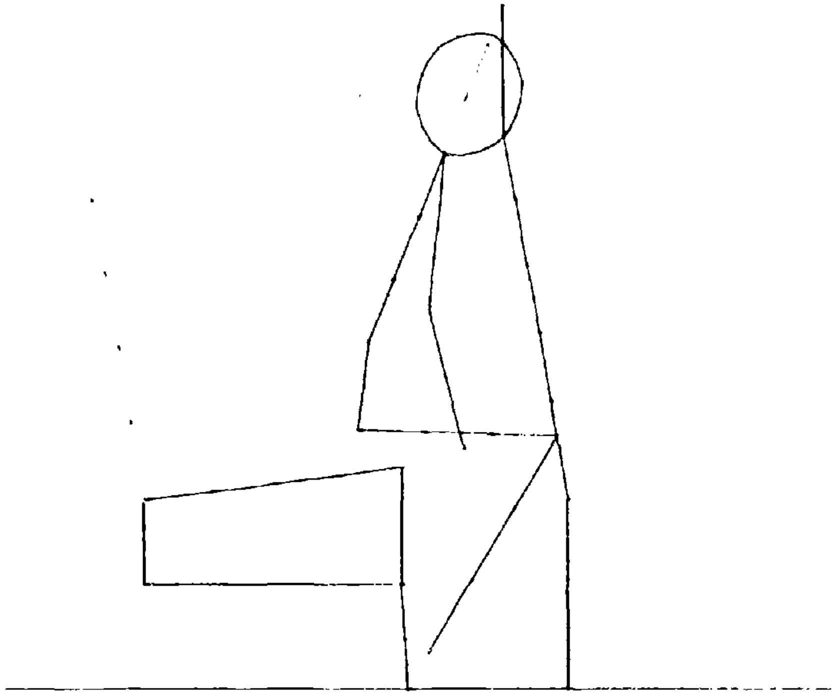


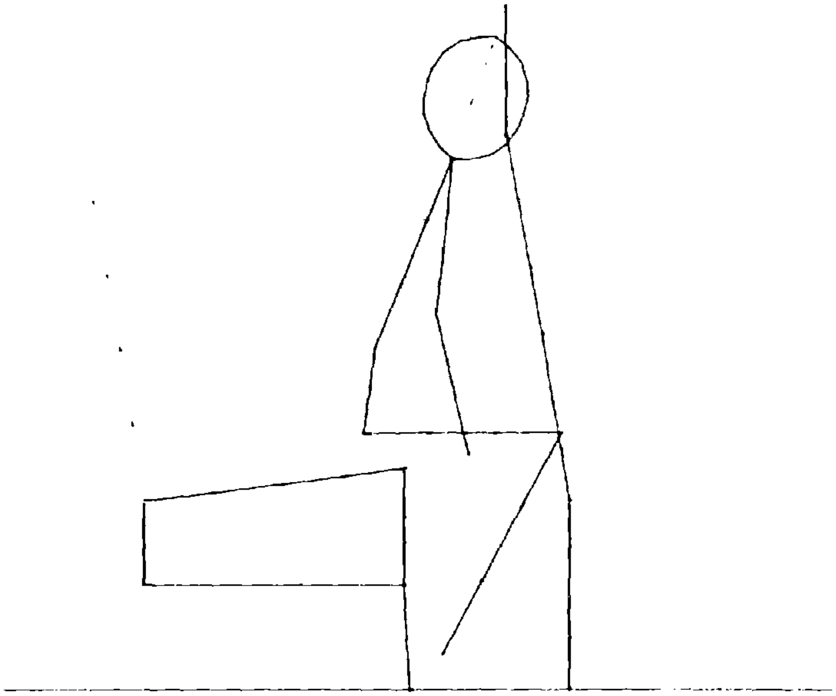
T = 350 MS

RAIL CAR CRASH - DEMONSTRATION RUN



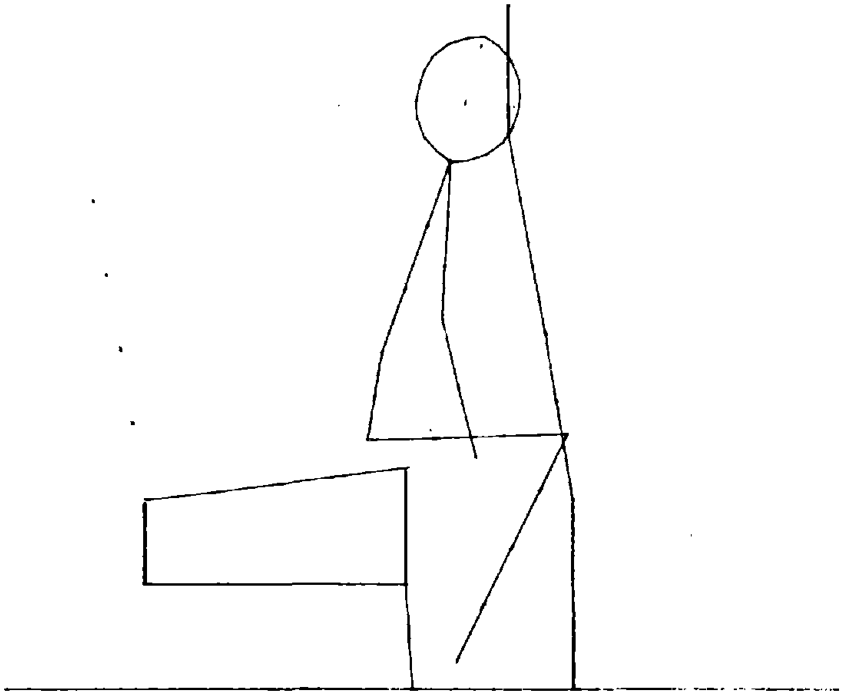
T = 375 MS

RAIL CAR CRASH - DEMONSTRATION RUN

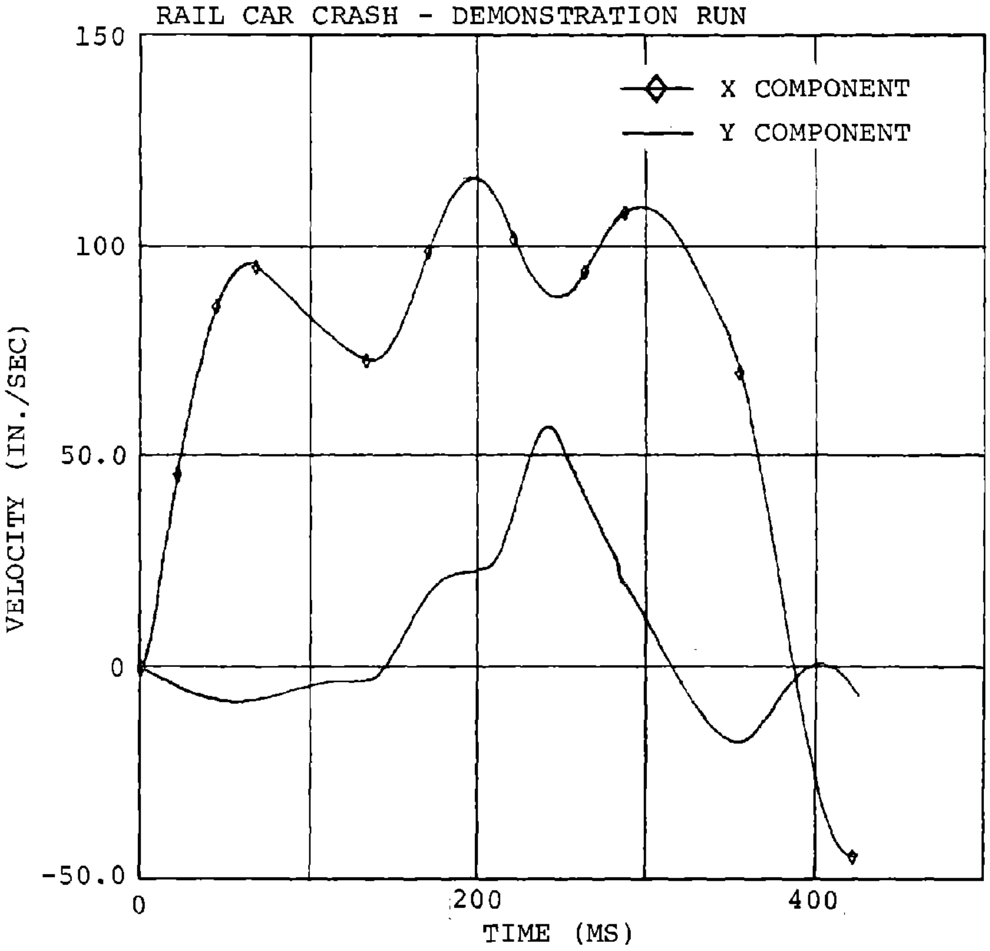


T = 400 MS

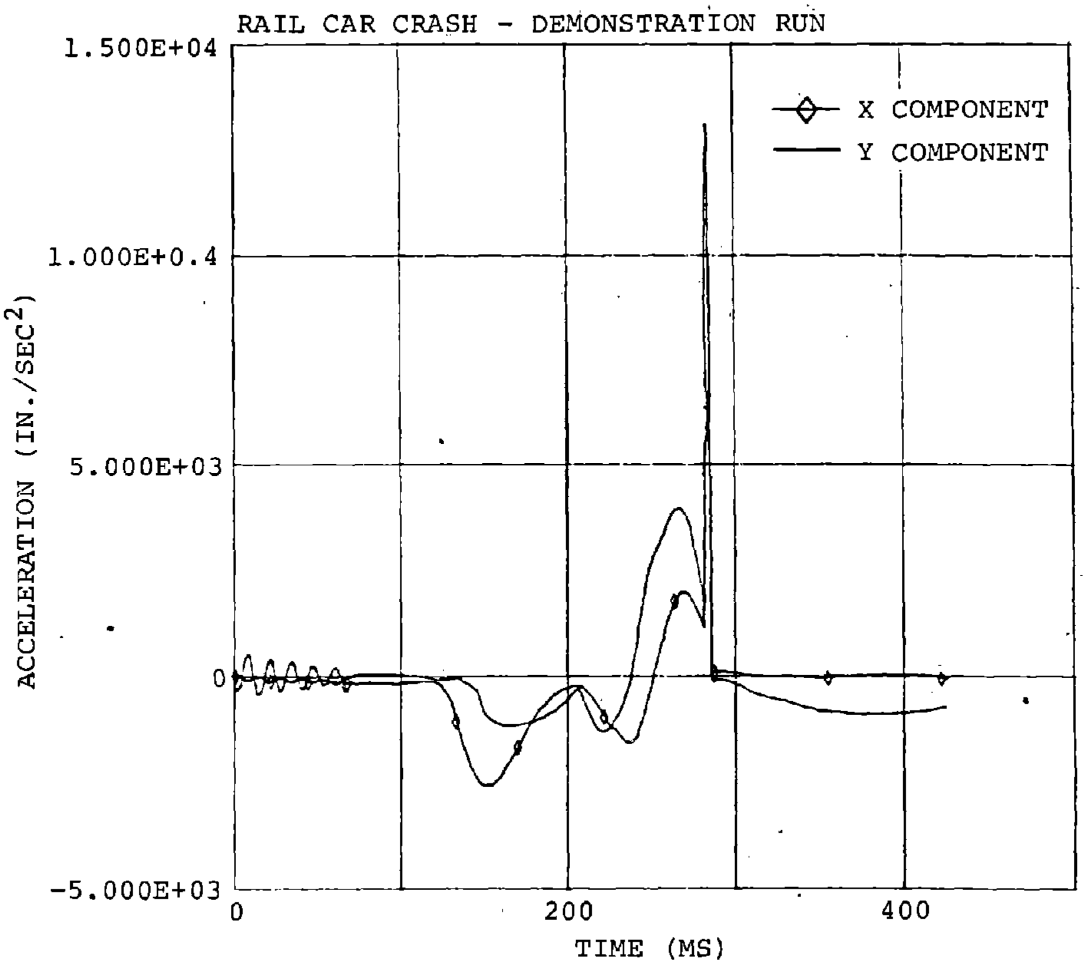
RAIL CAR CRASH - DEMONSTRATION RUN



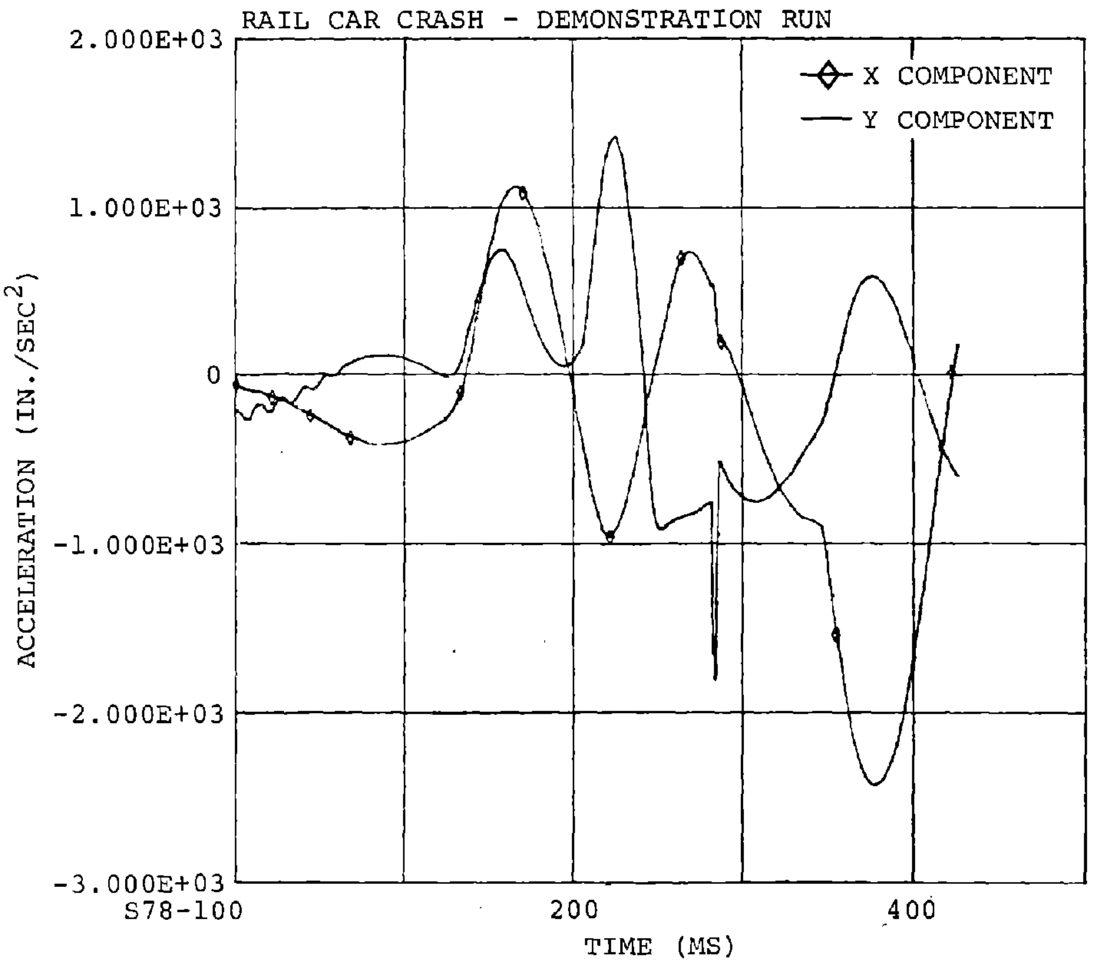
T = 425 MS



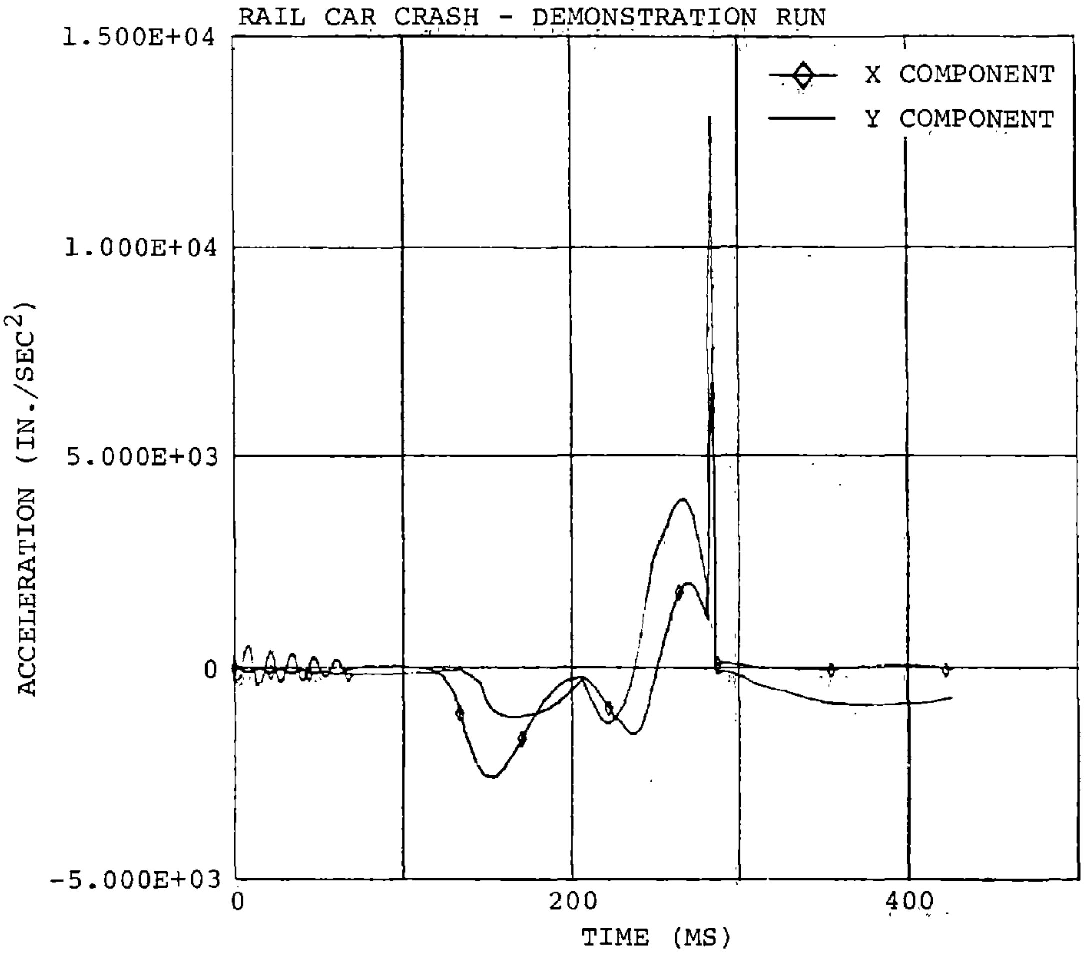
VELOCITY OF HEAD



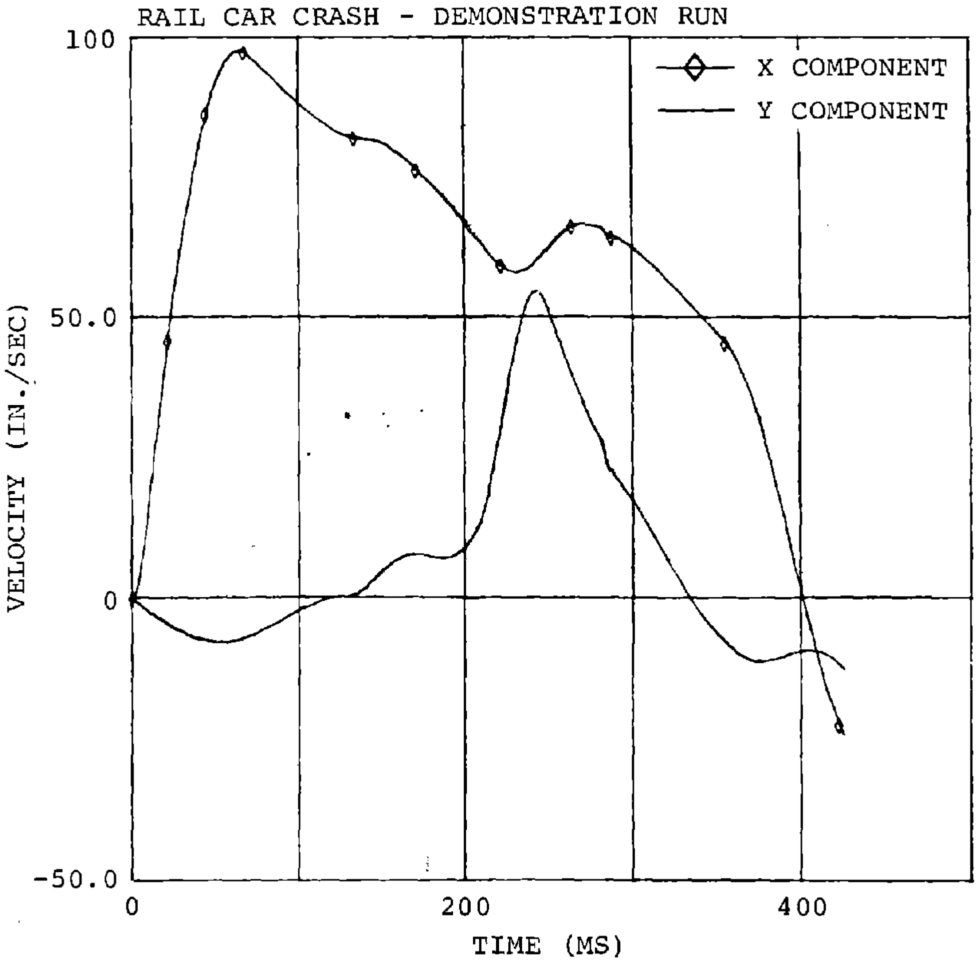
ACCELERATION OF LEFT KNEE



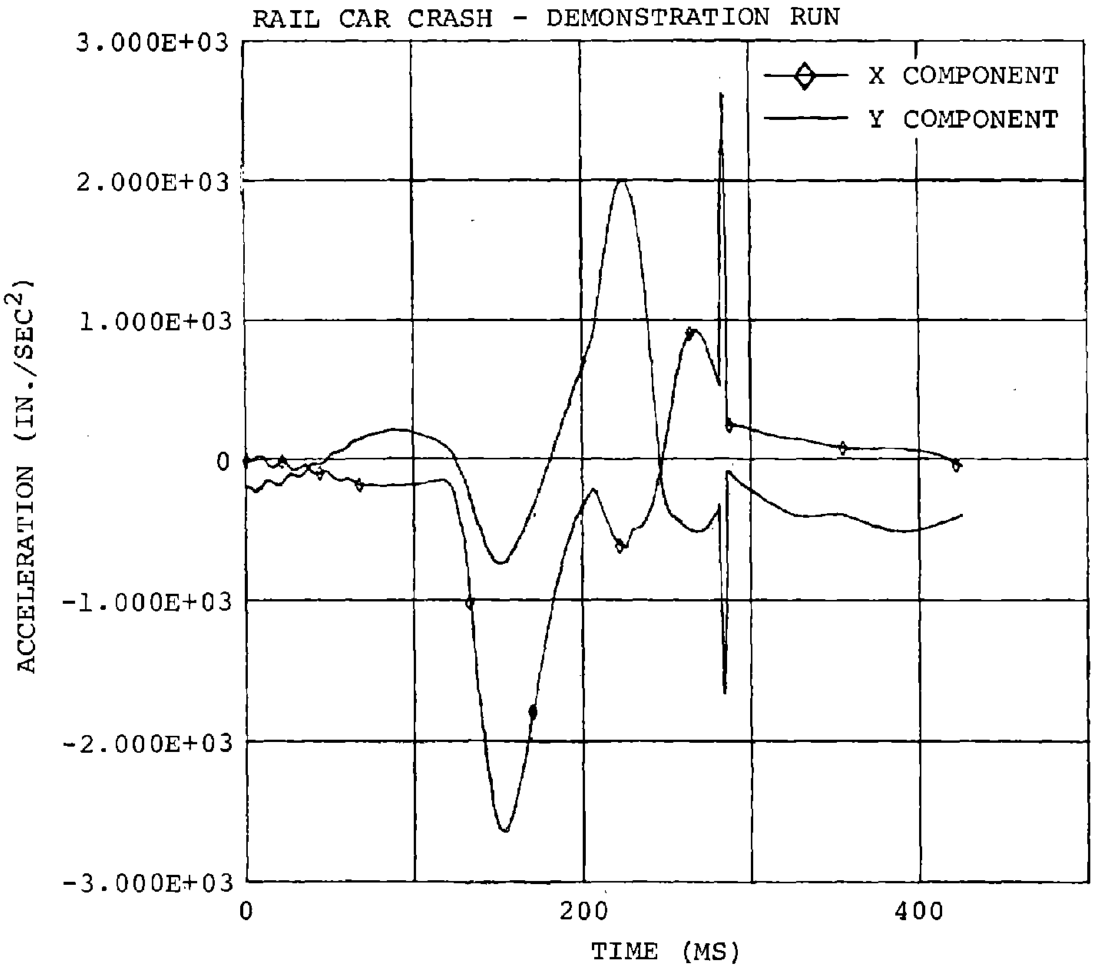
ACCELERATION OF HEAD



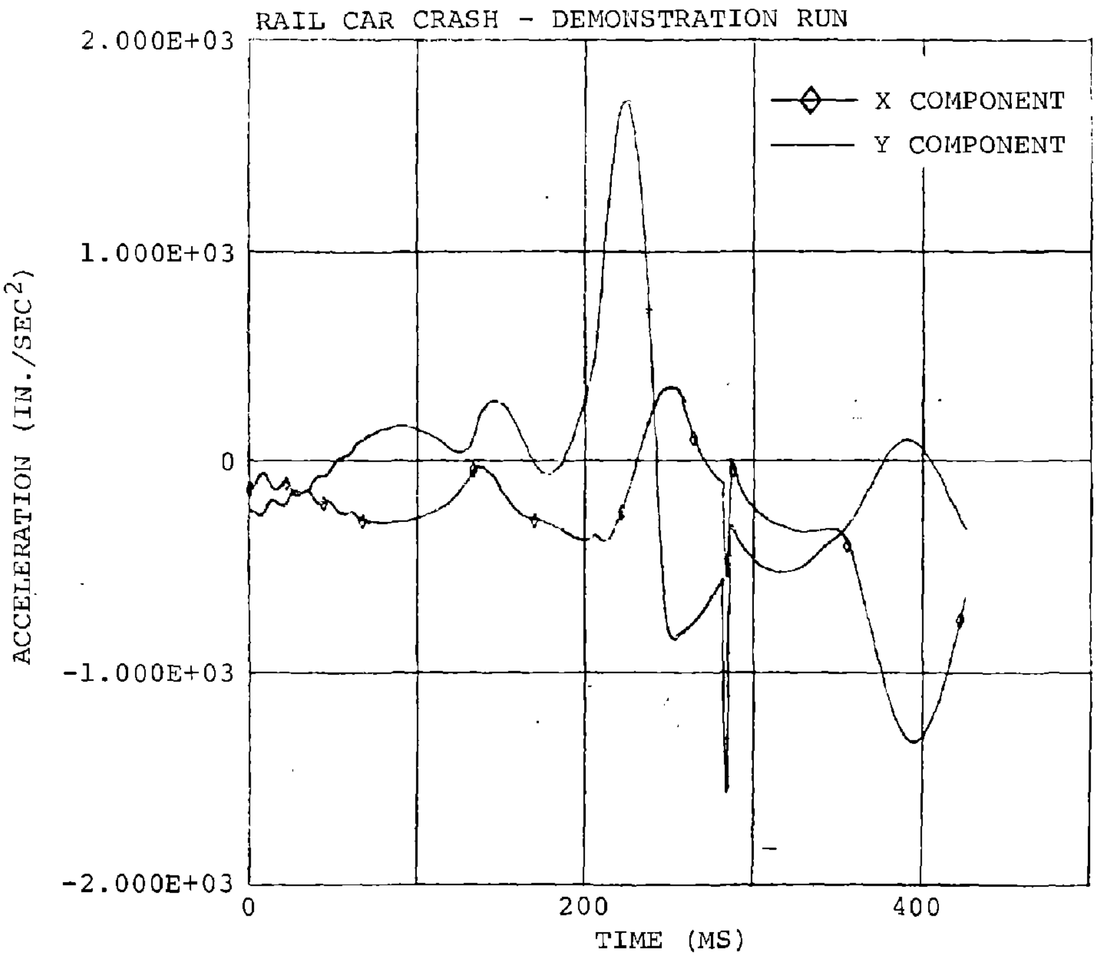
ACCELERATION OF RIGHT KNEE



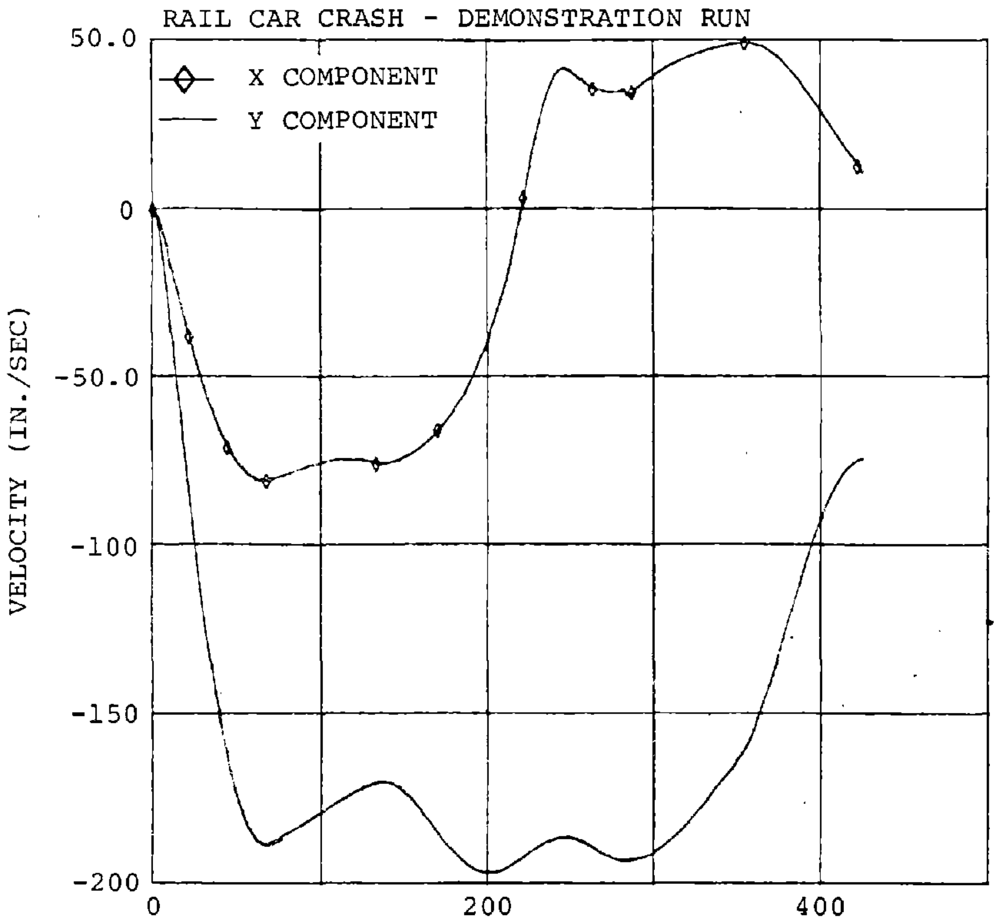
VELOCITY OF LEFT SHOULDER



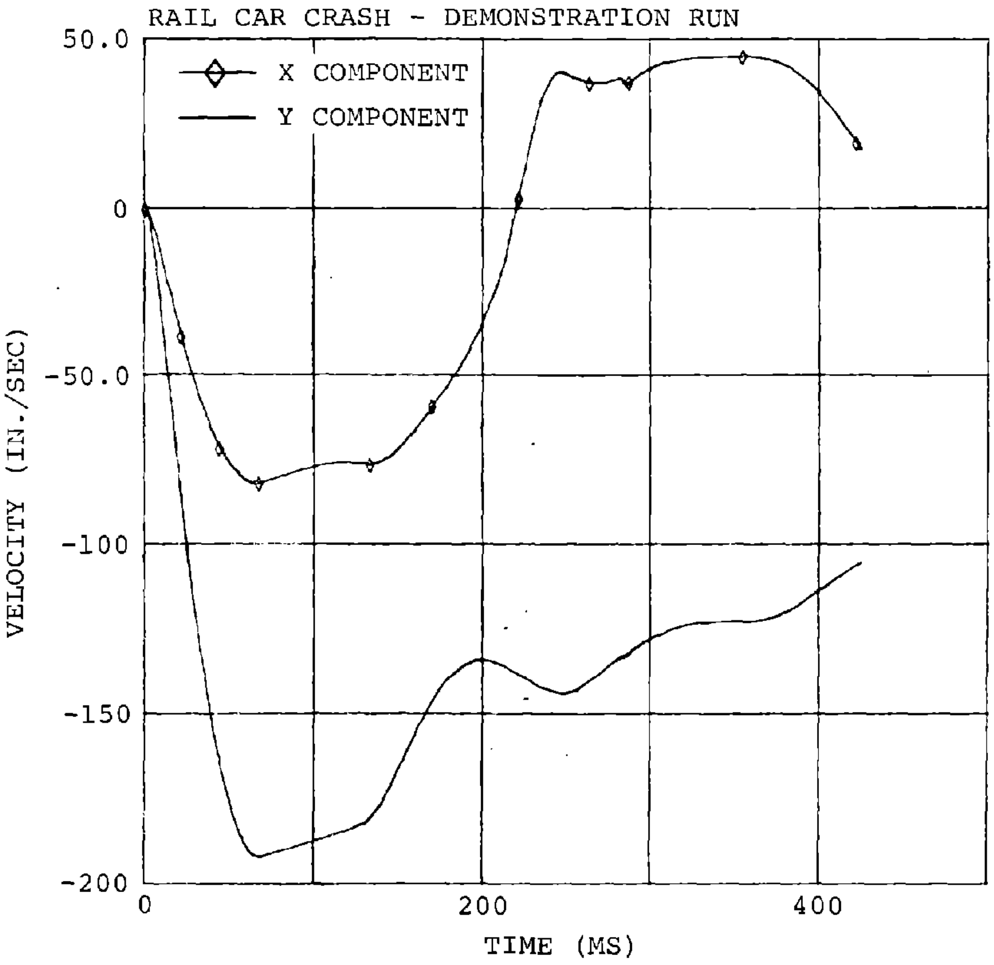
ACCELERATION OF LEFT HIP



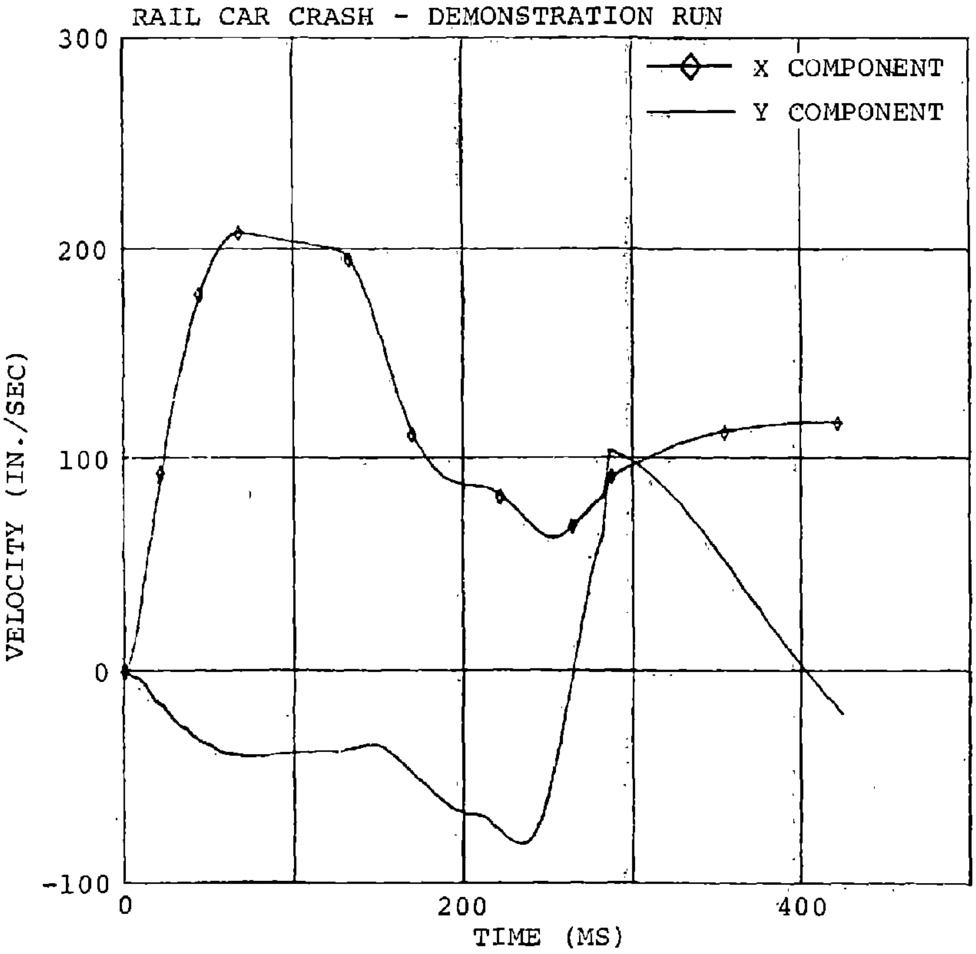
ACCELERATION OF LEFT SHOULDER



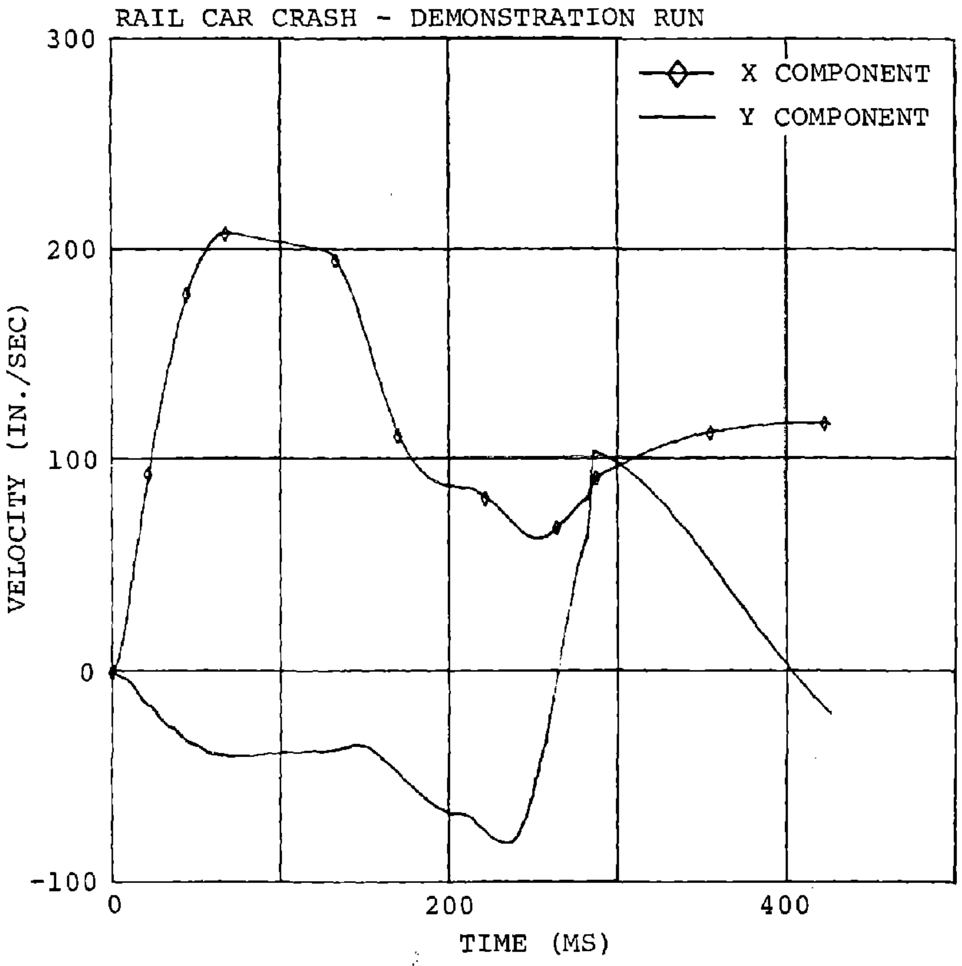
VELOCITY OF ACCELEROMETER (1 ON HEAD/NECK)



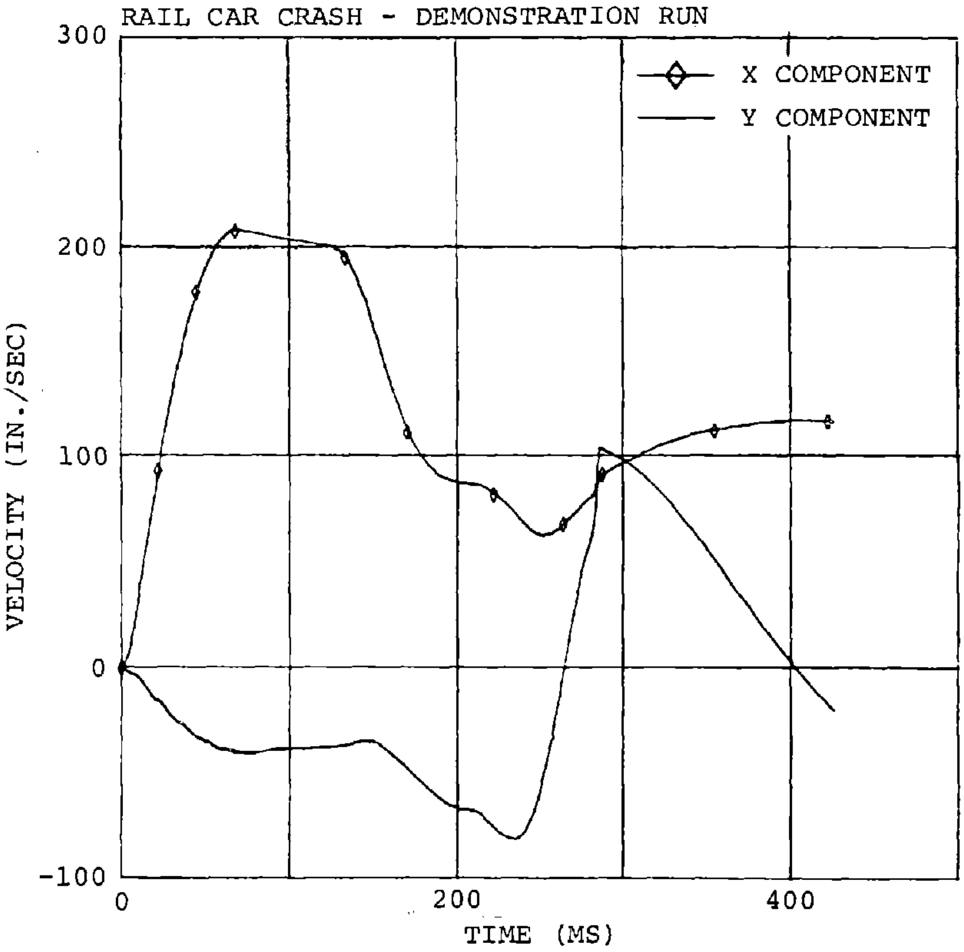
VELOCITY OF ACCELEROMETER (2 ON CHEST)



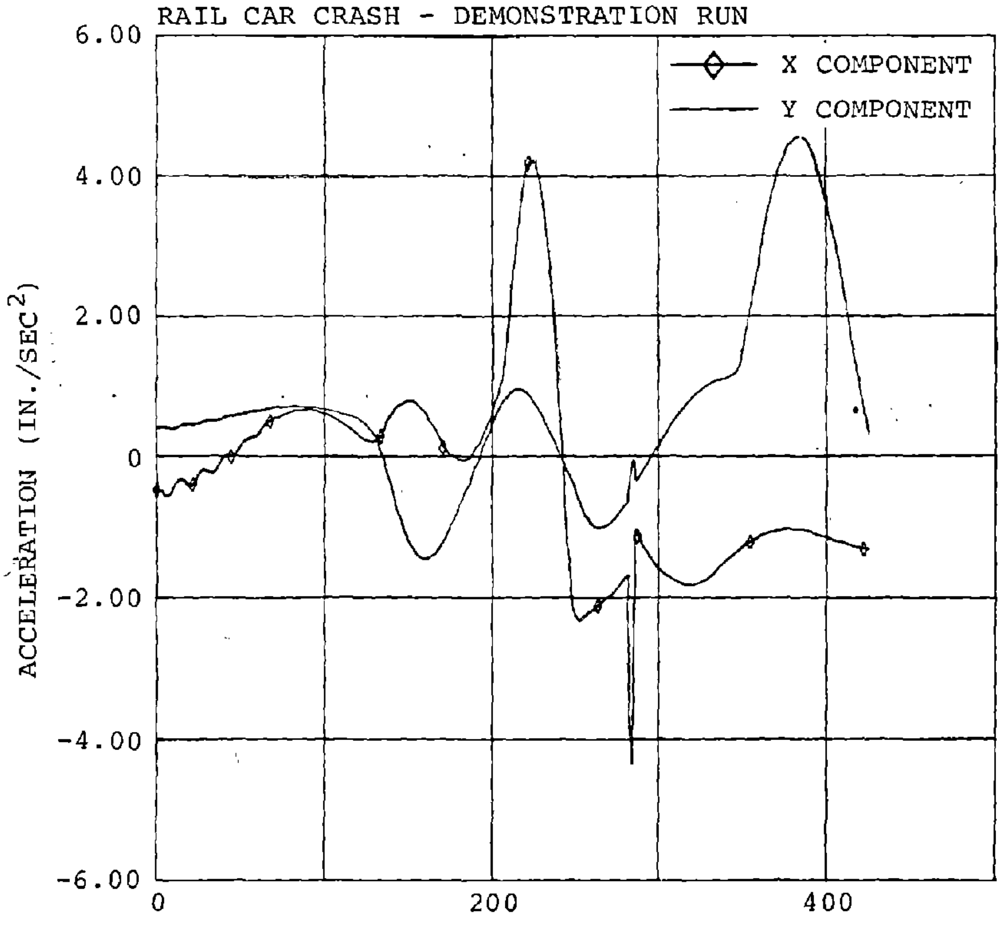
VELOCITY OF ACCELEROMETER (3 ON LEFT THIGH)



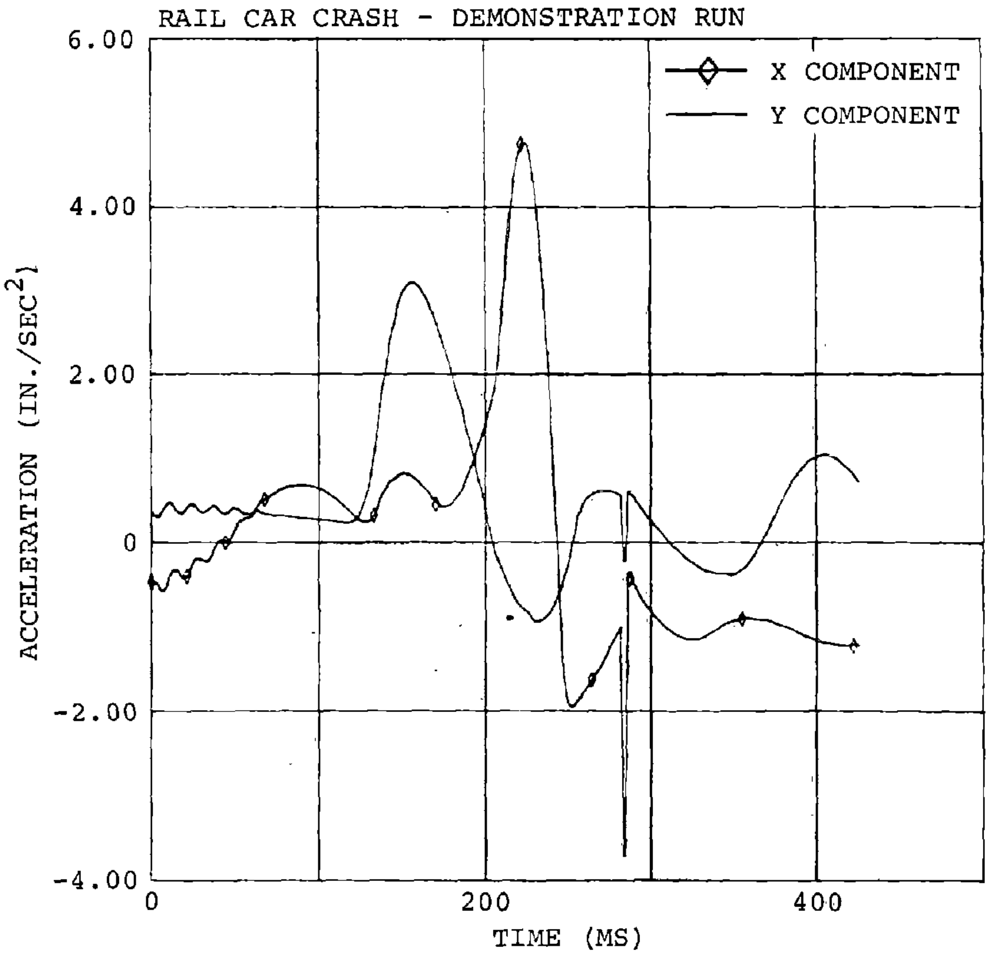
VELOCITY OF ACCELEROMETER (3 ON LEFT THIGH)



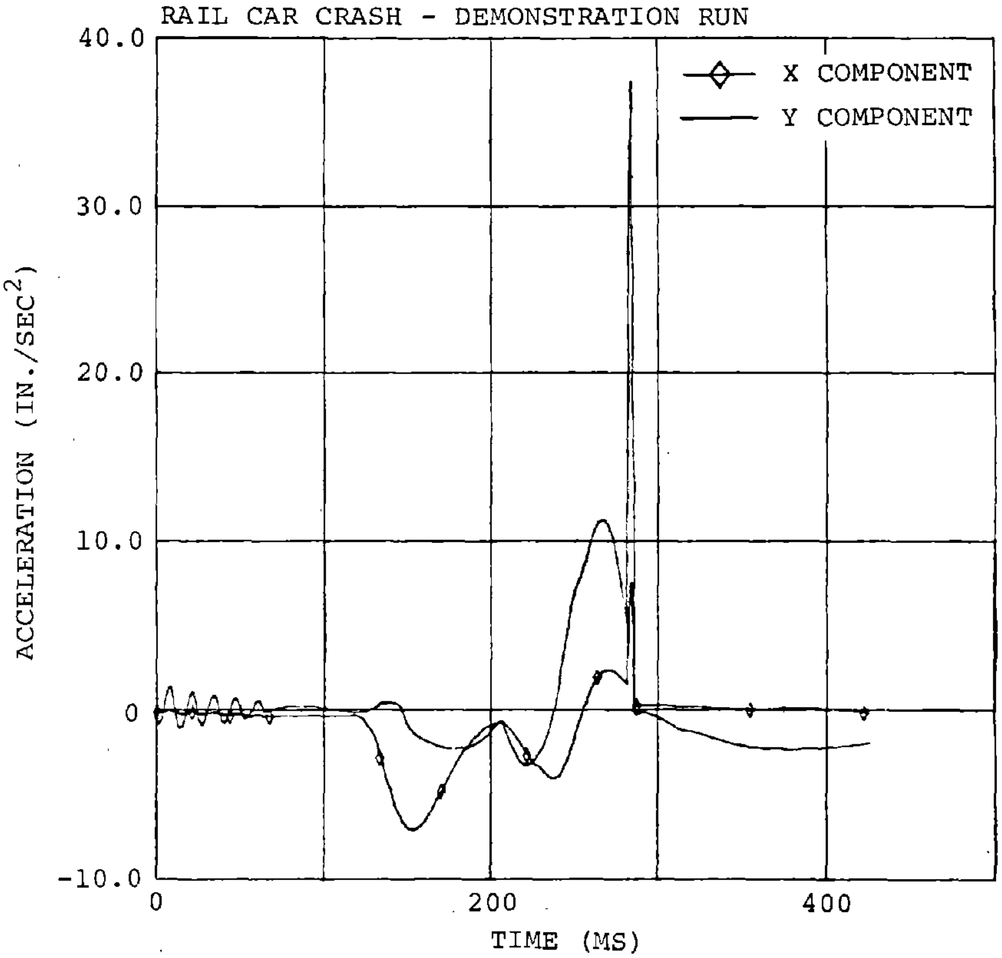
VELOCITY OF ACCELEROMETER (3 ON LEFT THIGH)



ACCELERATION OF ACCELEROMETER (1 ON HEAD/NECK)



ACCELERATION OF ACCELEROMETER (2 ON CHEST)



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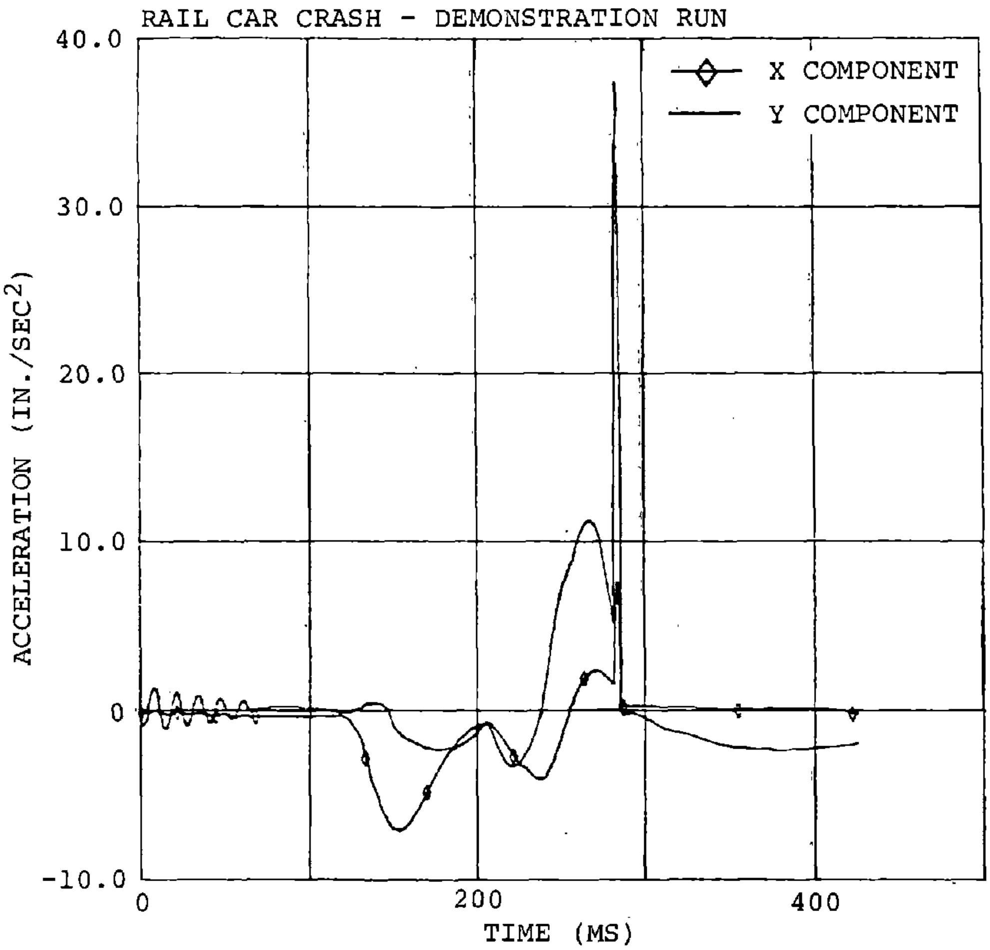
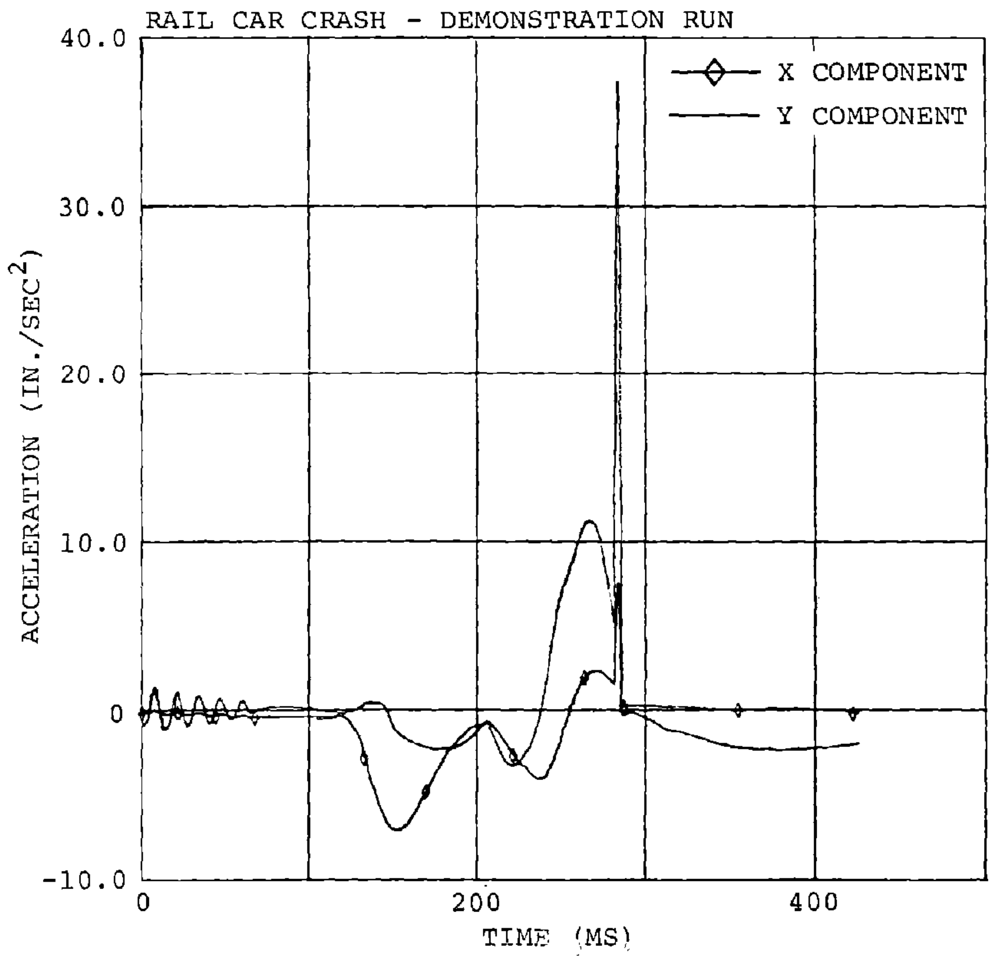
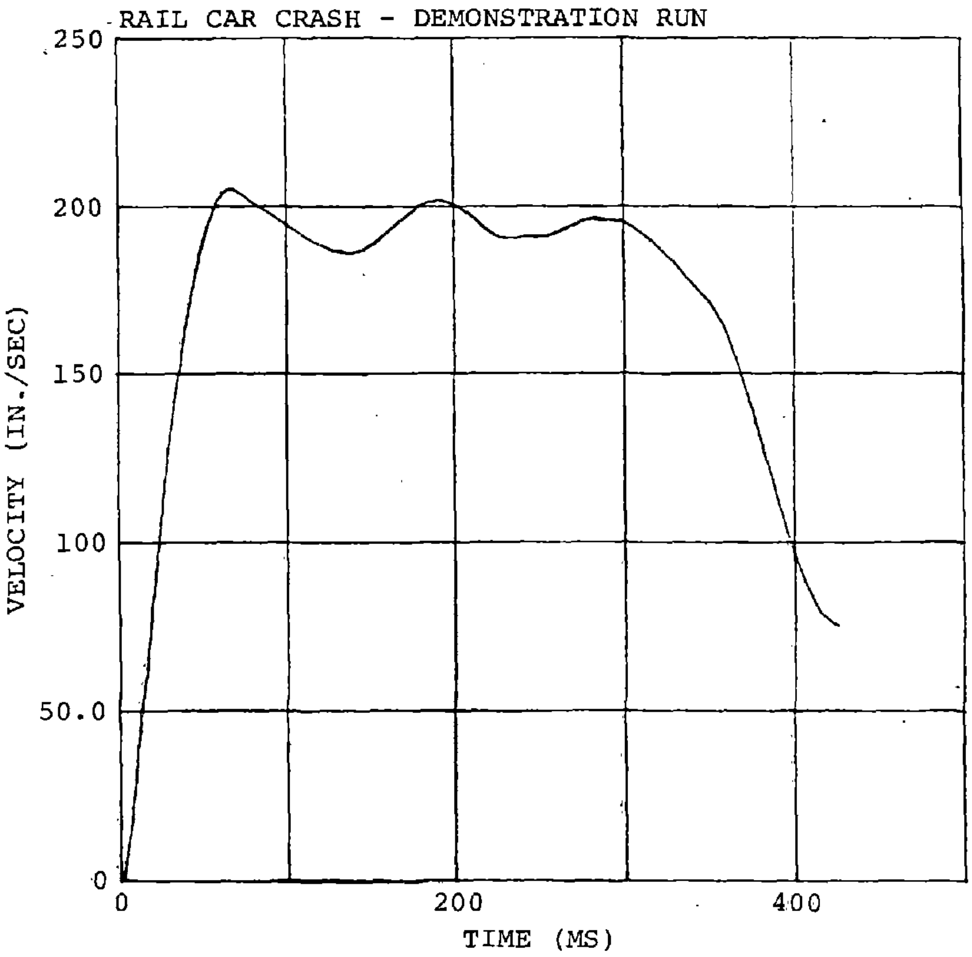


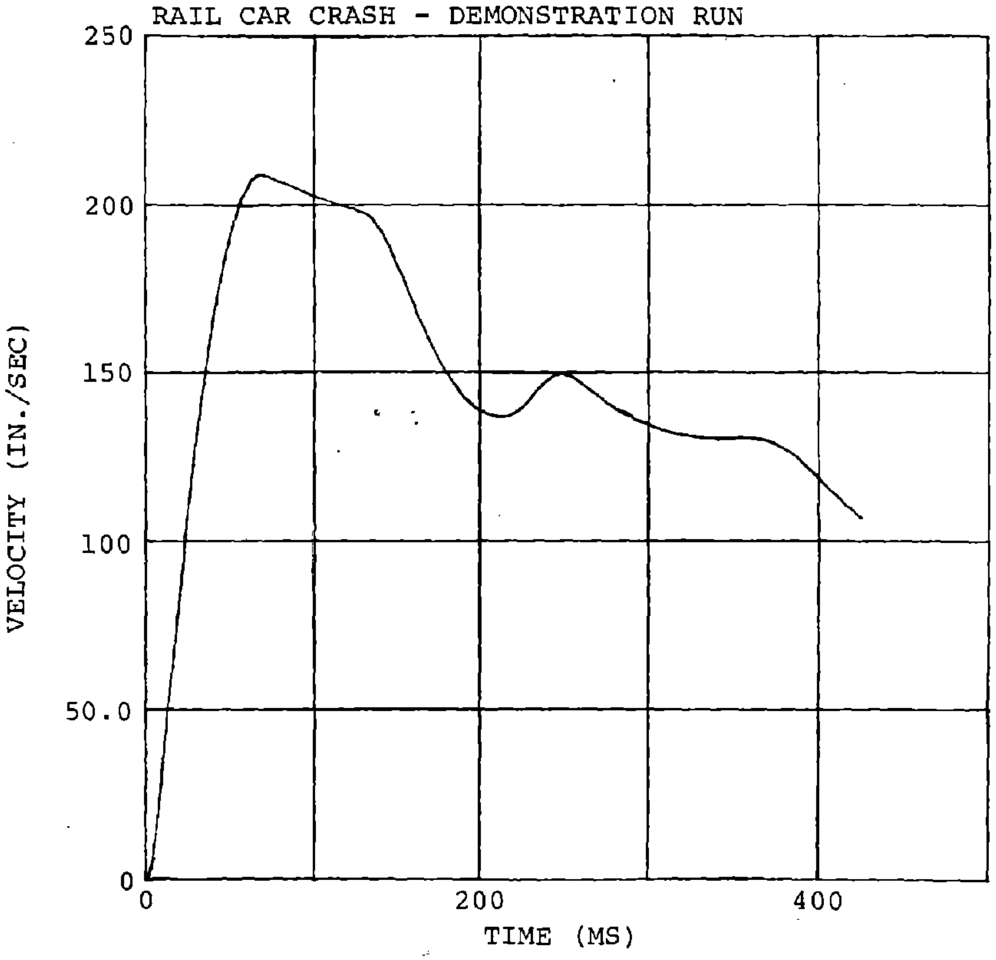
ACCELERATION OF ACCELEROMETER (3 ON LEFT THIGH)



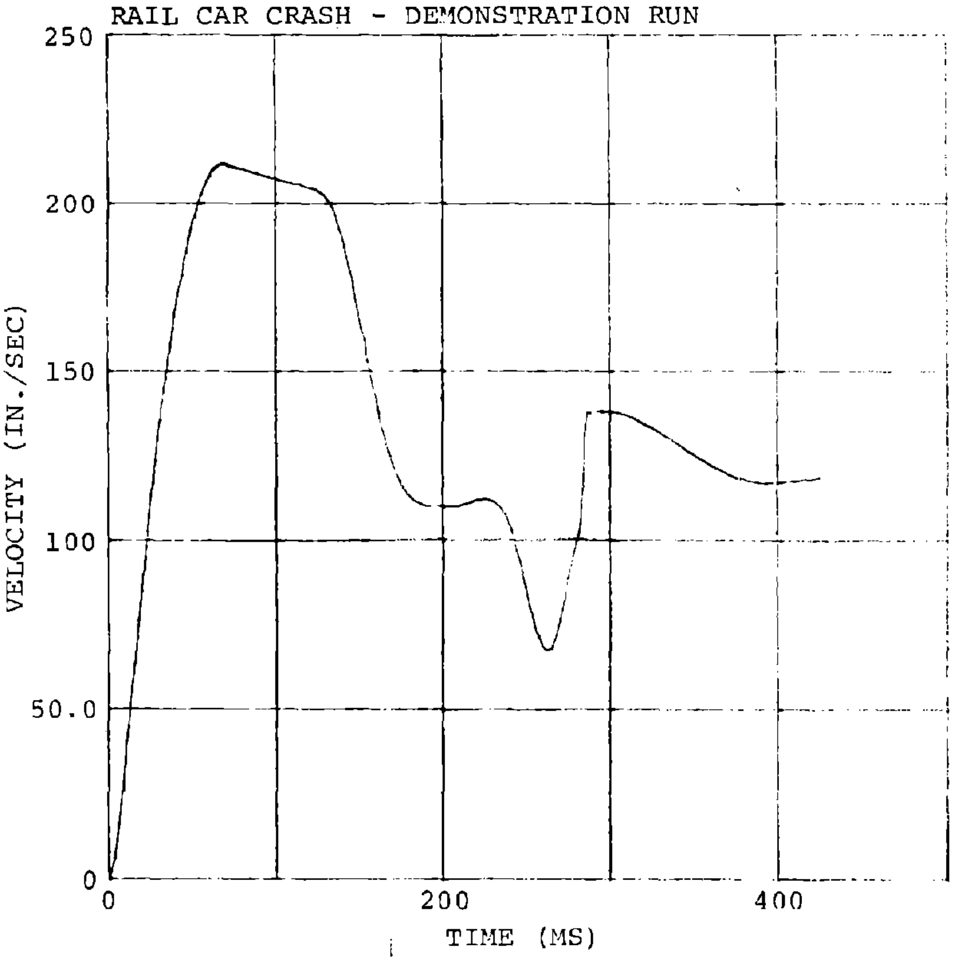
ACCELERATION OF ACCELEROMETER (3 ON LEFT THIGH)



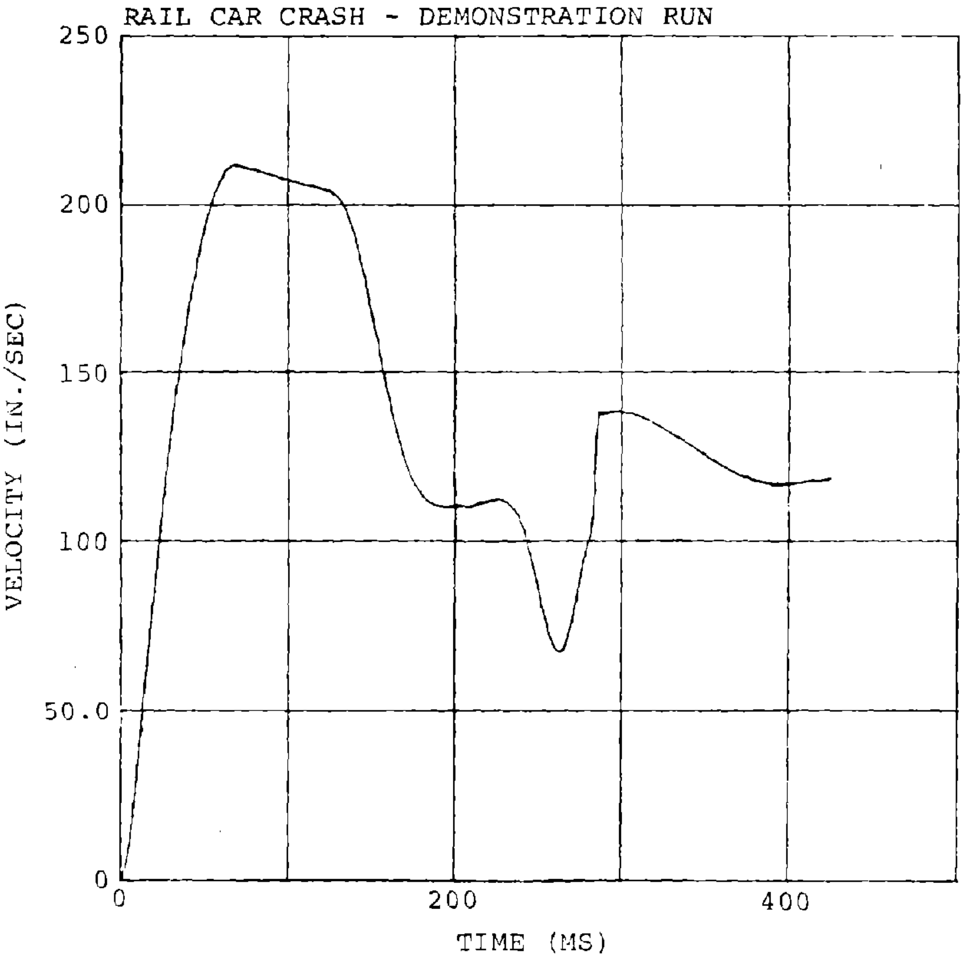
VELOCITY OF ACCELEROMETER (1 ON HEAD/NECK) MAGNITUDE



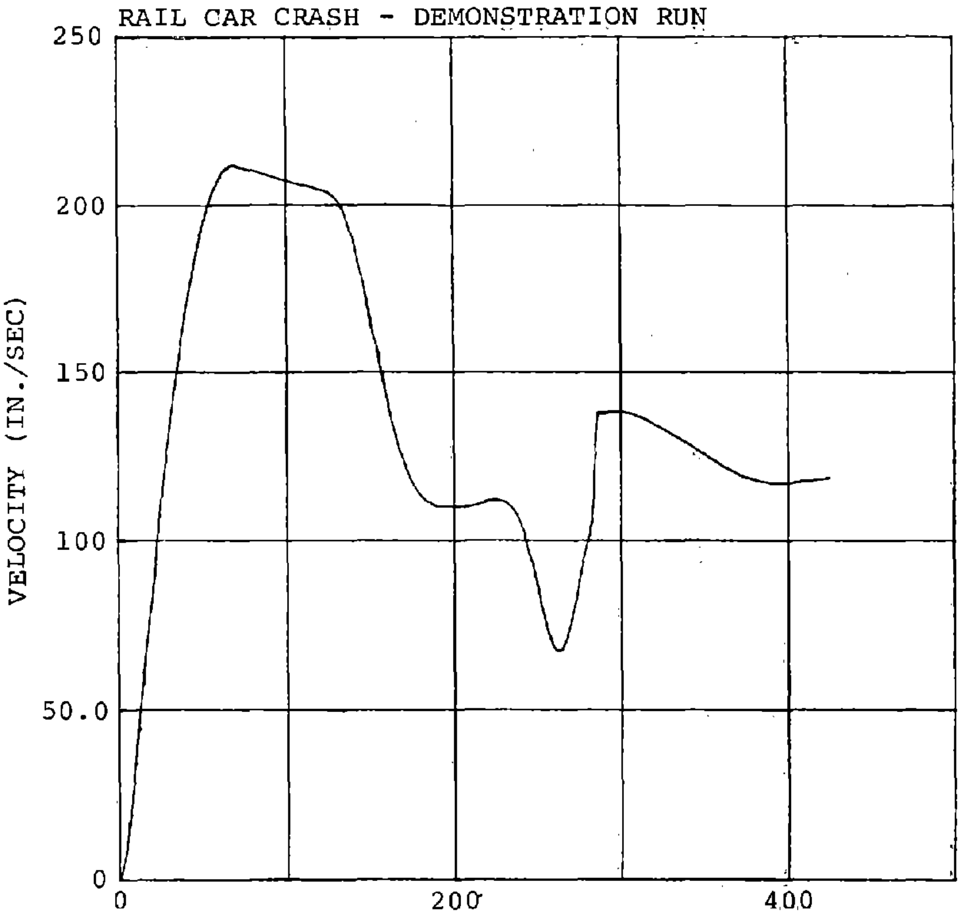
VELOCITY OF ACCELEROMETER (2 ON CHEST) MAGNITUDE



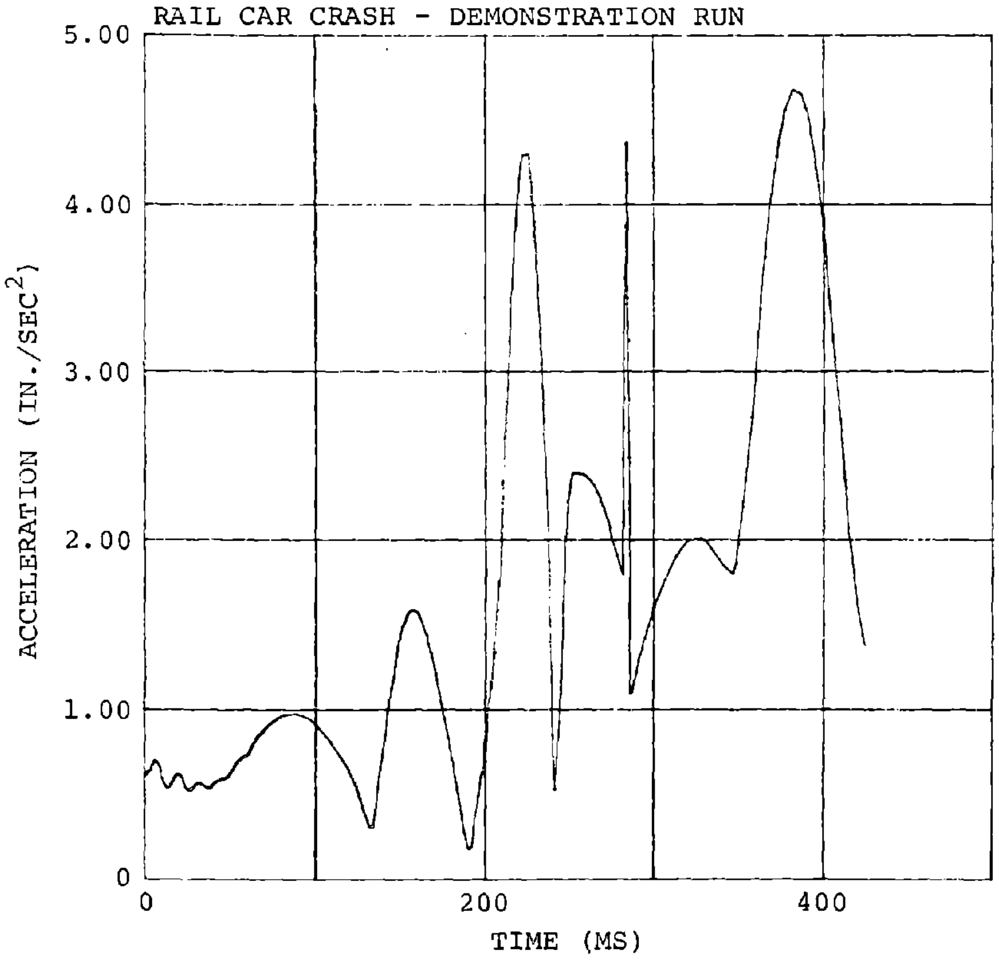
VELOCITY OF ACCELEROMETER (3 ON LEFT THIGH) MAGNITUDE



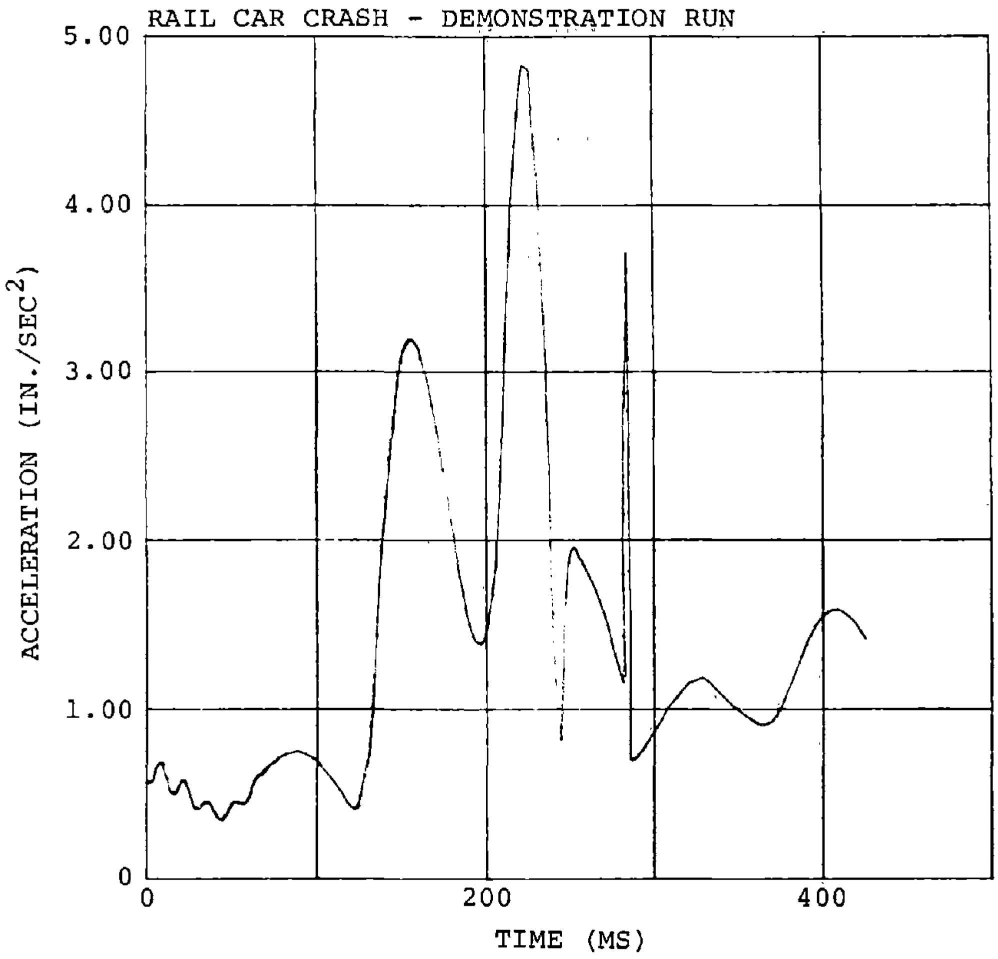
VELOCITY OF ACCELEROMETER (3 ON LEFT THIGH) MAGNITUDE



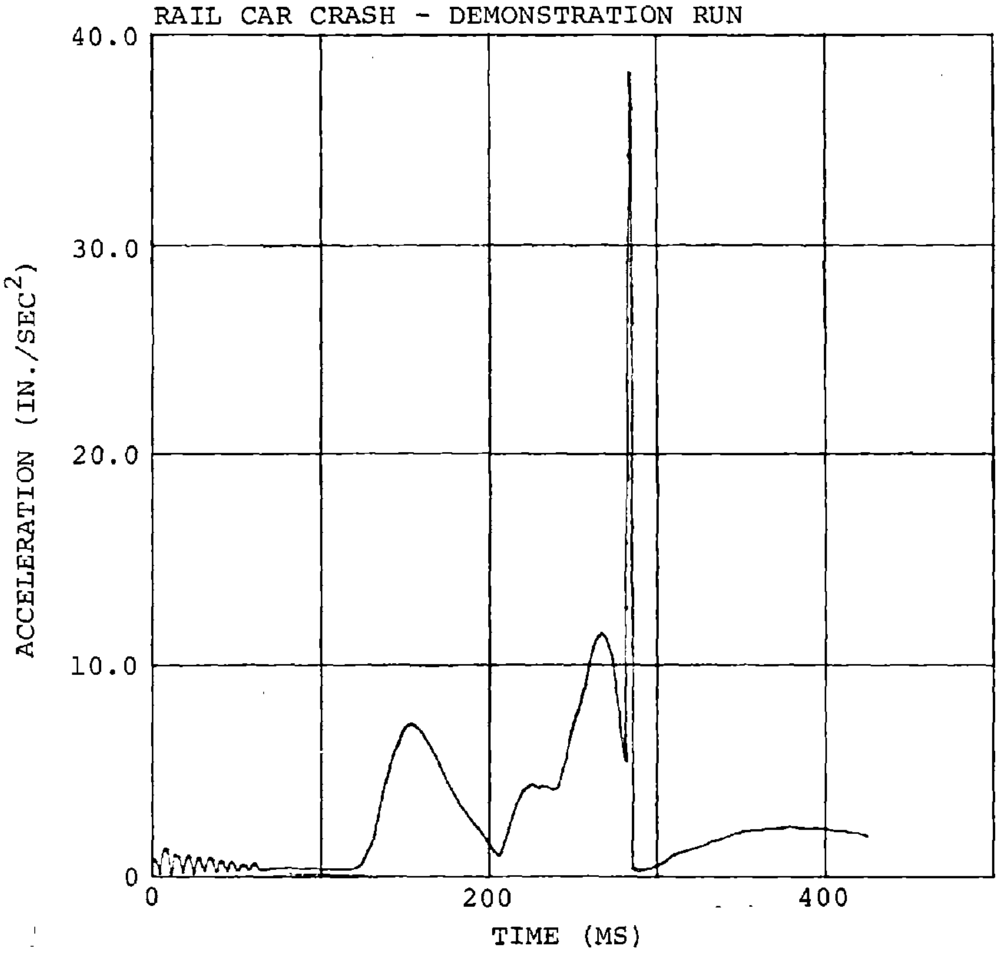
VELOCITY OF ACCELEROMETER (3 ON LEFT THIGH) MAGNITUDE



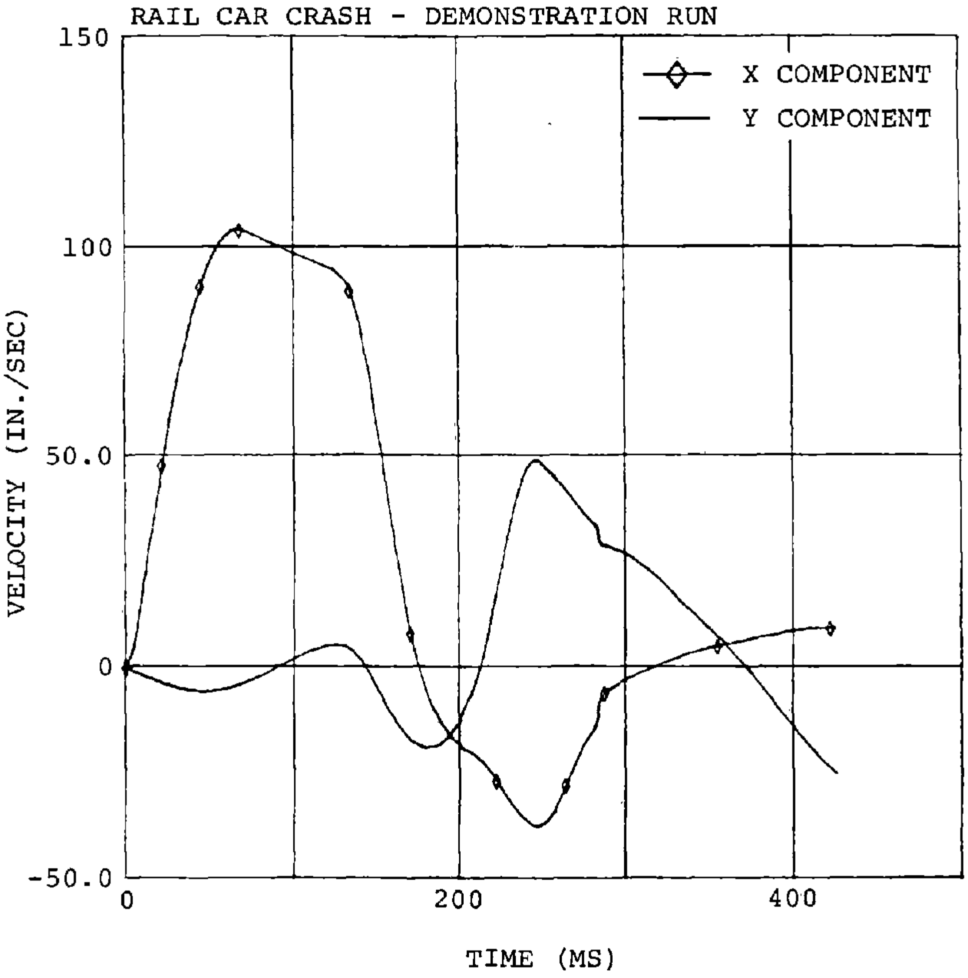
ACCELERATION OF ACCELEROMETER (1 ON HEAD/NECK) MAGNITUDE



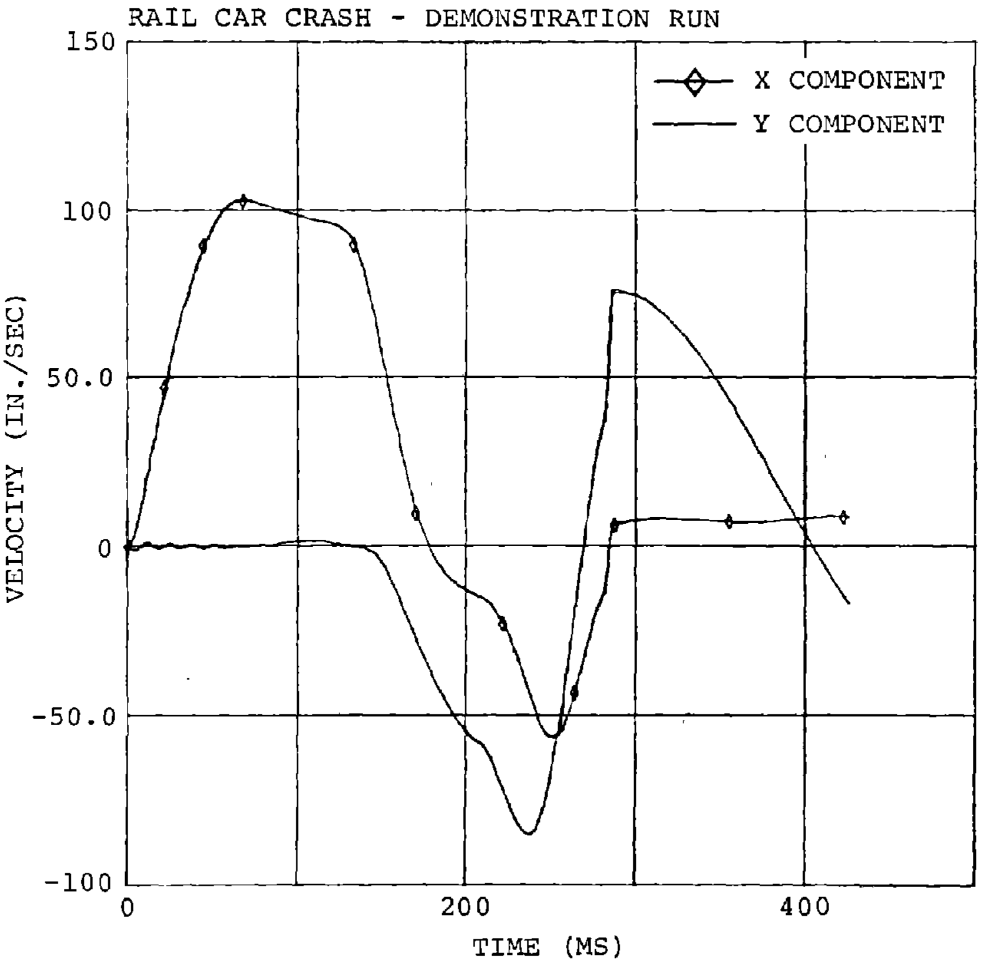
ACCELERATION OF ACCELEROMETER (2 ON CHEST) MAGNITUDE



ACCELERATION OF ACCELEROMETER (3 ON LEFT THIGH) MAGNITUDE



VELOCITY OF LEFT HIP



VELOCITY OF LEFT KNEE

# APPENDIX - NEW TECHNOLOGY

No innovation, discovery, or invention was made in the performance of this study. However, some improvements are noted. For example, in Section 5, pages 56ff, a comprehensive analysis of rail vehicle-accident data is provided for the years 1967-1973, wherein is provided an identification and categorization of injury types, locations, and causal factors, which identification and categorization of these data have not been done before. Also in Section 9, pages 173ff, candidate injury-minimization techniques are presented for the first time for specific types of rail vehicles.

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