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STUDY OF IMPACT TOLERANCE THROUGH FREE-FALL INVESTIGATIONS

FINAL REPORT

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16. Abstract

This study has combined techniques of detailed investigation of selected human free-fall impacts and computer simulation of representative falls in order to expand knowledge of human impact tolerance. Of 2100 falls occurring in the U.S. and Canada, 110 cases were selected for on-site investigation of biomedical and biophysical factors. Seven head-first, two side-first, and three feet-first falls were then simulated using the MVMA 2-D Crash Victim Simulator. Children were generally injured less severely than adults under similar fall circumstances, and tended to land on their heads a greater proportion of the time. It was found that survival limits for children may be higher than previously believed. Body position at impact was a major factor in resulting injuries. In falls to rigid surfaces certain types of injury can be predicted on the basis of age and fall distance. For children under age 8 it is concluded that a constant acceleration of up to 350 G for 2.5-3 msec approaches the survival limit for head impacts. For children younger than 18 months the minimum limit tolerance level for reversible head injury may be reached when fall distance is somewhat greater than four feet.

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CHAPTER 1

INTRODUCTION AND BACKGROUND

A. Purpose and Scope.

The research described in this report was undertaken to obtain detailed information from selected free-fall impacts to estimate impact tolerance values for certain segments of the population. The population groups of primary interest were children, the elderly, and females of any age. The impacts of particular interest were those resulting in injuries to the head and lower extremities, since those two types of injuries are also frequently seen in automobile crashes. The methods used to study those impacts included in-depth on-site investigation and biomedical and mathematical reconstruction.

For purposes of this study, a free-fall is defined as any unimpeded fall, jump, or dive. This excluded such instances as individuals falling down stairs, tumbling from hillsides or cliffs where numerous projections may be struck, falling while inside a vehicle (such as driving off a bridge), or falling on the same level (such as slipping and falling on a wet floor).

Human impact tolerance may be defined in several ways. Subjective discomfort during a test establishes one level of human tolerance, while survival vs. non-survival defines the extreme limits of tolerance. In this study, two limits of human impact tolerance were considered. The first was for moderate injuries, as described by Abbreviated Injury Scale (AIS) ratings of 2 or 3 (AAAM, 1976). These are limits at which some people will sustain only such moderate injuries. The second was the survival limit, the limit at which many individuals sustain critical injuries in which survival is uncertain.

This study was conducted under standards established by the University of Michigan Medical Center Committee to Review Grants for Clinical Research and Investigation Involving Human Beings, and conformed to guidelines of the Institutional Guide to Department of Health, Education and Welfare Policy on Protection of Human Subjects.

Such injuries are described by AIS ratings of 5. This latter group includes injuries which may result in long-term or permanent disability, but which do not always result in death. Results related to both of these definitions of tolerance limits will be presented. They apply to fairly severe impact environments for selected portions of the population, like children.

Because of the variability among and within individuals in their susceptibility to injury, large and representative samples are necessary to establish the upper and lower extremes of human tolerance. Therefore it is important to emphasize that tolerance limits obtained in this and other studies involving relatively limited samples should not be misinterpreted as minimum values that can be experienced by most of the population without serious consequences. This is particularly the case when considering tolerance limits for moderate injuries.

The remainder of this Chapter includes a discussion of various methods which may be used to obtain impact injury tolerance data, background information concerning free-fall studies conducted to date, and enumeration of the principal objectives of this study.

B. Use of Human Free-Fall Data for Determining Impact Tolerance

Injuries often occur when the occupant of a vehicle collides with interior components of the vehicle during a crash. The prevention of such injuries presents a challenging problem to engineers and designers of vehicles. The components must be rugged enough to withstand normal use and at the same time have energy absorbing characteristics that minimize occupant injury in case of collision. Designs that provide optimum protection to occupants require the knowledge of impact response characteristics of the human body, and this need has led to the development of a number of techniques for acquiring human impact tolerance data.

Impact tolerance information is obtained from several sources, including experimental tests of human volunteers, cadavers, and animals, and from investigation of auto crashes, which permits assessment of injuries in relation to crash dynamics. This information is used in the design of anthropomorphic dummies which in turn are frequently used in studies which correlate dummy responses to human injuries. Mathematical modeling utilizes data from all of these sources in attempts to predict the consequences of impacts under a specific set of conditions. Each of these data sources, however, has distinct limitations.

Impact tests using human volunteer subjects have been conducted primarily by the military. As a result, most of the data are for young adult male subjects. These studies are limited because they provide data for a relatively small segment of the general population, and because the impact forces must be kept below injury-producing levels.

Human volunteer testing has required that the imposed force be increased gradually and that the tests be stopped either when the subject feels subjective discomfort (the "ouch level") or when the researcher feels that proceeding further would present a risk of injury to the subject. Thus, such tests have generally remained at the subjective injury level and well below that at which significant or non-reversible injury occurs. Occasionally in such experiments, errors occur and subjects are injured. For example, a male subject seated in a rigid chair and subjected to a vertical drop at a reported maximum deceleration of 95 g sustained mesenteric tears and other abdominal injuries (Swearingen, 1960). In another test, a rear-facing sled impact exceeded the test protocol limit substantially, reached a deceleration of 83 g, and resulted in injuries (Beeding and Mosely, 1960). Also, various ejection tests have resulted in vertebral compression fractures.

Some non-impact human volunteer studies have been conducted for other segments of the population, such as kinematic studies (Snyder, et al, 1975a; 1975c) in which the biomechanics of cervical hyperextension/hyperflexion injury were explored utilizing both male and female subjects from 18 to 75 years of age. However, the dynamic testing was conducted at very low force levels (one g). No tests known to the authors have involved children in impact tests.

Conventional human volunteer tolerance testing has excluded women, children, and all males except the young adult in excellent physical condition. Yet, of 203 million Americans in 1962, only about 3% were in the category represented by volunteer tests to data (Public Health Service, 1962). It is evident that the available trauma tolerance data are relatively limited in application.

Since impact tests which produce significant injury cannot be conducted on human volunteers, a number of researchers have used human cadavers for this purpose. In most earlier studies, embalmed cadavers were used, but now the emphasis is shifting to using fresh, unembalmed cadavers in impact testing. The availability of cadavers has always been limited. Most cadaver work reported to date has been skewed toward the upper age levels with few subjects below middle age, and female cadavers are very seldom used. Child cadavers are virtually impossible to obtain and have been used in only one series of tests reported to date. These tests were performed using four child cadavers aged 2 to 11 years (Kallieris, et al, 1976). However, they were whole-body tests of restraint systems and not body regional impact tolerance determinations. Limitations of testing with cadavers involve difficulties with the condition of the sample (cause of death or atypical physique) and in differences between fresh and embalmed specimens. Further, since cadavers consist of non-functional physiological systems, their valid use must necessarily be restricted.

A wide range of animals have been used as human surrogates in impact studies. These have included mice, pigs, bears, dogs, baboons, chimpanzees, and various species of monkeys. Animals are important test subjects as they are living (functional) systems that are in many ways similar to humans, and they may be subjected to impacts up to and beyond survival limits. Sub-human primates have probably provided the best physiological data in impact tests. However, the extrapolation of injury and tolerance data from animals to humans has been a subject of controversy, and scaling techniques have not been perfected. The use of young or infant primates in impact tests presents additional difficulties in attempting to match results to similar human physiological/chronological ages.

Another method of studying impact tolerance is through in-depth investigation of motor vehicle crashes. The clinical literature contains many descriptions of injuries resulting from automotive collisions. In cases where surgery or post-mortem autopsy is carried out, information concerning body organs or systems most vulnerable to impact is obtained. A limitation of such studies is that the physician or researcher must estimate both the conditions at impact for many factors (such as position of the occupant or velocity at the time of impact) and the forces to which the injured occupants have been subjected.

The present study has used investigation of free-falls for collection of injury data related to specific impacts with known surfaces. The free-fall investigation technique has received comparatively little attention in the past, despite having certain specific advantages over other methods discussed. The subjects are human and involve all age groups and both sexes and thus provide a wider population sampling possibility than with other techniques. Falls occur with sufficient frequency so that cases can be selected according to desired criteria. The limitations are that the exact sequence of impact is not usually known and that impact forces must be calculated. However, by selecting cases in which the impact surfaces are non-yielding, the environmental factors can be measured, and the medical and radiological data are available, the number of variables is reduced. By judicious use of mathematical modeling techniques, estimates of forces, acceleration, and other response parameters can be made and these data can shed light on the impact tolerance capabilities of the human.

Thus, free-fall investigations are a valuable method of obtaining impact tolerance data, particularly for children. The technique is especially useful since children have not been used in volunteer impact tests and immature animals present physiological/chronological age extrapolation problems. Free-falls occur to children of all ages and both sexes over a wide range of impact directions and forces. As there was an almost complete lack of impact tolerance data on children, this study was expected to provide information that is directly needed, such as for the development of improved child anthropomorphic dummies.

C. Background

Falls are exceeded only by motor vehicle crashes as a major cause of accidental death in the United States. In 1976, 14,900 individuals were killed in falls, while hundreds of thousands of others were injured (National Safety Council, 1977). Recorded free-falls occur at a rate of more than 30 per day as a result of accidents, suicide, or homicide attempts. However, it is suspected that many falls are not reported in the news media.

To date, there have been few attempts to study free-falls scientifically, even though they occur so frequently. The ones which have attracted attention have been cases in the medical literature, such as a 320-foot fall in 1919 without fatal injury (Turner, 1919), or remarkable falls with inoperative parachutes (Alkemade, 1963; Meos, 1963). In Germany, Burkhardt (1939) reconstructed four cases of falls onto hard surfaces with an emphasis on their value as sources of forensic information. The free-fall investigation technique was pioneered by DeHaven at Cornell Medical College, who reported in 1942 on 8 cases of free-fall impacts with survival. A ninth case was reported in 1948 (DeHaven and Petry, 1948; Hasbrook, 1959). DeHaven concluded that the primary causes of injury, which he attributed to impact and localization of force, can be reduced by proper packaging of the vehicle occupant (DeHaven, 1942). In 1961, Snyder initiated an extensive program of fall investigation for the Protection and Survival Laboratories, Civil Aeromedical Research Institute, of the Federal Aviation Agency's Office of Aviation Medicine. In 1962 a case history was published providing extensive biophysical and medical documentation for a 275-foot (84 m) free-fall from the Golden Gate Bridge onto earth (Snyder, 1962). This provided documentation indicating that the extreme limit of human survival in the seated position may be considerable beyond the assumed fatal injury threshold. This was followed in 1963 by publication of an analysis of some 12,000 free-falls, of which more than 168 cases were investigated in detail (Snyder, 1963a; 1963b). Fall distances recorded were up to 275 feet (84 m) and calculated velocities of impact up to 116 ft/sec (35 m/sec). Impacted surfaces studied included concrete, asphalt, rock, gravel, soil, wood, and steel (Snyder, 1962; 1963a; 1963b; 1970), snow (Snyder, 1966), and water (Snyder, 1965a; 1965b; Snyder and Snow, 1967).

Since then several other studies have been reported in which an attempt was made to determine relationships of forces to injury mechanisms. In Egypt, El-Assal (1963) examined 46 cases of injury from falls in terms of regional trauma and biodynamics. Stech (1963) under an Air Force contract, attempted to relate severity of trauma to velocity change in some 30 mountaineering accidents, many of which were not true free-falls. Grech (1964) reviewed the radiological findings of 57 cases of falls from East African coconut trees and noted the similarity between the vertebral fractures that he observed and those resulting from "backward parachute landings." Lewis, et al (1965) published a study of 53 fall cases admitted to Harlem Hospital in New York. A similar tabulation, without supporting biophysical data, was compiled by Cummins and Potter (1970) in Bristol, England. They studied 43 cases of head injury attributed to falling from a height greater than 10 feet, and included some cases of infants and children. Unfortunately, none of the most recent studies involved on-site investigation, and the calculations were based upon estimates of fall distances taken from the clinical records. An exception has been the study done of free-falls from bridges in Sydney and Brisbane, Australia (Penfold, et al, 1966; Bailey and Tonge, 1967; Lane, et al, 1973).

Anatomical differences relating to impact response between children and adults have been described by Burdi, et al (1969), but little is known about child tolerances to impact. Free-fall impact injuries received by 19 children from ages 1½ through 4 years were reported by Snyder (1963a; 1963b), and in a recent study, Smith, et al (1975), at the University of Chicago, reviewed 66 cases of free-falls of children to age 8 relative to the medical/surgical problems posed by vertical falls. They found that fractures of skulls, upper extremities, and femurs were most common; only one pelvic fracture and one calcaneus fracture were recorded. Although falls from heights of up to 96 feet (29 m) were reported, the only environmental information used was that reported on the medical charts. Body orientation at impact, impact surfaces, and other factors were not verified, and height estimates from admission charts were accepted. [In contrast, in our study, estimates from admission charts have been shown to often be grossly inaccurate, usually by substantially overestimating the fall height.]

Ching, et al (1975), have reported case studies of children who suffered femur neck fractures due to falls or road accidents. These children varied in age from 5 to 14 years, but the injuries were not identified by cause of injury. Fractures to the radius and ulna of children up to age 15 years have been reported recently by Thomas, et al (1975). They recorded 375 fractures in children, but free-fall cases were not identified.

The most detailed study on infant or child tolerances was published by Snyder (1970). In this study, computerized categorization identified falls by 3,153 children between ages 1-12. Most cases were found unsatisfactory for impact analysis because not all variables were known or could be verified. However, 34 cases of free-falls of children aged 8 months to 12 years were investigated in detail, and impact data were reported as an initial basis for estimating child impact tolerances. Although data were limited, these were the first known reported cases in which both physical measurements and biomedical analysis had been concurrently obtained.

D. Objectives

Two general objectives were identified as the principal goals of this research. The first was to determine if a detailed study of selected free-fall accidents could provide new information about the ability of the human body to tolerate impact forces. The second was to determine if a computer model could be used to estimate human tolerance values through simulation of free-falls.

In order to obtain new information from the study of free-falls, several supporting objectives were adopted.

First, the study population was selected. Since the literature survey had demonstrated a lack of tolerance data for children, females, and the elderly, it was decided to concentrate the research efforts on those groups. Second, a method was established to receive notification of falls and select those to be investigated. Third, investigation criteria and techniques were established to provide the level of detail necessary to accurately reconstruct the circumstances, impact sequences, and injury consequences of falls. Finally, criteria were adopted to evaluate the information gained in the case investigations for application to human tolerance definition.

The use of computer simulation to estimate human tolerance data also required a systematic approach with several sub-objectives. First, it was necessary to demonstrate that the chosen model [the MVMA 2-D Crash Victim Simulator, Version 3 (Bowman et al, 1974 and 1977)] was effective in simulating free-falls. This was accomplished by performing a series of laboratory free-fall tests using an anthropomorphic dummy and successfully simulating dummy responses with the model. Second, it was necessary to establish baseline human data for the population groups to be simulated. This required the review of many data sources and the development of techniques to adapt these data to simulation of children. Third, it was necessary to develop a simulation matrix to efficiently provide data for comparison and evaluation. Fourth, it was necessary to analyze the simulated responses to provide estimates of human tolerance to impact injury. This final objective was accomplished primarily by correlating predicted dynamic response parameters with actual injuries from investigated cases.

CHAPTER 2
STUDY METHODOLOGY

Research techniques from several disciplines were used to accomplish the objectives of this study. Techniques derived from accident investigation methods, anthropomorphic dummy testing, and computerized dynamic response simulation were combined to produce the results that are described and analyzed in this report. The methods used to conduct the field investigations, perform free-fall simulations, and analyze the data are discussed in this chapter.

A. Selection of Cases for Investigation

1. Sources of Potential Cases. Information about free-falls may be obtained from law enforcement agencies, ambulance services, hospital emergency rooms, news media, and personal contact. The use of police, ambulance, or hospital sources in this study would have required the establishment of a special reporting system outside the scope of normal activities for these agencies. Therefore, newspaper reports of falls were the preferred source because of their public nature, reasonable accuracy, and national coverage. News reports were readily accessible through the established source of a news clipping service.

At the initiation of the study, a news clipping service was engaged to provide original clippings of reported free-falls. This service provided complete coverage of all regularly published English-language newspapers in the United States and Canada and was capable of providing the specialized type of clipping needed for the study. The same service had also provided clippings for earlier free-fall studies by the senior author. Newspaper items related to free-fall accidents were sent to HSRI each weekday to be screened for possible on-site study.

Personal contacts were also used for notification of potential cases. Colleagues and friends in a position to identify free-falls were contacted and asked to provide notification if falls occurred in their areas. Three on-site investigations resulted from such notifications.

2. Selection Criteria for Case Investigations. An average of 60 clippings per week was received from the clipping service. Each was read by both principal investigators and by the project coordinator and marked if of potential interest. Several criteria were used as guidelines in determining whether or not a fall should be considered for an on-site investigation.

First, the fall had to be a free-fall as defined for this study. If the newspaper article indicated some intermediate contact prior to final impact, such as hitting a bush or a rock ledge, there was usually no further consideration. This criterion also eliminated falls by parachutists since a partially opened parachute would reduce the velocity of the subject by an unknown amount and make it difficult to calculate the impact velocity.

A second major consideration was that the fall environment - location and height of the fall, the type of surface impacted - be determinable. It was necessary that the site be essentially unchanged between the time of the fall and the time of the on-site visit. For this reason, many falls at construction sites were not investigated, since progress of the construction (or demolition) changed the conditions from those at the time of the fall. For the same reason, falls onto soil and other non-rigid surfaces were usually not considered. Knowledge of permanent soil deformation and soil hardness were necessary for successful estimation of impact forces. These features usually changed after a fall due to trampling of the area and weather conditions, so falls onto soil were not usually considered for investigations. Also, falls into water or snow were not included, since the present study was centered on tolerance to severe impact conditions resulting from contact with more rigid surfaces. The preferred surface for the purposes of this study was a flat, level concrete sidewalk or patio. Finally, while survivable falls from extreme heights were of some interest, the majority of falls considered for investigation were limited to those under 30 feet (9 m).

The third major criterion used in screening clippings was the age and sex of the victim. As indicated in Chapter 1, this study was intended to assess impact tolerance for segments of the population about which little was known. Therefore, preference for on-site investigations was given to children, females, and older adults. Unless there was a close parallel to an existing case with a child, most falls of males in the 18 to 40-year age range were not considered. The extent and location of injuries, if reported, was also considered in selecting cases. Fatalities were usually eliminated, though several fatalities from fall heights of 8-15 feet (2.4-4.5 m) were investigated on the supposition that a subtle difference in the body orientation at impact could be the deciding factor in impact tolerance. The portions of the body that were injured were also of importance, with head or leg injuries similar to those frequently occurring in automobile crashes being given preference.

Aside from the three primary criteria described above, other items in the newspaper story influenced whether the case was studied or not. Identification of investigating police officers, hospital names, and existence of witnesses were positive influences, while published threats of legal action, obvious suicide attempts or probable inaccessibility to subject or location were negative ones.

These latter factors did not prevent an investigation from being attempted if other factors made the case potentially valuable.

In summary, the initial screening of newspaper clippings was aimed at creating a file of potential cases involving free-falls at a reasonably well-defined and accessible location and occurring to a child or older adult.

B. <u>Case Investigation Methods</u>

Free falls identified for possible investigation were grouped by geographic area and became the basis for developing trip itineraries. Locations for on-site investigations were selected by one of two means - either a trip was planned to an area due to a number of probable cases in the area, or free-fall investigations were conducted in conjunction with other travel. The trips specifically for investigations were limited to a 600-mile radius of Ann Arbor, Michigan, while cases at distant locations in the South and West were investigated in conjunction with travel on other business.

Prior to the trip, the investigator would re-evaluate the clippings for the region of interest and select those of primary interest. Where the clipping indicated hospitalization, the discharge date was sought from the hospital. This was primarily to assess the severity of injury (as indicated by the length-of-stay) and to find out whether or not the individual survived the fall. In those instances where a child fatality was to be studied, a letter was sent to the parents to explain the study, seek their cooperation and notify them of an impending visit.

The field investigations were conducted with the object of obtaining sufficient information to allow reconstruction of the fall and simulation of it using mathematical techniques. Each investigation had three major elements: a) conduct an interview, b) take measurements and c) obtain medical information.

1. Subject Interviews. The subject or subject's parents were often contacted as the initial step in the investigation. Usually, no contact was made with the subject prior to the trip, since the subject was more likely to participate in the study when approached by an investigator who had already traveled to the subject's home. During the interview, the exact location of the fall was determined together with as much information as possible about the position of the subject immediately prior to and after the fall. Occasionally a subject could recall an impact sequence for various parts of the body, and these descriptions were noted. The subject's height, weight and date of birth were requested and the clothing worn at the time of the fall was noted. The investigator then asked the subject to describe the injuries received in the fall and to assess the completeness of his or her recovery. On many occasions, the subject was also photographed.

At the close of the interview the subject was asked to sign a medical records release form. The release form was simply worded and assured the subject that the records would be kept confidential. The two forms shown in Appendix C were used: a first-person form for an adult subject and a second-person form for a child subject. A large majority of subjects interviewed approved the release. Those who refused to approve the release usually did so because of pending legal action relating to the fall.

2. Measurements at the Site. In most cases, especially those involving children, the subject fell at or near home. In those instances, the investigator would ask the subject or witnesses to point out the exact locations of

the fall and impact, and he would take direct measurements of the fall height. If the subject fell from inside a building, that location was also measured and photographed. Remaining measurements and photographs were completed outside the building after the interview. If the subject landed on soil, a small soil sample was obtained and a Soiltest Model CL-700 penetrometer was used to estimate soil hardness.

Most of the subjects who fell while on the job were at a location remote from their home. In a majority of those cases, the site was visited before the subject was contacted. Employers and police agencies were found to be generally cooperative and it was usually possible to obtain the needed measures and photographs together with additional data about the fall circumstances. Information given by employers and subjects was usually in close agreement.

3. Medical Information. Medical information was obtained primarily from two sources. First, during the course of the interview, the subject was asked to describe the injuries. The investigator elicited as much detail as possible about loss of consciousness, locations of bruises, and minor external injuries as an aid in determining impact sequences. Subject responses usually were detailed and reasonably accurate, but ranged from virtually no usable information to copies of medical records that the subject had obtained from a physician. In many cases the interviewer could observe the nature, extent and location of external trauma.

The second source of medical information was the hospital in which the subject was treated. The Medical Records Department of the treating hospital was contacted by the investigator, either in person or by mail after returning to the office.

When possible, the entire record was scanned and any information relating to injuries and recovery from injuries was noted. Most information was obtained from discharge summaries, emergency room records, physical examinations at the time of admission, and radiology reports. Copies of those records were obtained. After the records were reviewed, and particularly if the subject incurred bone fractures, the x-rays were borrowed for review at HSRI.

4. Other Methods. Circumstances on-site often resulted in the investigator's having to obtain information from sources other than those mentioned above. The most common of these were police reports and interviews with investigating police officers. The police were often helpful in determining the exact location of a site remote from the subject, and in providing names and addresses of witnesses. Very seldom were any injury data found in police reports. Other sources used regularly were fire department rescue squads and ambulance services. Local newspapers were usually consulted for additional local coverage. Occasionally, other techniques were adopted to locate subjects, obtain height measurements, or fill in other details.

5. Case Reporting and Follow-Up. After the initial investigation of a fall, a narrative report was prepared to summarize the case and record detailed information about the fall. Typically these case reports contained a brief summary with itemized pertinent data followed by narrative sections describing the fall environment, a diagram with on-site measurements, a description of the subject, injury and recovery data, and other comments pertinent to the investigation. Any follow-up items were handled at HSRI by telephone or mail, usually by the project coordinator.

C. General Analysis of Data from Clippings and Field Investigations

1. Preparation of Punched Cards. Data for each fall

of an individual were punched into a McBee Keysort rim-punch card especially designed for this study. This enabled accurate sorts to be made for selected variables and facilitated analysis, as well as forming an easily-stored individual record. Information coded on this card included a fall number (all clippings describing the fall of a particular person were given the same number), the date of the fall, the age and sex of the individual, the location and description of the fall, and, when available, the fall distance, material impacted, body position at impact, and the injuries received. A second set of cards, with similar information, was prepared for the investigated cases. The punched cards could then be sorted by variable for analysis purposes.

Also included on each card was information about the type of fall. A classification system consisting of eleven categories of falls was devised. Each fall was assigned to one of the categories described in Table 1. The fall category was assigned based upon what the victim fell from, rather than what he or she landed on. Categories 01, 02, 03, 05, 06 and 11 relate to general situations, such as falls from buildings under construction or repair, falls from rocky surfaces, and falls from structures other than buildings. Categories 04, 07, 08, and 09 represent four specific kinds of hazards--trees, skydiving accidents, schools, and elevator shafts. The specific categories took precedence over general ones, so that a workman who fell from a ladder while trimming a tree would be assigned to category 04 (trees) rather than category 11 (general occupational falls).

2. Analysis from Punched Cards. It was possible to derive many useful results from the clipping and case investigation data. The clipping data provided detailed information about the number of falls reported and about the distribution of falls by time of year and sex of the victim. Also available from the clippings, though in somewhat less detail, were

TABLE 1

Category Designations Used for Classifying News Clippings

Category	Types of Falls Included
01	Falls from buildings under construction--multi-story construction sites, bridges and dams being built.
02	Falls from buildings under repair and maintenance (any structure)--roofing, window-washing, painting, falls from ladders while repairing home, grain elevators, dismantling buildings, firefighters falling from buildings, etc.
03	Falls from existing buildings (non-occupational) windows, balconies, fire escapes, roofs, railings, lofts, down air shafts, stair landings, open manholes (includes many suicide attempts).
04	Falls from trees--playing, trimming.
05	Falls from rock--quarries, mountain climbing, off ledges, into gorges, mine shafts, over cliffs, embankments, waterfalls.
06	Falls from other structures (non-occupational)-bridges, dams, railroad trestles, ship masts, highway overpasses, bleachers, docks, towers, walls, chairlifts, clothes-poles, wells.
07	Falls from airplanes and hang gliders (primarily skydivers).
08	Falls in schools--through skylights, in gym class, from diving boards, playground equipment.
09	Falls in elevators and down elevator shafts.
10	Miscellaneous--from joyriding, vehicles (non-occupational).
11	Other occupational falls during normal work--telephone poles, lift trucks, overhead cranes.

distributions of falls by age and category of fall, and by numbers of fatalities. The set of cards punched for the case investigations provided detailed comparisons for sex, age, category of fall, fall distance and impact surface, primary body contacts, and head and other injuries. These comparisons were made singly and in combinations of variables. The results are presented in Chapter 3.

D. Simulations of Free-Falls

The subjects whose falls were investigated did not, of course, have any instrumentation attached to their bodies. Therefore, impact accelerations, deflections and forces that are related to human tolerance levels could be estimated only by using simulation techniques. An instrumented anthropomorphic dummy did not seem to be a good simulator since orientation at impact would be difficult to control in a free-fall situation and since dummy reactions are often not human-like. The chosen simulation device was a computerized model of a human, specifically the MVMA Two-Dimensional Crash Victim Simulator, Version 3 (Bowman, et al, 1974 and 1977). This model is a sophisticated whole-body model which, it was thought, could be used to simulate impacts onto both rigid and yielding surfaces for falls in which the motions were predominantly planar. Since, at the time, the model had never been used to simulate free-fall impacts, a two-phase simulation program was planned. First a series of highly-controlled dummy drops were staged so that the results of several fully-instrumented free-falls could be obtained. Then, using known dummy design and response data, the model was exercised to simulate the dummy drops. This phase established the ability of the model to accurately predict dummy free-fall impact dynamics. The second phase of the simulation program was to substitute human response and anthropometric data and reconstruct several free-falls from investigated cases.

1. General Features of the MVMA 2-D Model. The MVMA Two Dimensional Crash Victim Simulator was developed at HSRI.

This model includes the following features in its representation of the human body:

1. A nine-mass, ten-segment body linkage;
2. An extensible, two-joint neck and realistically-flexible shoulder complex;
3. Energy-absorbing joints;
4. Time-dependent muscle activity level;
5. Contact-sensing ellipses of arbitrary size, position, and number which define the body profile; and,
6. General and arbitrarily-definable non-linear materials with energy-absorbing capability for all parts of the body.

The model configuration used to simulate the anthropomorphic dummy falling in a semi-crouched position is shown in Figure 1. The ten physical links represent the head, extremities, shoulder and spine. The human spinal column is more or less continuously flexible since it is composed of thirty-three vertebrae, twenty-four of which have intervening fibrocartilaginous disks. The model simulates flexibility of the combined thoracic and lumbar spines by two articulations, which connect three torso links. These are joints 3 and 4 in the figure. Flexibility of the cervical spine is accounted for by two articulations, one at the occipital condyles and one at the seventh-cervical/first-thoracic juncture, joints 1 and 2, respectively.

Nine masses are associated with the ten links. The neck link L_n is extensible and compressible and has non-zero mass* while the shoulder link (9-7) has no mass but is included in the model to account for sagittal-plane clavicular-scapular shrugging motions. All other links are inextensible and articulate at the joint positions illustrated.

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*Neck mass is distributed at the end points of the neck link.

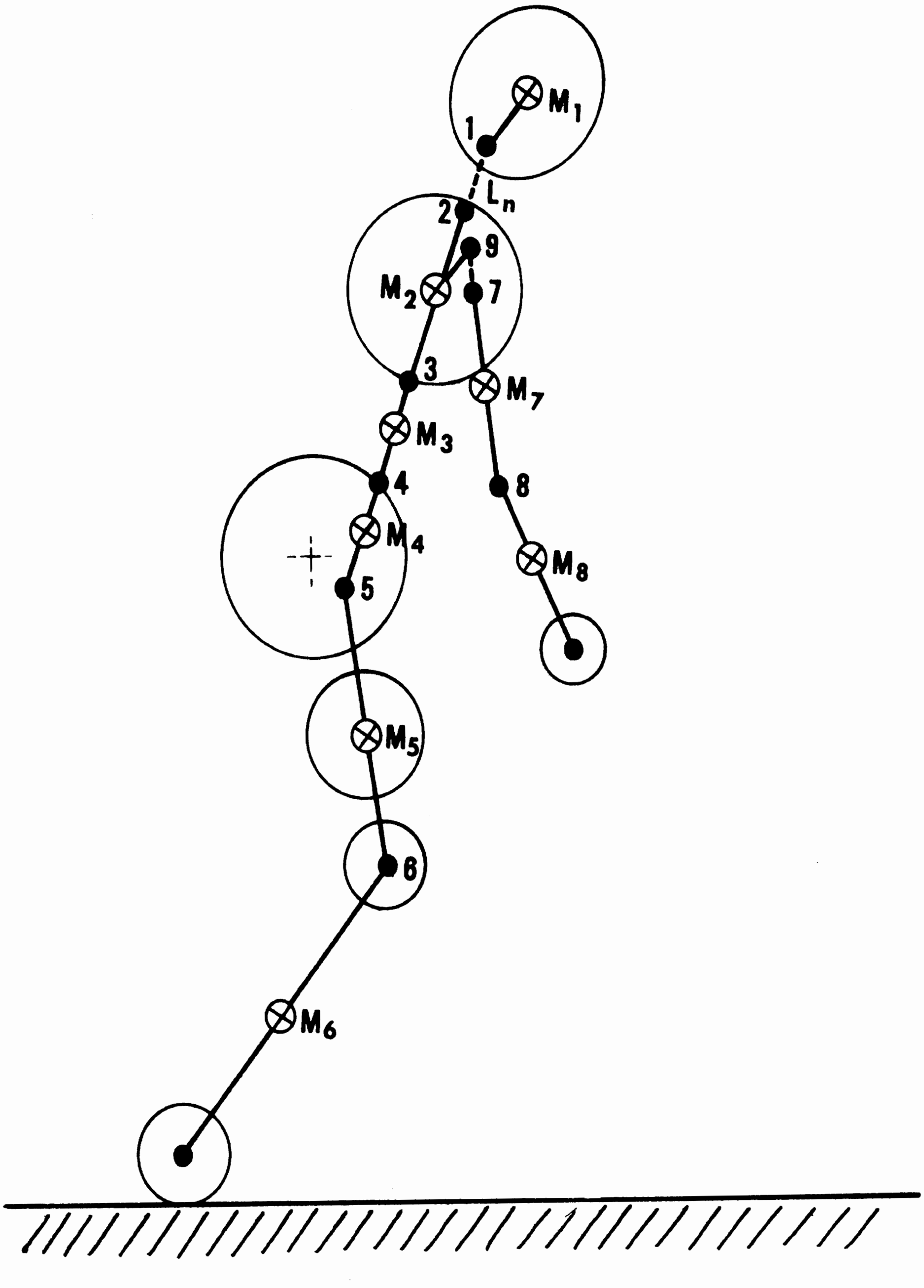
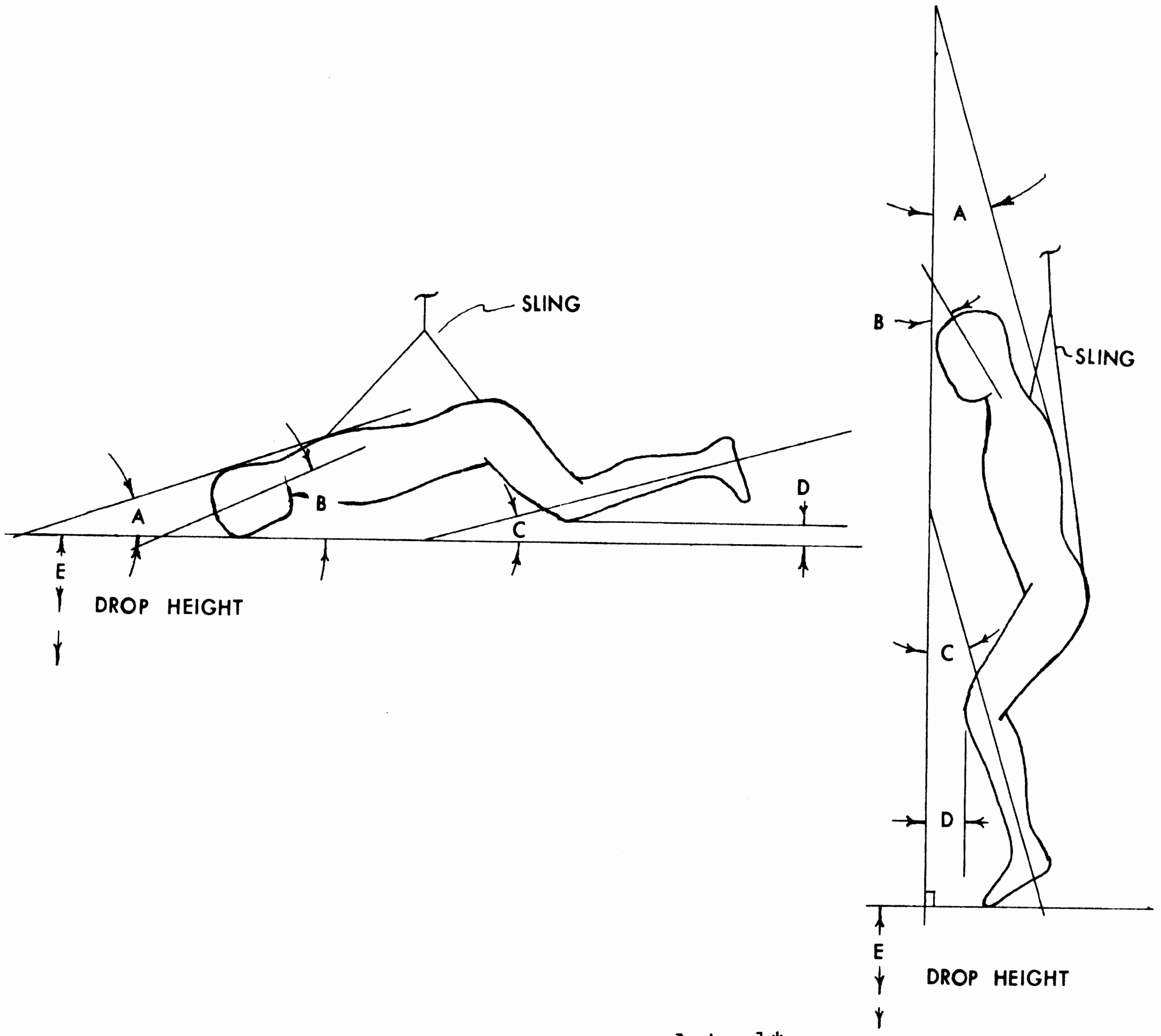


Figure 1. MVMA 2-D Model Representation of Anthropomorphic Dummy, Crouched-Position Fall. Shown are body joints (numbered 1-9), ten links, masses (M_1-M_8), and contact-sensing ellipses.

Also shown in Figure 1 are the contact-sensing ellipses which were included in the dummy simulations. These ellipses, of specified size and material properties, were used to represent the head, chest, hips, thigh, knee, foot, and hand. Since it was felt that arm and hand contacts with the struck surface would not significantly attenuate head, chest, or pelvic responses, arm links were not included in the human simulations (their mass was represented in the chest). It should be noted that masses are associated with the links, not with the contact ellipses. Therefore, inertial responses will be properly modeled whether or not an ellipse is assigned to a link. It is only necessary to specify ellipses for those parts of the body for which contact with the struck surface is anticipated.

2. Simulations of Free-Falls of Instrumented Dummies. Test Procedures. A series of five free-fall experiments were conducted using an instrumented anthropomorphic dummy, the HSRI dummy known as "Repeatable Pete" (McElhaney, 1973). Two of the drop tests were performed with the dummy initially in a prone, slightly head-down position. These drops were from 5 and 8 feet (1.5 & 2.4 m). Two drops were from a standing semi-crouched position. These were matched tests, with the dummy's feet being five feet above the floor in each case. The fifth test was a five-foot drop in which the dummy fell first onto its right foot, then pivoted onto the right side. This test, however, was not suitable for simulation using the two-dimensional model. The nominal and actual test positions for the prone and crouched experiments are diagrammed in Figure 2. The dummy was balanced and suspended by a clothesline sling with a single line connected from the sling at the balance point of the dummy to a hoist which was used to raise the dummy to proper height. The dummy was released and allowed to fall freely by cutting the taut line with a sharp blade. The technique severed the line instantly and permitted the dummy to fall to the concrete floor without



Dimension	Design	Actual* Test 01	Test 02	Test 04
A	20°	16°	18°	20°
B	20°	32°	37°	43°
C	20°	22°	22°	41°
D	12 in (30.5cm)	7.5 in(19cm)	10.5 in(27cm)	12.5 in(32cm)
E (01,04)	5'0"(1.5m)	5'0"(1.5m)		5'0"(1.5m)
E (02)	10'0"(3.0m)		7'11"(2.4m)	

*As measured from high-speed film at initial point of contact (except for Dimensions D&E which were measured prior to the test).

Figure 2. Dummy Configurations for Free-Fall Drop Tests.

of position. The experiments were filmed using two Photo-Sonics Model 1B high-speed (500 frames/sec) motion picture cameras for side and front views. The dummy was instrumented with GSE Model 2430 force transducers in the femurs, Setra Model 113 accelerometers in the chest, and Endevco Model 2264 accelerometers in the head and pelvis. For each experiment, eleven channels of data were recorded: triaxial accelerations at the centers of gravity of the head and the thorax; triaxial accelerations of the pelvis; and axial force in each femur. The data channels were tape-recorded during the experiment and later transferred to hard copy by using a strip-chart recorder.

The comparison of design with actual test dimensions in Figure 2 shows some minor differences. These occurred because of the nature of the dummy's joints, particularly the neck joints. It would have been necessary to provide artificial bracing of the head and greater than one-g stiffness to other joints to maintain design dimensions. This was thought to be undersirable for a free-fall test, so the dummy was allowed to remain in an unforced condition. The drop release system worked very well except that the cord was severed too soon for Test 03 and most of the high-speed film documentation was lost, although the tape-recorded data were obtained. The only other problem encountered was in the thorax accelerometer system. Power supply problems resulted in a spurious signal in several of the test runs, so those acceleration data were usually not considered when model predictions were compared to experimental results.

Data reduction for the dummy drop experiments was limited to that necessary to provide input data and comparison data for the simulations. Peak resultant accelerations were calculated from the strip-chart record of the triaxial accelerations. The elapsed time from initial contact to peak resultant acceleration was also noted. The high-speed films of Tests 01, 02, and 04 were studied using a Vanguard Data Analyzer. The first frame in which the entire falling dummy was visible was analyzed for body link position angles. Then the frame showing initial contact between the dummy and the floor was analyzed for the same positional data. The two frames were compared to check for dummy rotation during free-fall and to check velocity against the impact velocity calculated for use in the model. There were no more than two degrees of body rotation in any test, so it was not necessary to include rotational compensation in the simulation.

Simulations and Comparison of Results. The data used to designate initial conditions of the model came from several sources. Since time zero for the simulation was specified to be the point of initial contact of the dummy with the floor, the positional measurements from that film frame established the "position" of the simulated dummy in the model. Dummy anthropometric dimensions and the material properties of the dummy were either taken from or developed from data in several references, especially McElhaney (1973), Melvin, et al (1972), and Naab and Massing (1974). The result was a data set for the MVMA 2-D Model which was thought to be an accurate representation of the HSRI "Repeatable Pete" dummy.

Using the baseline input data, the model was exercised to simulate the five-foot prone fall, Test 01, and the output was compared with test data. Minor discrepancies relating to material properties and to dummy-floor coefficients of friction were noted and appropriate changes were made to the data set. A model run with an artificially stiff neck also demonstrated that head deceleration was not materially affected by neck stiffness.

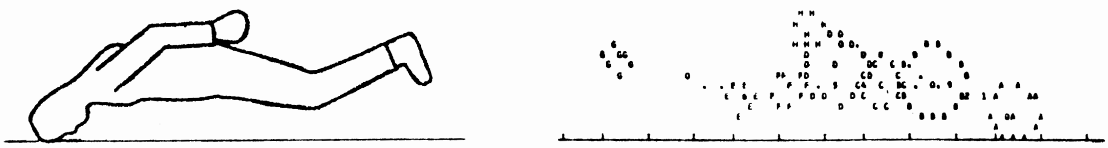
After several runs for which undeterminable dummy parameters were progressively adjusted, the model prediction essentially matched the drop test results for the five-foot drop. In Figure 3, the kinematic response of the dummy for that test is compared to the response predicted by the model. The dummy head struck first, followed by almost simultaneous contacts by the chest, knee, thigh and foot. The model, as shown by the printer-plot stick figure, predicted the same sequence. The model also predicted essentially the same rebound characteristics. There were slight differences in the timing of body contacts, with the model predicting torso and knee contact slightly before the contacts were actually made. The eight-foot prone-position drop (Test 02) was then simulated using the same data set. The model predictions were again very close to the test results, and no further data set modifications were made for the prone drop conditions.

Simulation of the feet-first, crouched-position drop was expected to be more difficult than that of the prone position drops. For the prone drops, the head made a direct impact to the rigid surface with no intervening articulations. The crouched-position simulation was complicated by the fact that the sensor in the dummy that was closest to the point of contact was the axial load sensor in the femur, near the pelvis. This sensor is included in the model, but accurate prediction of test results at that position depends upon accurate modeling of joints at the dummy's ankles and knees and correct simulation of dummy kinematics. The problem was further complicated because the model has a fixed joint at the ankle and so dummy ankle-joint characteristics had to be modeled through appropriate specification of foot material properties.

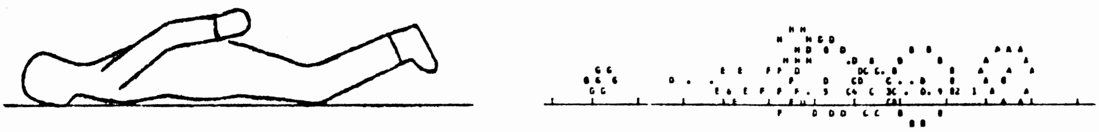
Despite the complications, only a few runs were needed

Frame from High-Speed Movie

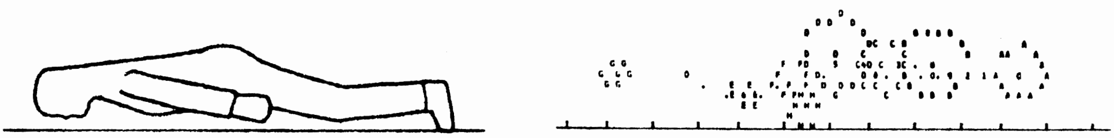
Corresponding Printer-Plot Stick Figure



t=0 (initial contact)



t=30 ms (just before dummy rebound)



t=100 ms (rebound)

Figure 3 Comparison of Prone Dummy Fall and Model Prediction. Five-foot drop onto concrete.

to obtain model predictions that were close to observed dummy responses. Figure 4 shows a comparison of dummy kinematics and model predictions for Test 04. Again, the agreement is remarkably close. The model predicted knee contact only 10 msec before it actually occurred and predicted head contact at the same time as the dummy head contacted the floor. There were only slight differences in kinematic predictions throughout the knee contact and pitchover phases.

In Table 2, predicted values obtained in the simulations are compared to corresponding dummy test results. For the two prone drops, the peak acceleration predictions are extremely close to the experimental values, varying by no more than three percent. A greater variation was found in predicting peak value times. These may be attributable to differences in joint characteristics. For the prone drops, the important prediction was for peak acceleration of the head, and an excellent match was obtained. The excellent match of pelvis accelerations is thought to be fortuitous since the dummy pelvis is of a very complicated shape and virtually unknown material properties and is several articulations removed from the initial points of contact.

In Table 2, Part C, measured and predicted values are compared for the five-foot drop in crouched position. The most important predictions in this case are femur and pelvis responses since they are closest to initial point of contact. The dummy landed in a slightly unbalanced position, loading one leg to 10,201 lb (45370 N) and the other to 6868 lb (30530 N) an average of 8532 lb (37950 N). Since the model has only one leg, it can predict only the average of two legs for a two-legged impact - in this case 7503 lb (33370 N), or 14% low. The prediction of pelvic accelerations is again very close (12% high), especially

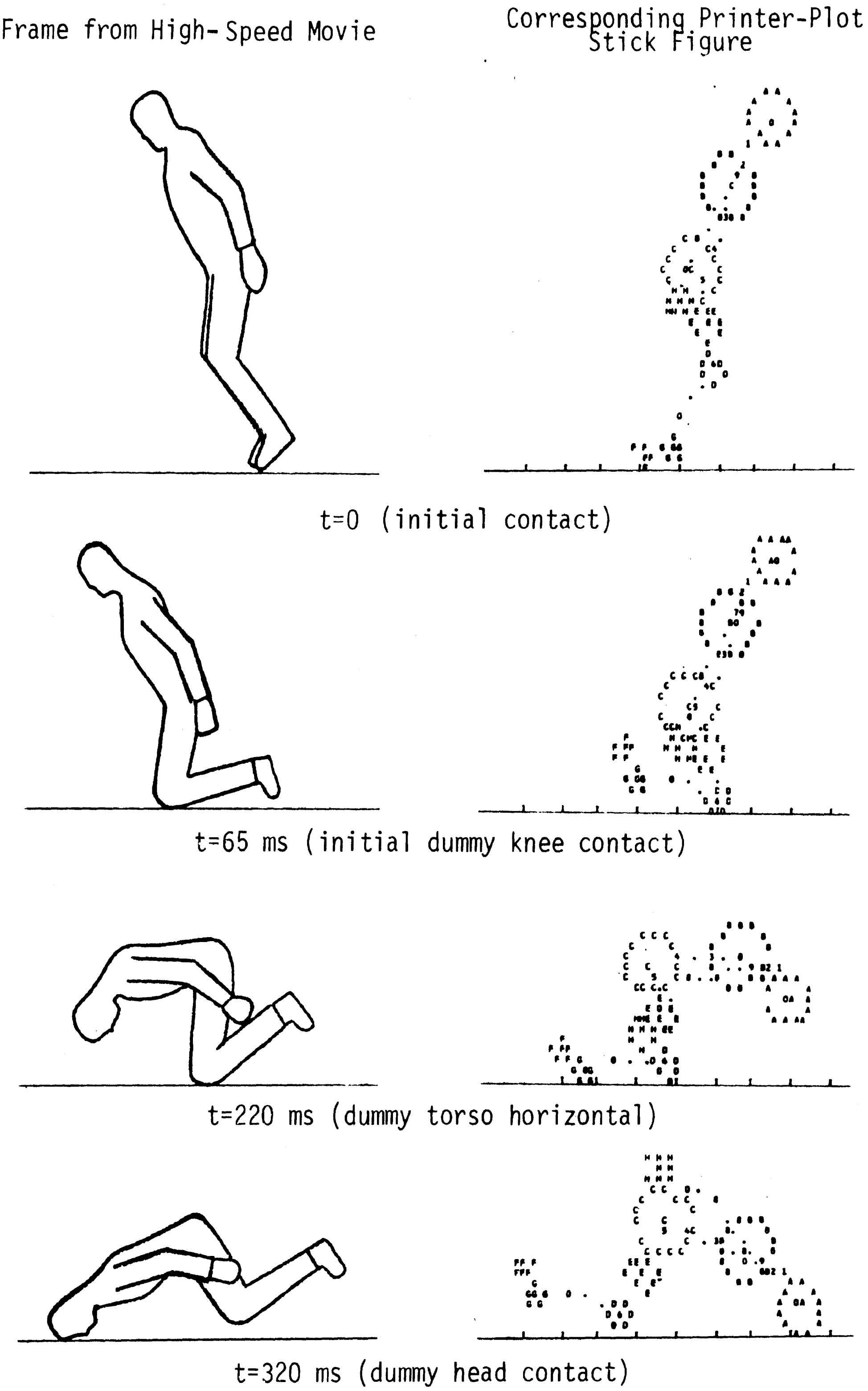


Figure 4 Comparison of Feet-First Dummy Fall and Model Prediction. Five-foot drop onto concrete.

TABLE 2

Comparison of Dummy Responses and Model Predictions

	Peak Resultant Acceleration		Time from Initial Contact to Peak Accel.	
	Measured in Test	Predicted by Model	Measured in Test	Predicted by Model
A. Test 01, Dummy prone, five-foot drop.				
Head	563 G's	>499G's*	2.1 ms	1.5*
Thorax**	18	81	60.0	29
Pelvis	104	106	41.9	31
B. Test 02, Dummy prone, eight-foot drop.				
Head	709 G's	733 G's	1.9 ms	1.75 ms
Thorax**	135	98	34.4	31
Pelvis	177	174	35.6	30.5
C. Test 04, Dummy crouched, five-foot drop.				
Head	170 G's	114	320.4 ms	322
Thorax**	70	114	47.0	60
Pelvis	193	216	46.4	61

Peak femur load: measured 8532 lb (37950 N) at 45.2 ms (avg of two legs); predicted 7503 (33370 N) at 61 ms

* A 0.5 ms time step was used. At 1.5 ms, there was still a substantial positive rate-of-onset of acceleration. Extrapolation based on rate-of-onset gives a calculated peak acceleration of 564 G's (range 547-582 G's), and a time to peak acceleration of approximately 1.75 ms.

** Thorax accelerations and times are suspect. See text.

considering the complicated nature of the dummy pelvis. The time differences for femur and pelvis loads are likely due to the lack of a movable joint at the ankle. The head acceleration prediction is 32% lower than the measured value. This inaccuracy was neither unexpected nor disappointing, since the head was farthest removed from the point of contact. Peak head acceleration was recorded as the dummy pitched forward and struck its head on the floor. The model predicted the timing of this event very accurately.

The objective of the dummy drops and simulations was to demonstrate that the MVMA 2-D model could adequately simulate the head-first and feet-first free-fall impact modes. The model was found to closely predict dummy peak accelerations for the responses of interest and to adequately predict response time histories. Dummy and simulation kinematics were in good agreement, and small differences in kinematics did not affect the accuracy with which primary response parameters were predicted. The investigators concluded that the dummy falls had been successfully simulated and therefore it was expected that the model would be useful for predicting free-fall impact dynamics of humans.

3. Simulations of Free-Falls of Humans. The objective of selecting certain investigated cases for simulation was to provide a representative group of falls that might be usable in developing impact tolerance data. The cases were chosen so that comparisons between falls could be made for age, body mass, and fall distance. Three body positions at impact were chosen: head-first, feet-first, and side-first attitudes. A majority of simulated cases were of head-first falls, since development of head impact tolerance data was considered most important. The details of the cases chosen for simulation were known completely enough that the body position at impact would be specified with some confidence. Twelve human falls were simulated.

Development of Physical and Material Properties. The level of sophistication of the MVMA 2-D Model provides the potential for detailed and accurate prediction of human impact response. However, it also requires detailed and extensive input data specifying size dimensions, inertial properties, and material properties for the various body parts.

A detailed description of the model as it was implemented in the human free-fall simulation has been compiled by B. M. Bowman and is included as Appendix B. That Appendix includes discussions of the body linkage system and the development of the body dimensions, inertial properties, and material properties used in the human simulations.

Each input data set contained specifications to define the falling subject at the instant of contact with the surface. A major problem was the specification of detailed properties for child subjects who ranged in age from 13 months through 13 years. Only height and weight were known for each subject, so body linkage lengths and contact ellipse dimensions were developed from published data such as Snyder, et al, 1975b. Masses and moments of inertia for children were adapted from masterform data for 3- and 6-year old child dummies published by Reynolds, et al (1976). For the teenaged subjects, masses and moments of inertia were scaled from the MVMA model baseline data set for 50th percentile males (1976).

Material properties, which are prescribed for each contact ellipse, must be specified as load-deflection characteristics in order to satisfy model input requirements. However, such data for various body parts are only partially known for adults and virtually unknown for children. Therefore, material properties were first developed for adults based on available data, then scaled to children by applying growth and aging factors and standard scaling techniques. A complete discussion of this development process is contained in Appendix B.

The dimensional, inertial, and material properties defined for the simulations were considered reasonable. The force-deflection curves developed for adult skull and chest were felt to be the most representative of the actual human condition, since there were good data from which the curves could be developed. The scaling factors used to adjust adult data to input values for children of various ages were developed based on growth curves, since no direct data for children were found to exist. The model was found to have low sensitivity to inaccuracies in these scaling factors, as will be shown in the results. The complex knee-femur-pelvis system is represented in the analytical model in a simplified manner. Although a careful evaluation of available data provided an apparently good means for simulating knee impacts with the model, the true condition may still not have been represented accurately. The force-deflection properties specified for the hip were probably not very representative of humans. They were established arbitrarily, based on the successful simulation of dummy drops. However, hip responses were primary in only two of the simulations, so potential inaccuracies did not substantially affect the overall value of the simulations.

Selection of Simulation Data for Analysis. The output from each computer simulation run contained a prodigious amount of information. Results were printed at incremented values of time for such parameters as body joint responses; body link angular accelerations and velocities; and loads, deformations, velocities, and accelerations of all major body parts. Severity indices (Head Injury Criterion and Gadd Severity Index) were calculated, and a printer-plot "stick figure", similar to those in Figures 3 and 4, was produced for each of several specified time points. More than 100 pages of output were produced per run.

For the human free-fall simulations, 40 individual data items were drawn from each of 47 runs and used for the comparisons and contrasts discussed in this report. Twelve data items were related to head response. Head contact points at initial contact and at maximum head loading were noted. The head response characteristics of peak deflection, peak normal force, peak resultant acceleration and three-millisecond average acceleration were all recorded, together with the time at which each peak occurred. Finally, the calculated Head Injury Criterion (HIC) (US DOT, 1969) and Gadd Severity Index (SI) (Gadd, 1966) were noted. It should be mentioned that only peak and 3-msec average values, as opposed to complete time histories, were used in the head response analysis. The most significant data were believed to come from the initial loading phase. Little-known characteristics of joint properties, rebound, and unloading-reloading interactions, particularly for children, made the analysis of a complete acceleration or deflection time history essentially meaningless.

The following data for chest impact were extracted: time of initial chest contact, peak deflection and time to peak deflection, peak force and peak resultant acceleration, and the time ranges over which force and acceleration were greater than 50% of their peak values. Hip data included the same items as for the chest, except that peak deflections were not recorded. The arbitrary force-deflection curve specified for the hip caused hip "deflections" much greater than seemed reasonable.

Force data were extracted to describe the response of the lower extremities. These data consisted of peak axial femur loads in the upper thigh and at the knee, peak shear force at the knee, peak knee contact force, peak axial force in the tibia at knee and foot, and peak normal force in the foot. In each case but one, the simulator output for the lower extremities was divided by two to give a single-leg value.

This chapter described the several methods used in the study for the collection of data pertinent to development of measures for human impact tolerance. It was hoped that use of data obtained from field investigations together with dynamic response data predicted by computer simulation of specific fall events would be an effective means of establishing tolerance data. The analysis of these data is the subject of Chapter 3.

CHAPTER 3

RESULTS AND DATA ANALYSIS

A. Introduction

More than 3,000 newspaper reports of falls were received during the 13 months of the study. The falls of 110 individuals were selected for detailed investigation, and twelve of those falls were simulated using the computer model. The clipping file data, the field investigations and the computer simulations were the three sources of data which provided the results presented in this report.

1. Chapter Organization. A great amount of data resulted from this research. Consequently, this chapter, which includes the results and analysis for all aspects of the study, is lengthy. The chapter is organized into five sections. The introduction, Section A, includes an outline of material in the chapter and a brief introduction to the investigated cases. The second section, Section B, is devoted to general results. The section includes sampling biases, information about the newspaper clippings, and both clipping and investigation results for frequency of fall occurrences (analyzed by sex, age, and type of hazard, without regard to injury).

Results and analysis relating to injuries are presented in Sections C and D of Chapter 3. Section C deals with "whole-body" injury data. It includes an analysis of fatalities reported in the clippings and injury results from the case investigations, analyzed to show the effects of several subject and fall environment parameters (age, impact surface, etc) on overall injuries resulting from a fall. Also included in this section is a discussion of potential general "predictors" of injury. This discussion explores the relationship between whole-body injury coding methods, impact orientation, and subject age and is based on analysis of case investigation data. Section D contains results specific to head impacts and to impacts of other body regions. Case investigation and simulation results are presented and analyzed to examine the correlation between fall parameters and observed injuries. This section also includes discussion of several potential "predictors" of head injury and discussion of human tolerance implications of the study results. Section E is general discussion.

2. Overview of Investigated Cases. Between August 1, 1975, and August 3, 1976, the locations of 128 falls were visited by the investigators. In eighteen instances, the falls were not investigated in depth because the site or subject was inaccessible or because the fall was clearly not a free fall. Detailed investigations were carried out for 110 falls in 24 states and three Canadian Provinces. A detailed summary of each of these 110 cases has been prepared and is included as Appendix A of this report. These summaries contain descriptions of the fall circumstances and impact surface; the subject's physical characteristics, injuries, and recovery; and other data such as sources of information and simulation results. Subjects and locations are not identified by name. Of the cases that were investigated in depth, 95 were true free-falls: that is, there was no intermediate contact between the place from which the subject fell and the surface on which the subject came to rest. Of the remaining 15 subjects who did strike an intermediate surface, three fell onto small bushes that did not seem to break the fall, three fell onto a porch roof before falling to the ground, two may have contacted railings, two landed on automobiles and one landed on another person. The remaining four were possible contacts with wires, stairs, an awning, and a ladder.

B. General Results

1. Sampling Biases. It is important to note that the data considered in this study do not represent a statistically

random sample of free-fall incidents in the United States and Canada. In addition, free-falls as defined here constitute a subset of all falls and, as a consequence, potentially hazardous falls that are not free-falls are not represented in the sample. Free-falls occur less often than other kinds of falls, and these less common incidents are highlighted in this study. The primary purpose of this study was to examine certain types of free-fall accidents in depth, not to identify all hazardous situations in which falls occur nor to get accurate statistics on injuries from all types of falls.

The free-fall statistics reported in this study, since they were obtained from newspaper clippings, may have been affected by the following sample biases:

1. Free-falls from low heights which result in little or no injury are less likely to be reported in newspapers. Even falls from moderate but not spectacular heights that did not result in injury may not be reported.

2. Some free-falls may have been reported in the newspapers but not spotted by the clipping service. Although the service estimated that 93% of reported items were clipped, it is likely that less severe falls would be missed more often because they may be reported in small, inconspicuous articles.

3. Data gathered from news reports and not verified by on-site investigation are biased in that inaccuracies in reporting are not accounted for. For example, it was occasionally discovered that what was described as a free-fall was really a broken fall or tumble down a slope. The most consistently inaccurate reporting was related to the height of fall. In the 48 cases where comparison was made between the fall height reported and that actually measured on-site, the newspaper accounts averaged 21% high and sometimes were as much as 100% high. Details about the surface impacted,

body orientation, and the injuries received were usually not mentioned or were inaccurate. The news clippings were most accurate in reporting names, ages, addresses, and fall locations.

With respect to the investigated cases, it was our objective to study human tolerance at or approaching the limits of survival. It should be noted that this approach differs from that used by some other investigators who define human tolerance as the minimum level at which injury may occur. Depending upon the tolerance definition chosen, several additional statistical biases could be introduced which can affect the use of human tolerance estimates resulting from this study.

1. Many free-falls that resulted in fatalities were not investigated. This may have resulted in over-representation of the stronger segments of the population. Thus, tolerance values calculated from the investigated falls could be biased towards the stronger members of the population.

2. Only five falls of individuals over sixty years old were investigated. The elderly comprised only 13% of free-falls and 9% of investigated falls, though they constitute a large majority (71% in 1975) of all falls. The elderly often are fatally injured in falls of all types, so the data collected did not include many of the most vulnerable individuals in the population.

3. Most of the on-site investigations were for falls onto rigid surfaces. Therefore, injury tolerance values from such data would reflect human response under the severest conditions.

2. Data Bases and Age Distributions. Newspaper clippings were obtained for the period mid-July 1975 through mid-August 1976. In those 13 months, a total of 3151 clippings were received, with most of them coming from the clipping service. Only 75 clips were not free-falls according to the criteria

that were provided to the clipping service. Another 82 were exact duplicates of clips already received from other papers owned by the same publisher. Thus, a total of 2994 unique clippings about free-falls were received in the study period. This total includes both the situation in which the same story was reported with different articles and in which the falls of more than one person were reported in a single article. Adjustment for these duplications gave a total of 2257 individual falls that were reported.

Since the months of July 1975 and August 1976 included only partial coverage, and since a one-year period was desirable for statistical purposes, falls that occurred in July 1975 and August 1976 were not included in the clipping data analysis. An additional 123 falls were thus eliminated, and only the 2134 falls that were reported as having occurred from August 1, 1975 through July 31,1976,were included in the analysis.

Figure 5, which shows the data classified by the month in which the fall occurred, illustrates that fewer falls were reported during the colder months of the year. November, December and January had the fewest falls, while June, July and August had the most. Presumably, the opportunities for falls are reduced by cold weather conditions which restrict recreation and outdoor activities and cause windows to be kept closed.

Figure 5 also contains a breakdown of falls by the sex of the individual. Six times as many males as females were involved in reported free-falls (1830 vs 304) in the one-year period. Males constitute nearly 86% of all reported falls, and this proportion remained relatively constant throughout the year (range: 82.1-90.3%). There is no indication that seasonally-related activities performed primarily by males (such as building construction) affect the male-female ratio of falls.

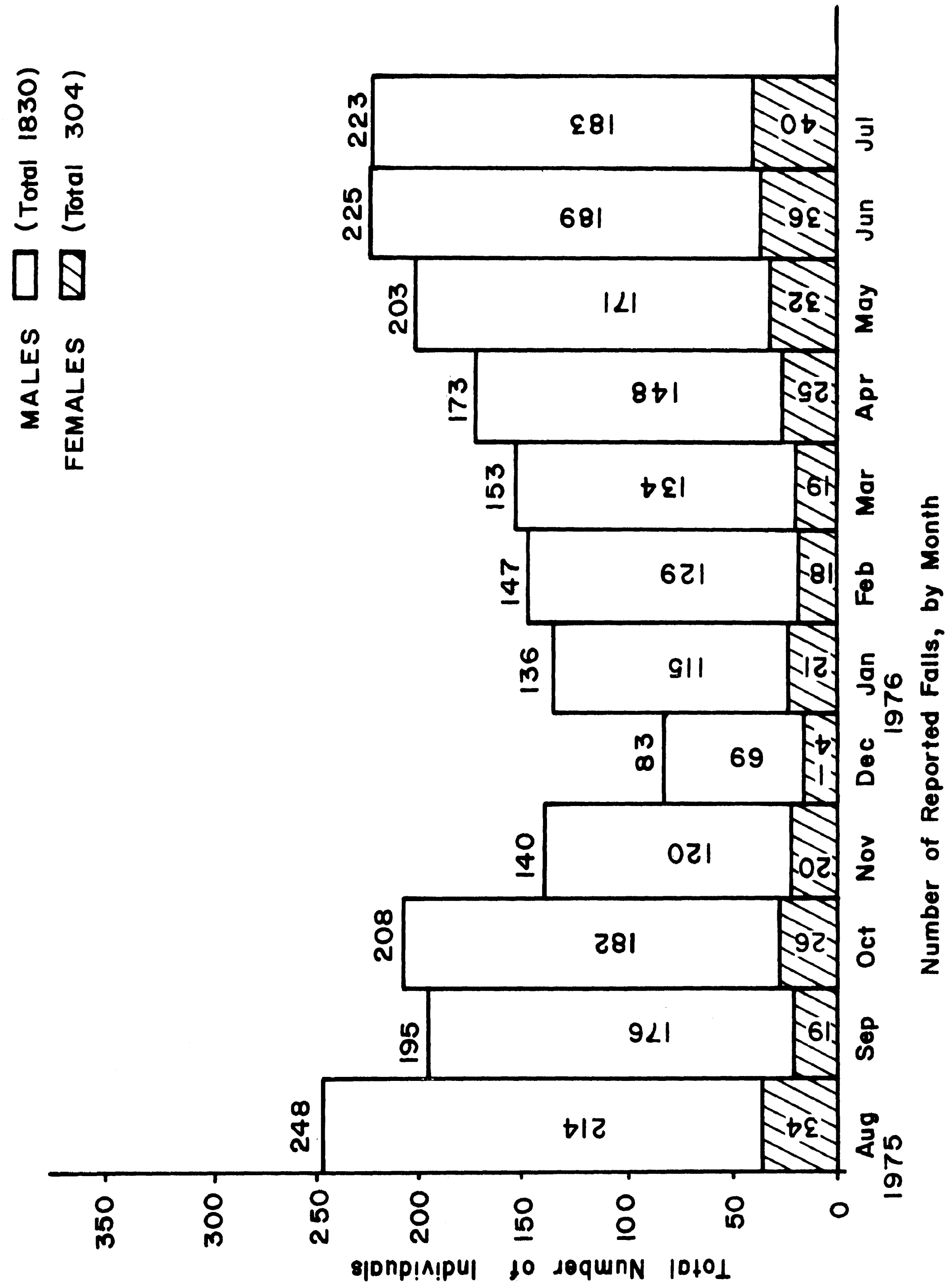


Figure 5. Distribution by Month of 2134 Individual Falls in the Period 1 Aug 75 through 31 Jul 76

Newspapers reported the age of the fall victim 88% of the time, so it was possible to analyze the data to determine the effects of age on the frequency of falls. The results were grouped into three age categories for children and teenagers (0-6, 7-12, and 13-19 years.) Individuals older than 19 years were classified by ten-year intervals, except that all persons 70 years and older were classified together. For falls involving persons of unreported age, the clippings were reviewed to determine a general level of maturity (child, teenager, or adult). Using this technique, four persons were classified as children under 12, seven as teenagers, and 236 as adults. Only 8 persons could not be so classified. Figure 6 summarizes the results of analysis by age. In every age category, more males are represented than females. During the "working years," from ages 20 through 69, in every age category males experienced 90% of the falls. The largest percentage of reported falls (39%) occurred among youths and young adults (13-29 years). The fall descriptions in the clippings indicate that these are the ages at which both males and females undertake the most hazardous recreational and occupational activities. This age group constitutes the segment of the population that is most at risk of being involved in a free-fall.

It is interesting to note the difference in data base between a study of free-fall accidents and falls of all types. Data concerning all falls, including free-falls, impeded falls, and falls onto the same level, were provided in the National Safety Council publication Accident Facts (1977). Several categories of data were chosen for comparison of national data for all falls and newspaper reports of free-falls. These are presented in Table 3.

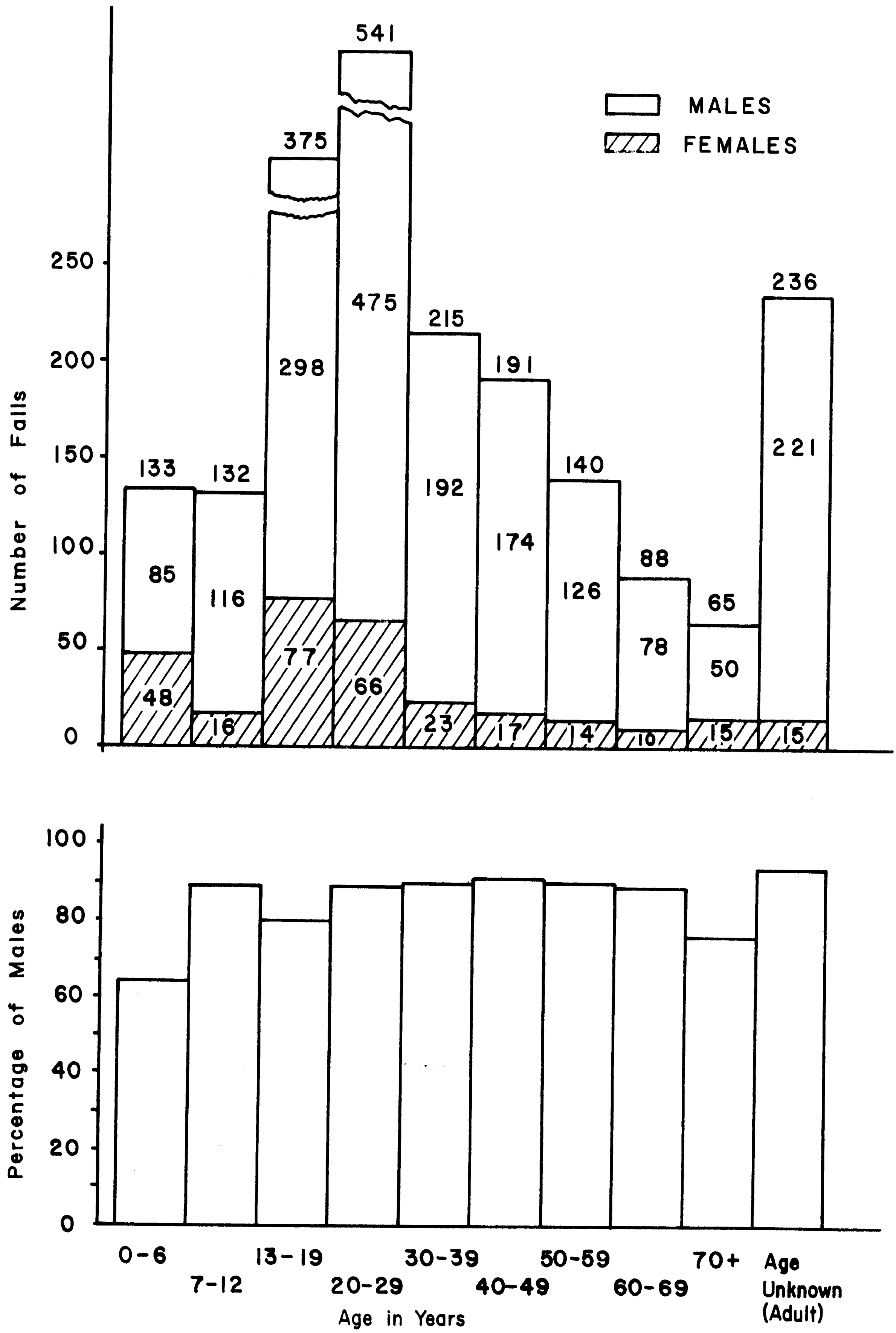


Figure 6. Distribution of Reported Falls by Age and Sex

TABLE 3

Comparison of U.S. Data for All Falls and Newspaper Data for Free-Falls

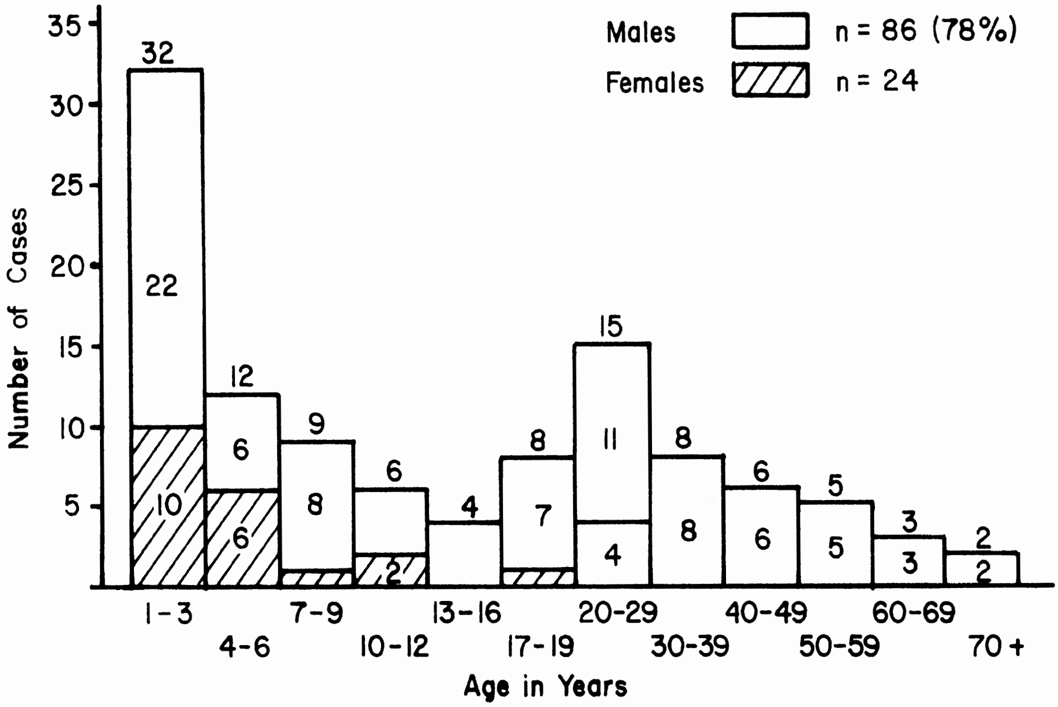
	Fatalities due to all falls. United States January 1 - December 31, 1976*		Newspaper reports of free-falls. August 1, 1975 - July 31, 1976
1.	Total number of deaths = 14,896	1.	Total number of deaths = 825
2.	Relatively little monthy variation in fatalities	2.	Significant seasonal variation in reported falls - more in warmer months.
3.	71% of the fatalities were of people over 65 years old and 2% under 15 years old	3.	13% of the fatalities were of people over 60 old and 8% under 13 years old
4.	At least 750 deaths of people who fell on same level.	4.	Falls on same level not reported.
5.	Age group, years — Fatalities	5.	Age group, years — Fatalities
	0 - 14 — 300		0 - 12 — 65
	15 - 24 — 500		13 - 29 — 354
	25 - 44 — 900		30 - 49 — 188

*National Safety Council, 1977.

Sex and age distribution data are shown in Figure 7 for the 110 investigated cases. The falls of 86 males and 24 females were studied; this is also the approximate ratio of males to females seen in the newspaper clippings. It was intended to include more females, but too few falls by females were reported which satisfied the criteria for investigation. The objective of concentrating investigation activities on falls by children and the elderly was accomplished: 65% of the subjects were persons under 19 years old and 9% were over 50 years old. Forty percent of all subjects were children under age six, and females were a large percentage of this group. Most of the falls of adult males aged 20-49 were included because of close similarities between their falls and the falls of children.

3. Analysis by General Characteristics of Falls

a. Newspaper Clippings. The distribution of free-falls by type of fall is shown in Table 4 for the 2134 falls reported from August 1975 through July 1976. The data are further subdivided by sex and are shown for three age groups (children, teenagers and adults). All adults are included in one age group because the exact age of 236 of these individuals was not reported. Regardless of age, more males than females were involved in every type of fall. In construction and occupational falls, there were virtually no female victims, probably reflecting the fact that women are not often employed in hazardous occupations. Children tend to fall from structures in buildings and from the outside surfaces of buildings and other structures, and they seldom fall from cliffs or other natural hazards. Only four children fell after gaining access to construction sites. Some teenagers do suffer occupational falls, though it was not possible to determine if their involvement is proportional to that of adults. Teenagers are more often involved in falls related to hazardous recreational activities--many fall while hiking and mountain climbing. Adults comprised



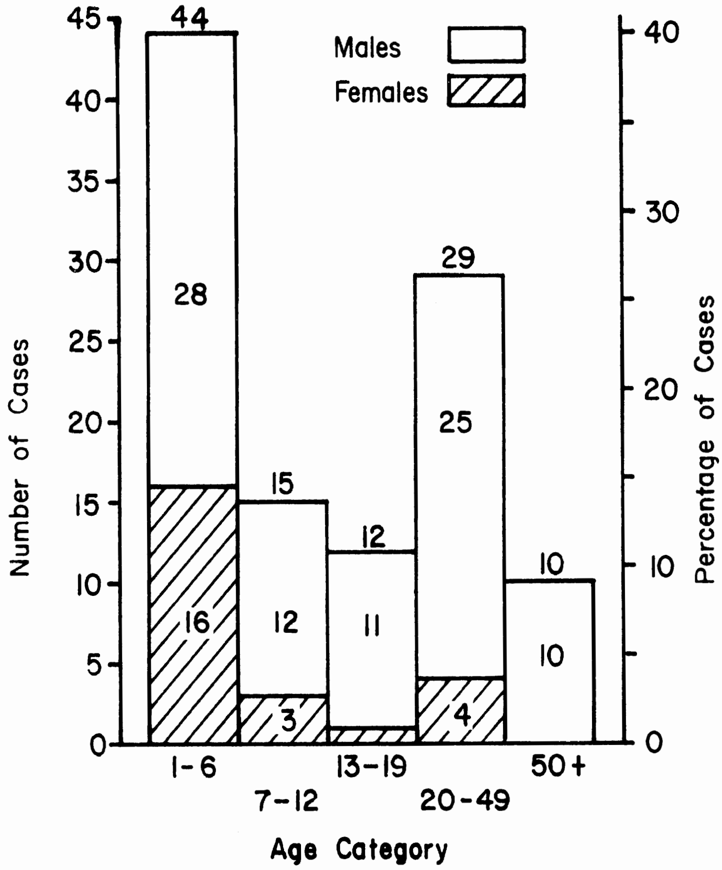


Figure 7. Distribution of Investigated Cases by Age and Sex.

Table 4

Distribution of Reported Falls by Type of Fall

	CATEGORY [1]	SEX [2]	AGE GROUPS 0-12	13-19	20+ [3]	Sub-total	% of Subtotal	% of Total [4]
01	Buildings under Construction	F	0	0	0	0	0%	
		M	4	9	209	222	100%	
		T	4	9	209	222		10.4%
02	Building Repair and Maintenance	F	0	0	10	10	2.2	
		M	0	18	429	447	97.8	
		T	0	18	439	457		21.4
03	Existing Buildings	F	50	16	75	141	31.3	
		M	86	34	190	310	68.7	
		T	136	50	265	451		21.1
04	Trees	F	2	4	1	7	11.5	
		M	10	15	29	54	88.5	
		T	12	19	30	61		2.9
05	Rock	F	2	34	33	69	15.0	
		M	35	162	195	392	85.0	
		T	37	196	228	461		21.6
06	Other Structures	F	2	8	22	32	15.5	
		M	47	45	83	175	84.5	
		T	49	53	105	207		9.7
07	Airplanes	F	0	2	11	13	27.7	
		M	0	1	33	34	72.3	
		T	0	3	44	47		2.2
08	Schools	F	2	3	0	5	20.0	
		M	11	6	3	20	80.0	
		T	13	9	3	25		1.2
09	Elevators	F	2	1	3	6	15.0	
		M	6	4	24	34	85.0	
		T	8	5	27	40		1.9
10	Miscellaneous	F	4	8	4	16	42.1	
		M	5	5	12	22	57.9	
		T	9	13	16	38		1.8
11	Other Occupational	F	0	0	0	0	0	
		M	0	3	109	112	100	
		T	0	3	109	112		5.2

Notes:

[1] For more complete category descriptions See Table 1.

[2] F=Female M=Male T=Total of both Sexes

[3] All adults are included in one age group because the exact age of 236 of these adults was not reported.

[4] Percent of total (2134) falls.

The falls of 5 females and 8 males could not be categorized.

the majority of falls in all categories except trees (04)* and schools (08), and a majority of adult falls are related to occupational accidents.

From the results shown in Table 4, several observations can be made regarding specific fall categories. A large number of falls at buildings under construction (01) were the result of workmen falling from loose scaffolds or open beams. Many scaffolds and ladders are involved in falls from buildings being maintained or repaired (02), and this category also includes many falls from roofs and eaves. The falls from existing buildings (03) are not occupational and include the most hazardous situations for young children. Eighty-six of the 136 children included in this category were age 4 or under, and a majority of their falls were from open windows or open-railing balconies. This category also includes suicide attempts by people who jump from buildings. There were 61 falls from trees (3% of all falls) and slightly over half were children at play.

The primary recreational fall hazards are related to rocky areas and ledges, and Category 05 included 22% of all falls. Few children fell from cliffs and trails, but many teenagers and young adults did. Mountain climbing falls and falls into abandoned quarries and mine shafts were frequently reported. However, fewer than 13% of the falls from rock involved persons over 30 years, reflecting the youth-oriented nature of these activities. Non-occupational falls from structures other than buildings comprised Category 06. These were falls from bridges, trestles, walls, etc., and all age groups were represented. Again, a number of the adult falls in this group were suicide attempts. Skydiving and hang-gliding accidents were reported for 47 individuals (2% of falls). Most of these resulted from partially opened parachutes

*In these paragraphs, the numbers in parentheses refer to the category number in Table 4.

or collapsed hang-gliders. All but four skydiving accidents occurred to people between the ages of 17 and 39.

The few falls which occurred in schools (Category 08) were generally falls in gymnasiums or through skylights or from diving boards. Schools were apparently safe places to work, as only 3 adults fell while performing school maintenance work. Ten elevator-shaft falls (Category 09) occurred when young people attempted to escape from elevators that were stuck between floors. This problem was more common in big-city, low-income housing projects. Several workmen fell when freight elevator safety gates malfunctioned and the men walked into open shafts in poorly lit areas. Category 11 included miscellaneous occupation-related falls such as those of telephone linemen or lift truck and crane operators. Unspecified falls "on the job" were also included here.

A summary of the hazard data from Table 4 is presented in Table 5, in which various fall categories are grouped according to their general nature. Free-falls that occurred to persons engaged in their normal occupations are included in Categories 01, 02, and 11. They constitute the largest group, 757 reported falls or 36% of the total. The predominance of males in hazardous occupations is noted: 99% of those who fell at work were males. The categories which include recreational activities (04, 05, and 07) contain 569 falls, 27% of the total. Non-occupational falls from buildings and other structures (Categories 03 and 06) constitute another large group: 658 reported falls, 31% of the total. This last group is further subdivided by age to illustrate that males constitute about three-quarters of these falls regardless of age. The above results show that there is a need to provide better fall protection for young people in and around buildings and for workers at their jobs.

Table 5

Distribution of Falls by Type of Hazard

Type of Hazard	Female	Male	Total	% Males	Hazard Total as % of Total Falls
	Number of Falls				
1) Primarily Occupational (Categories 01, 02, 11)					
Ages 20+	10	747	757	98.7	35.5
2) Primarily Recreational (Categories 04, 05, 07)					
All age groups	89	480	569	84.4	26.7
3) Primarily Existing-Structure Hazards (Non-occupational) (Cat. 03, 06)					
Ages 0-12	52	133	185	71.9	8.7
13-19	24	78	102	76.5	4.8
20+	97	271	368	73.6	17.2
All age groups	173	485	658	73.7	30.8

b. Investigated Cases. General results of the investigated cases are summarized in Table 6 for several environmental characteristics of the falls. Data are presented for the types of falls, fall distance, and type of surface impacted.

The distribution of falls by type of fall for the investigated cases (Table 6, Part 1) is very different from that for the newspaper clippings. Most of the falls that were selected for in-depth study were those from existing structures, since many falls of children were of this type. Although few occupational falls were studied, they were the source of many of the adult cases. Few recreational falls were investigated, since they often involved locations far from the subject's home or had indefinable impact surfaces. The single sky-diving fall was a local occurrence. Although the parachutist was killed on impact, the case was of interest because the police contacted one of the investigators immediately and an on-scene investigation was possible.

As noted in Chapter 2, the selection process tended to screen out falls of less than 10 feet (3 m) and greater than 30 feet (9 m). Table 6, Part 2, shows that 75% of the on-site investigations were for falls of less than 30 feet, and 52% of the cases were for falls of from 10 to 20 feet (3-6 m). Nine falls of greater than 50 feet (15 m) involved survival under unusual circumstances and were therefore of special interest.

Part 3 of Table 6 indicates that 76 of the investigated falls (69%) involved initial contact with a rigid surface. Only 18% of the investigations involved impacts on other than hard surfaces. For the purposes of the summary in Table 6, the following arbitrary definitions were adopted: "rigid" surfaces were unyielding ones such as concrete, asphalt,

Table 6

Distribution of Cases by Environmental Factors

1. Fall Categories (See Table 1 for Complete Definitions)

Category	No.of Cases	% of Cases	Category	No.of Cases	% of Cases
01 Buildings-Constr.	5	4.5%	06 Other Structures	8	7.3%
02 Buildings-Repair	19	17.3%	07 Airplanes	1	0.9
03 Buildings-Existing	68	61.8%	08 Schools	2	1.8
			09 Elevators	2	1.8
04 Trees	3	2.7	10 Misc.	0	0
05 Rock	1	0.9	11 Other Occup.	1	0.9

2. Fall Distance

Age Group (M + F)	Height of Fall (in feet) 1 ft. ≃ .3m							
	<10	10-14	15-19	20-24	25-29	30-49	50-79	80+
1-3 yrs		13	6	2	3	5	2	1
4-6	1	4	4	2		1		
7-12	2	5	6			2		
13-19		2	1	3	1	2	3	
20-49	1	7	3	5	3	5	1	4
50+	2	2	4			2		
Total	6	33	24	12	7	17	6	5
% of Cases	5.5%	30.0	21.8	10.9	6.4	15.5	5.5	4.5

3. Type of Surface Impacted

Surface*	Rigid	Hard	Moderate	Soft	Crushable
No. of Cases	76	14	9	8	3
% of Cases	69.1%	12.7	8.2	7.3	2.7

* See Text for definitions.

steel, roofs and thick ice; "hard" surfaces were hard-packed and frozen soil or wooden platforms; "moderate" surfaces were normal grass-covered lawns; "soft" surfaces were damp soils, bushes, and sand; and the "crushable" surfaces were automobile roofs and hoods.

C. Injury Results of a General Nature.

1. Injury Information from Clippings. Newspaper accounts of injuries resulting from falls were usually not specific. Approximately 15% of the fall reports lacked any injury information. Often the only indication of injury was that an individual was reported in "critical" or "satisfactory" condition. However, the two extremes of injury--no injuries and fatalities--did seem to be reported accurately. Only 43 of the falls (2%) resulted in reports of "no injury". At the other extreme, 830 falls (39% of all reported falls) had resulted in a fatality by the time the fall was reported in the newspaper. Males and females were found to have about the same frequency of fatal injuries.

Table 7 summarizes fatality statistics from the newspaper clippings for the various types of falls. The results show that occupational falls and recreational falls from rock each have about the same percentage of fatalities. Sky-diving falls were the most likely of any to cause death (75% fatalities), but this is not surprising given the fall distances involved in parachute failures. Falls at school caused the fewest fatalities, possibly because the typical fall involved a child falling a short distance.

Figure 8 shows the age distribution of fatalities and the percentage of fatalities by age group. Persons under twenty years suffered fatalities 27% of the time; those from 20 to 49 years, 46% of the time; and those over 50 years, 64.5% of the time. These results apparently reconfirm what has been noted by many other researchers in many different

Table 7

Summary of Fatalities

	Category	Number of Falls	Number of Fatalities	Percent Fatalities
01	Bldgs-Const.	222	71	32.0%
02	Bldgs-Repair	457	174	38.1
03	Bldgs-Existing	451	199	44.1
04	Trees	61	16	26.2
05	Rock	461	166	36.0
06	Other Struct.	207	86	41.5
07	Airplanes	47	35	74.5
08	Schools	25	3	12.0
09	Elevators	40	18	45.0
10	Misc.	38	13	34.2
11	Other Occup.	112	44	39.3
		2121	825	38.9%

Sexes are combined. 13 falls, including 5 fatalities, could not be classified as to Category.

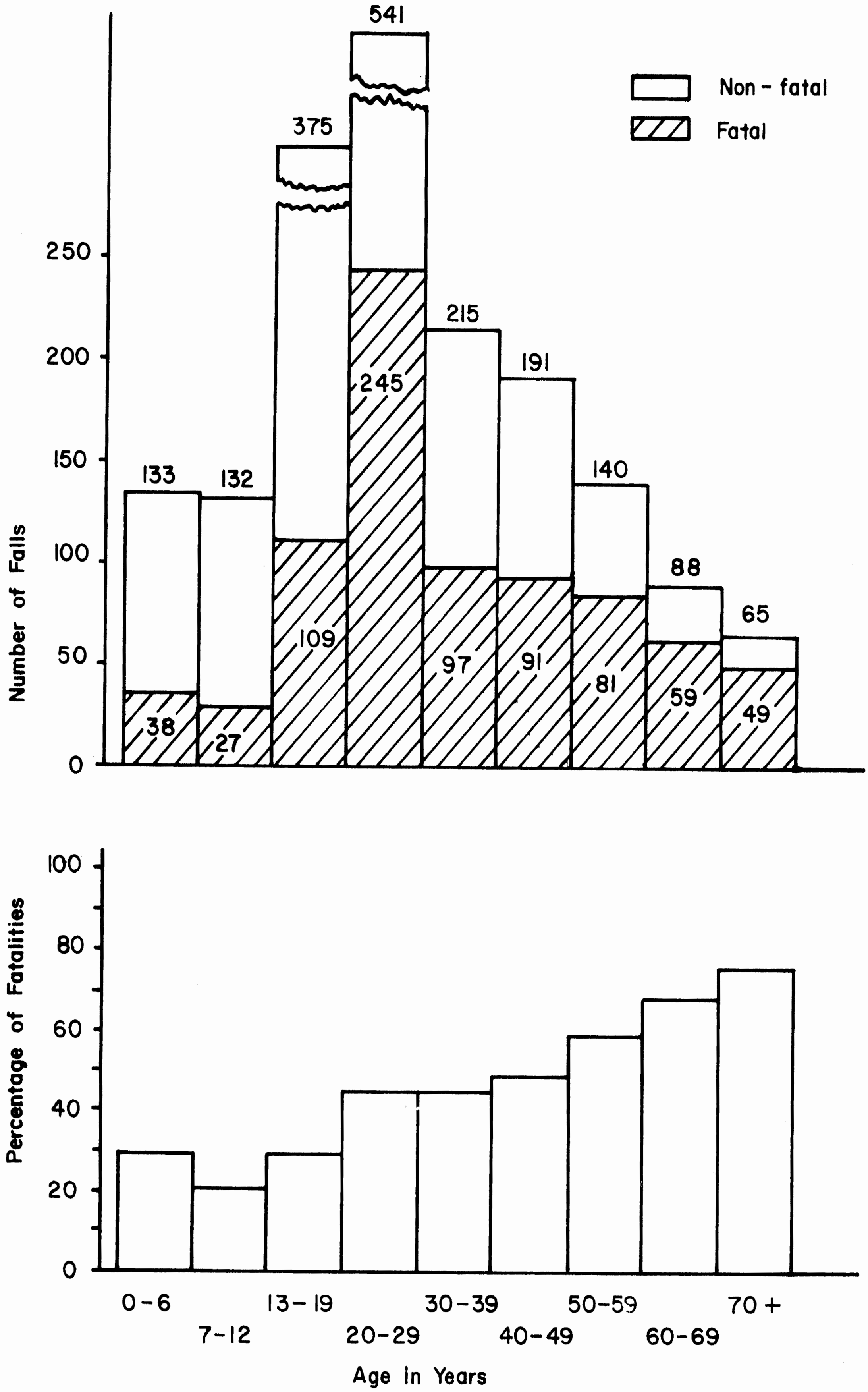


Figure 8. Fatalities Reported for Different Age Groups

studies--the older an individual, the more serious the consequences of injury.

2. General Injury Results from Investigated Cases. In most investigated cases, it was possible to estimate which part of the body made initial contact with the impact surface. These estimates were usually made by the investigator after obtaining subject recollections, witness statements, and detailed injury information. The data in Table 8, Part I, show the estimated principal point of contact of the fall victim. The largest percentage of investigations were for head-first falls. The data also show that children tended to land on their heads and adults tended to land on their feet or sides. These same data were examined for influence of fall distance on position at impact (Table 8, Part 2). Persons who fell less than 20 feet (6.1 m) landed on their heads 74% of the time, while persons who fell more than 20 feet landed on their feet 63% of the time. The investigation data show that children tended to land head-first regardless of fall distance, but especially in falls of less than 20 feet. Examination of fall circumstances shows that many of these children started falling from a standing position and rotated during the fall to land on their heads. The relatively larger head mass and head dimensions of children compared to adults probably contributed to the greater likelihood of children landing head-first. Adults, perhaps because of better coordination, tended to try and maintain a standing position while falling so that they landed on their feet, or at least on their sides while attempting to achieve a feet-first attitude.

The limited data available from newspaper clippings also tended to support the observations from the field investigations. The clipping data for falls from existing structures (Category 03) were reviewed, since there was a good distribution by age in that category. More head injuries were reported for children age 12 and under than for teenagers or adults.

Table 8

Distribution of Cases by Body Impact Point

1. Body Contact Point

Age Group (M + F)	Estimated Initial or Primary Body Contact					
	Head	Back	Side	Seat	Upr. Extr.	Lwr. Extr.
1-3	15	6	5	3		1
4-6	11					
7-12	7	1	3	1	2	1
13-19	1	3	1		1	5
20-49	3	5	6	1	1	9
50+	2		2			3
Total	39	15	17	5	4	19
% of Cases	39.4%	15.2	17.2	5.1	4.0	19.2

The primary contact could not be determined in 11 cases.

2. Body Contact as a Function of Fall Distance

Age Group	Initial Contact and Fall Distance					
	Head-first		Side-first		Feet-first	
	<20 ft*	20 ft	<20 ft*	20 ft	<20 ft*	20 ft
1-3	10	5	3	2	1	
4-6	9	2		1		
7-12	7		3			1
13-19		1		1	1	4
20-49	2	1	4	2	2	7
50+	1	1	2		3	
	29	10	12	6	7	12

*20 ft = 6.1 m

Head injuries were noted for 46% of the children, 36% of teenagers, and 21% of adults who fell. However, even though children sustain head injuries more often, those injuries prove fatal less often. The newspaper data indicated that, for children and teenagers, 16% of reported head injuries were fatal injuries; the comparable fatality rate for adults was 39%.

Major injuries sustained by subjects in the investigated cases are shown in Table 9. Medical information obtained from the cases showed that 48% of the persons who fell sustained significant head injuries - skull fracture and/or concussion. A majority of such head injuries occurred to children. However, teenagers and adults incurred serious head injuries far out of proportion to their percentage of head-first falls. In several cases, subjects received head injuries because of secondary impact of the head after initially landing on their feet or side.

The 27 injuries classified as internal injuries or spinal fractures are primarily pneumo/hemothorax or fractures of the lumbar vertebrae or ribs. Three adult subjects suffered fractures of the cervical spine (an 18 year old female who fell 73 feet, a 37 year old male who impacted feet first at terminal velocity and a 33 year old male who landed prone on a curb after falling 15 feet). No children in the investigated cases had any neck injuries other than minor pain, and the newspaper reports did not mention any neck fractures in children due to free-falls. Children apparently injure their heads but not their necks in this type of accident. Among the investigated cases, very few internal injuries other than lung and rib injuries were seen (one ruptured spleen, one kidney contusion, one complaint of severe abdominal pain).

Pelvic fractures accounted for only 10% of major injuries, and they occurred almost exclusively in adults. The

Table 9

Major Injuries from Investigated Cases

Age Group (M + F)	Skull fx, Concussion	Internal inj, Spinal fx.	Pelvis Fracture	Upr. Extr. Fracture	Lwr. Extr. Fracture
1-3	15	4		1	5
4-6	11	1		1	1
7-12	8	2	1	6	3
13-19	6	3	1	1	5
20-49	11	12	8	10	10
50+	2	5	1	2	5
Total	53	27	11	21	29
% of Cases	48.2%	24.5	10.0	19.1	26.4

2 Subjects, age 1-3, suffered no injuries; 13 subjects suffered fatal injuries. Many subjects suffered multiple major injuries.

single pelvic fracture to a child occurred when a 12½ year female fell nearly 34 feet and landed feet-first, fracturing both pubic rami. Most pelvic fractures were caused by the subject impacting the hip in a side-first fall.

Persons who suddenly find themselves falling will often extend their arms. This action is thought to be reflex (Carlsöö and Johansson, 1962) and it resulted in many fractures to the upper extremities. A majority of upper extremity fractures were to bones in one wrist or to the radius and ulna of one arm. These fractures were about evenly divided between children and adults, and most were the result of landing on the side or in a sitting-type position. A few bilateral lower arm or wrist fractures were seen as the subject attempted to break a head-first fall, and a few other falls produced fractures of the proximal humerus or clavicle.

A majority of lower extremity fractures occurred to adults and teenagers, since they tended to land on their feet and sides. Five of the six lower extremity fractures noted in children were broken femurs resulting from knee impacts while falling sideways. There were no femur fractures noted in teenagers--fractures of the tibia and fibula of one leg were most common. The 12 fractures to adult lower extremities were evenly divided among bilateral lower leg and ankle breaks, fractures of one lower leg or ankle, and femur fractures. Most of these injuries occurred as a result of landing on the feet or knees.

3. Prediction of Injury Severity. The velocity at which a falling body impacts a surface is determined by the height of the fall. It is of interest to know if impact velocity can be used to predict injury severity. The descriptor of injury severity that was initially selected was the Injury Severity Score, or ISS. The ISS, which was developed by Baker,

et al. (1974b), is a numerical score which is derived from an individual's three most severely injured body regions. The ISS is a good general descriptor of injury, and several studies have shown that the the Injury Severity Score is a good predictor of threat to life (Baker and O'Neill, 1976). The ISS was therefore calculated for all subjects in the investigated cases (See Appendix A).

Figure 9 shows ISS as a function of impact velocity for each subject in the investigated cases. No other factors such as age, impact surface, or body orientation were taken into account, so that the graph would illustrate the simplest possible method of predicting injury from fall height. There is no apparent correlation between impact velocity and the ISS score. Many high-velocity impacts resulted in low injury-severity scores, and many low-velocity impacts had high degrees of injury severity.

It was evident from the data in Figure 9 that a more detailed analysis would be necessary to isolate parameters that would correlate well with injury severity. Therefore, the data were examined again, with additional restrictions. In addition to ISS, the Overall Abbreviated Injury Scale (OAIS) was considered as a second indicator of injury severity. The OAIS is based on the Abbreviated Injury Scale (AIS) which is in use internationally as a method of quantifying injury severity in auto accidents (AAAM, 1976). OAIS values indicate injuries which increase in overall severity in increments from zero (no injury) through 6 (maximum injury, invariably resulting in death).

For this analysis, the data were divided into subsets using the descriptions of fall circumstances in Appendix A as a basis for classification. Only those 81 subjects who fell onto "rigid" or "hard" surfaces were included. "Rigid"

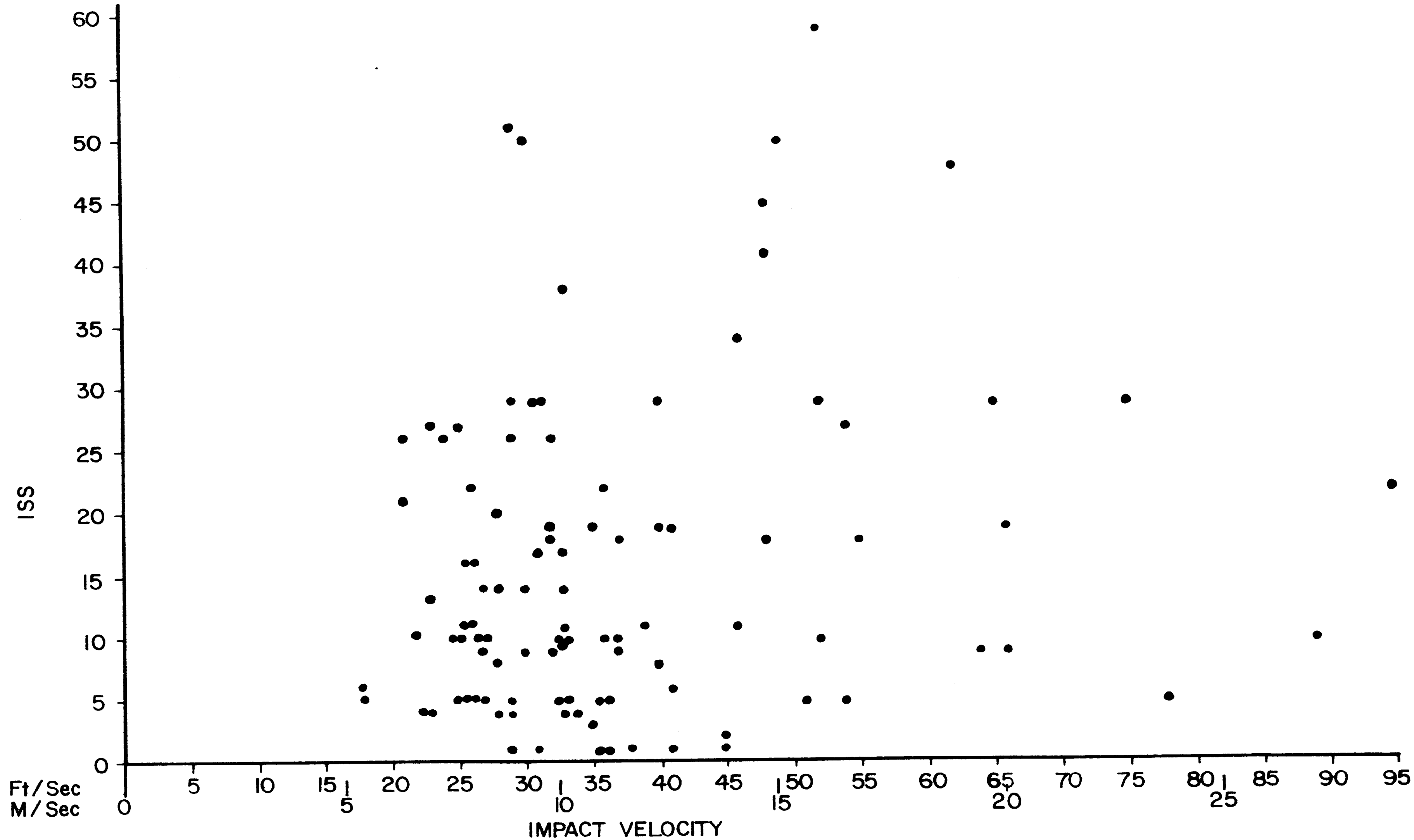


Figure 9. Relationship between Impact Velocity and Injury Severity.

surfaces were concrete, asphalt, roofs and ice, and "hard" surfaces were wooden platforms and hard-packed or frozen soil. A 2 x 2 matrix was used for this analysis--two age classifications and two body orientations. The subjects were classified into two age groups, nine years and younger or ten years and older. Age nine was chosen because of estimates that skull strength approaches adulthood strength after age nine(see Figure B-8). The two classes of body orientations at impact were head-first and other than head-first. The body position at impact and the body part in initial contact with the surface were used to classify orientations.

It was also desirable to examine the usefulness of several potential indicators that could be easily calculated or determined from field investigation data. Many dynamic response parameters are commonly considered as possible indicators of degree or likelihood of injury. These include maximum deflection, maximum strain, peak acceleration, absorbed energy, momentum change, and a variety of acceleration-related parameters. Of these, only whole-body absorbed energy and momentum change (in addition to velocity change) are easily estimated for free-fall cases investigated in the field. Both may be determined for falls onto a rigid surface provided only that total body mass is known in addition to the impact velocity. Body mass was known from the investigations, or, if not known, could be reasonably estimated from published anthropometric data. Therefore, it was decided to examine, for each element of the 2 x 2 matrix, possible correlations between three independent variables (impact) and two dependent variables (OAIS and ISS). The 24 graphs resulting from this analysis method are shown in Figures 10, 11, and 12, for impact velocity, momentum, and kinetic energy, respectively.

If the potential indicators selected were good indicators, one would expect to see a positive relationship between the independent and dependent variables--for example, an increase in impact velocity resulting in an increased indication of injury. There is no such indication in the majority of the plots.

For OAIS vs velocity (Figure 10a) there is a good correlation for head impacts age 10 and older and a weak correlation for impacts other than to the head, age 10 and older. In Figure 10b, for ISS vs velocity, a relationship is again seen for head impacts, age 10 and older. No other correlations are evident for impact velocity as an indicator of injury.

The factor of body mass appeared to be less significant than velocity. Figure 11 shows OAIS and ISS vs momentum change (momentum = mass x velocity). The only suggestion of a positive relationship between the variables is for head-first impacts, age 10 and older. No other correlations are seen.

A body striking a rigid surface must absorb virtually all of the energy dissipated while the body comes to rest. This whole-body absorbed energy is represented by kinetic energy (1/2 mass x vel^2) in Figure 12. Two of the OAIS vs energy plots (Figure 12a) were thought to show correlation--strong for impacts other than to the head, age 10 and older, and weak for head impacts, age 10 and older. Three ISS vs energy plots (Figure 12b) show correlation--strong for head-first impacts age 10 and older, weak for impacts other than head-first, age 10 and older, and weak for head-first impacts age nine and younger.

Although it was difficult to generalize about possible injury prediction from these easily-determined whole-body dynamic response characteristics, several observations can be made:

1) There were large amounts of scatter in all of the plots. This suggests that there are wide biological variations among individuals in their susceptibility to injury,

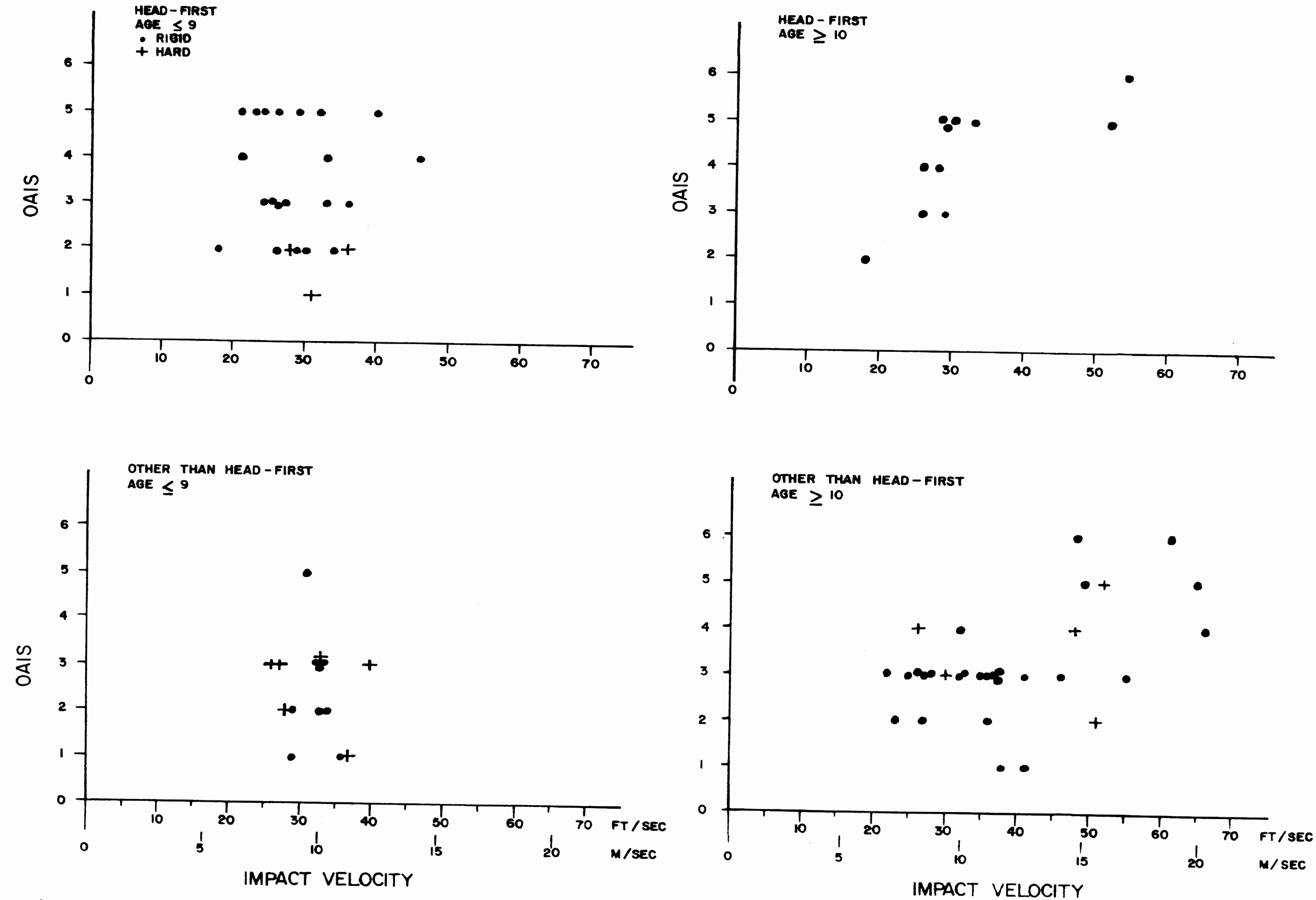


Figure 10a. Impact Velocity and Overall Abbreviated Injury Scale.
10. Relationship between Impact Velocity and Injury Codes.

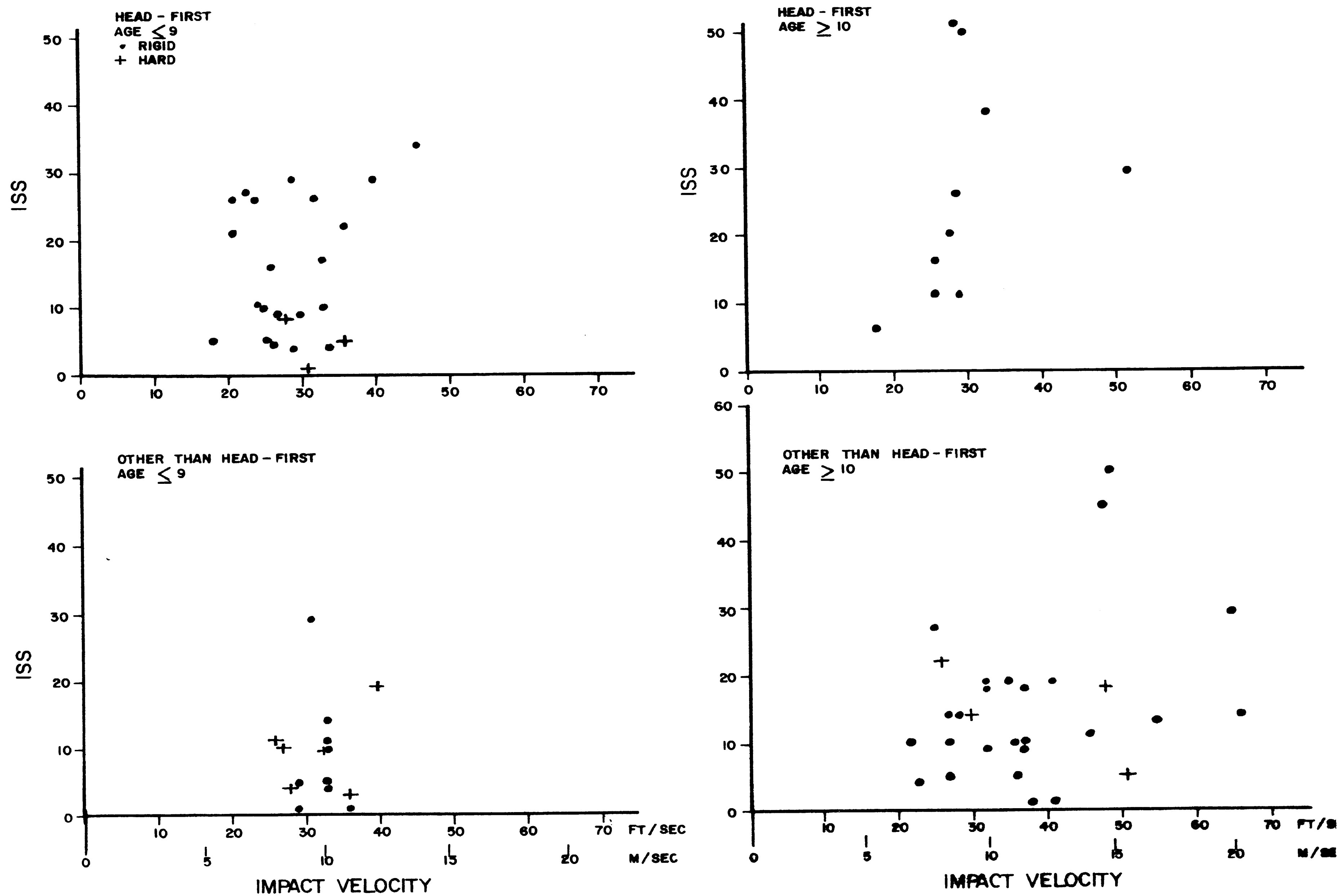


Figure 10b. Impact Velocity and Injury Severity Score.

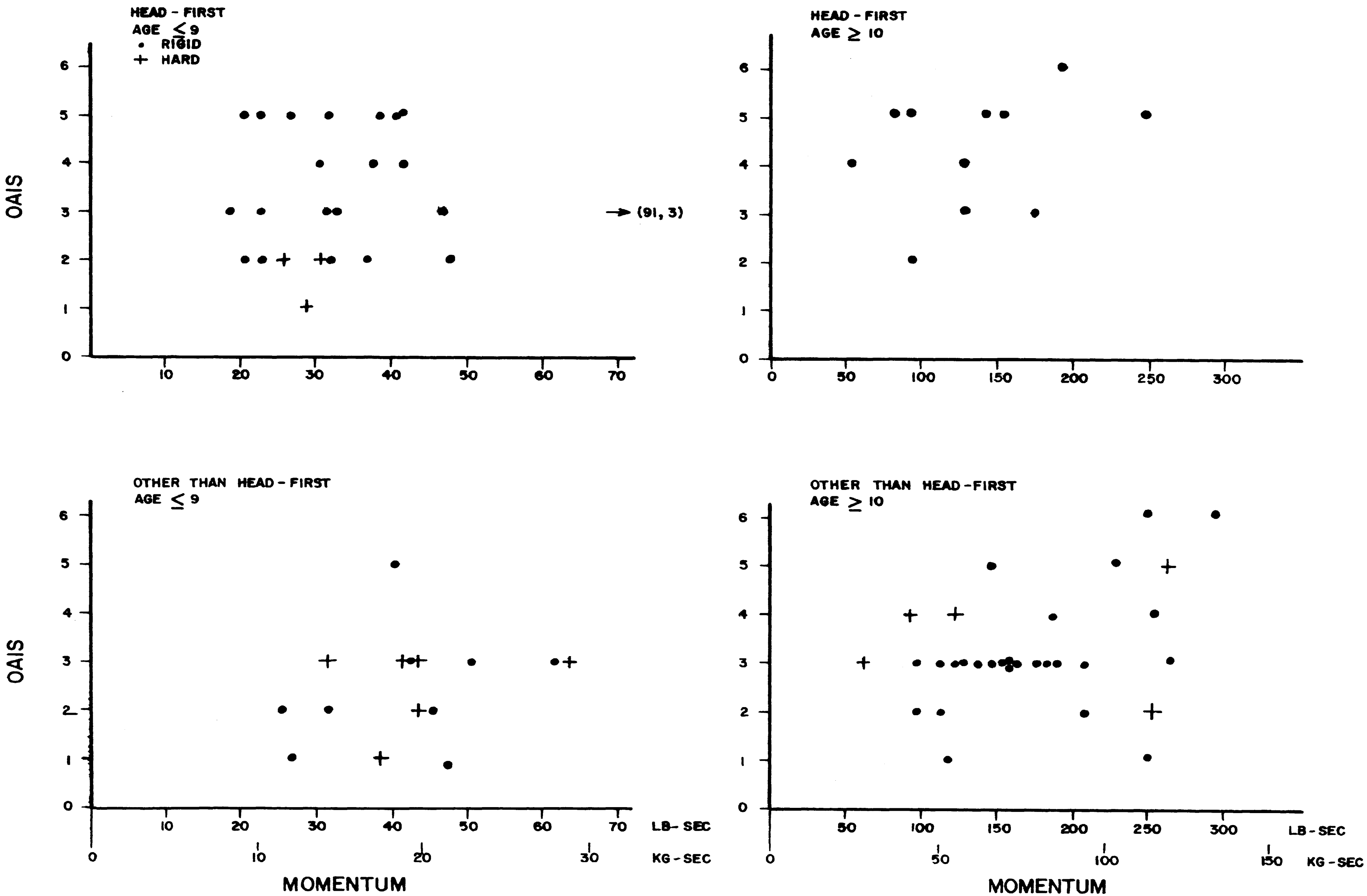


Figure 11a. Momentum Change and Overall Abbreviated Injury Scale.
11. Relationship between Momentum Change and Injury Codes.

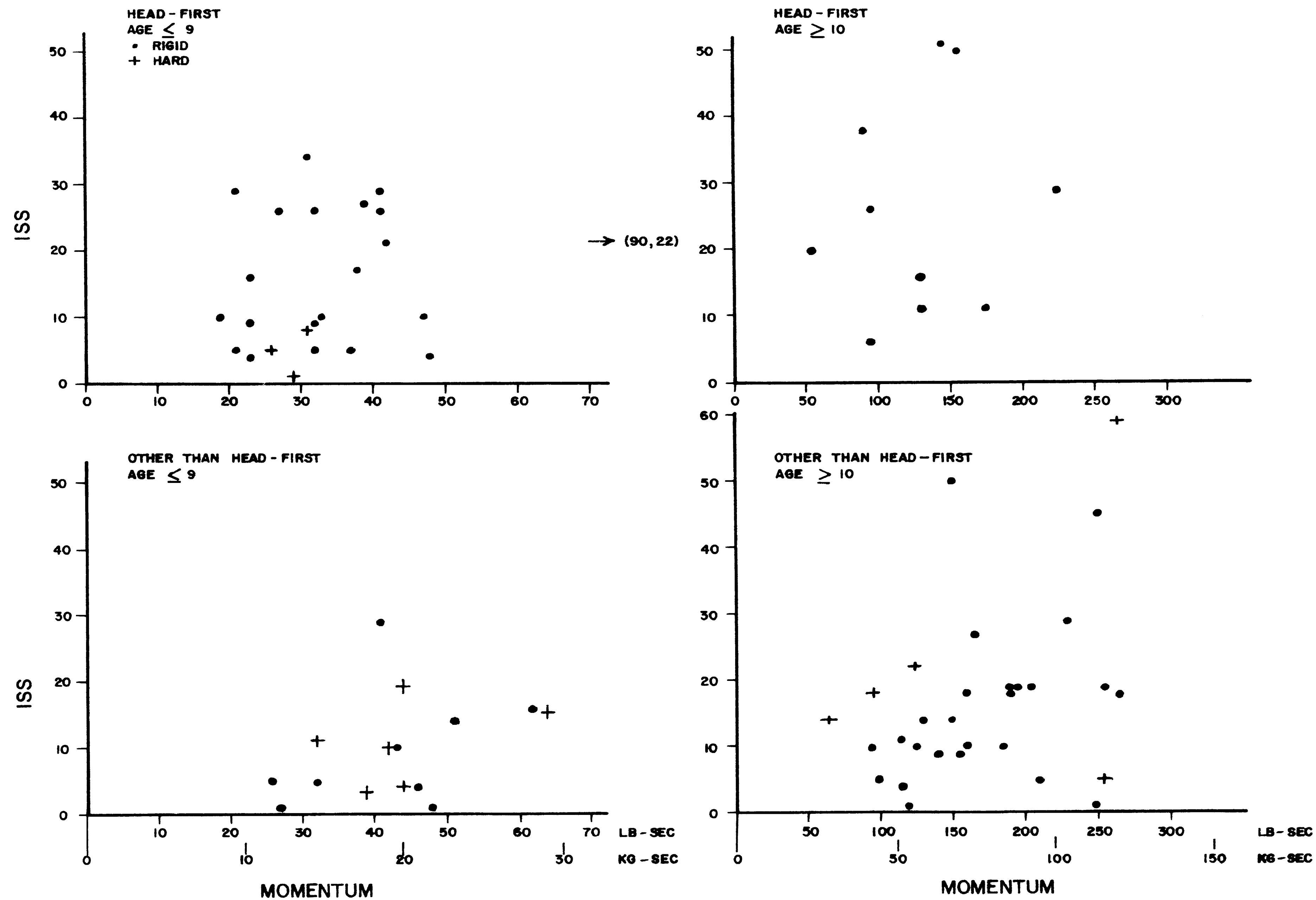


Figure 11b. Momentum Change and Injury Severity Score.

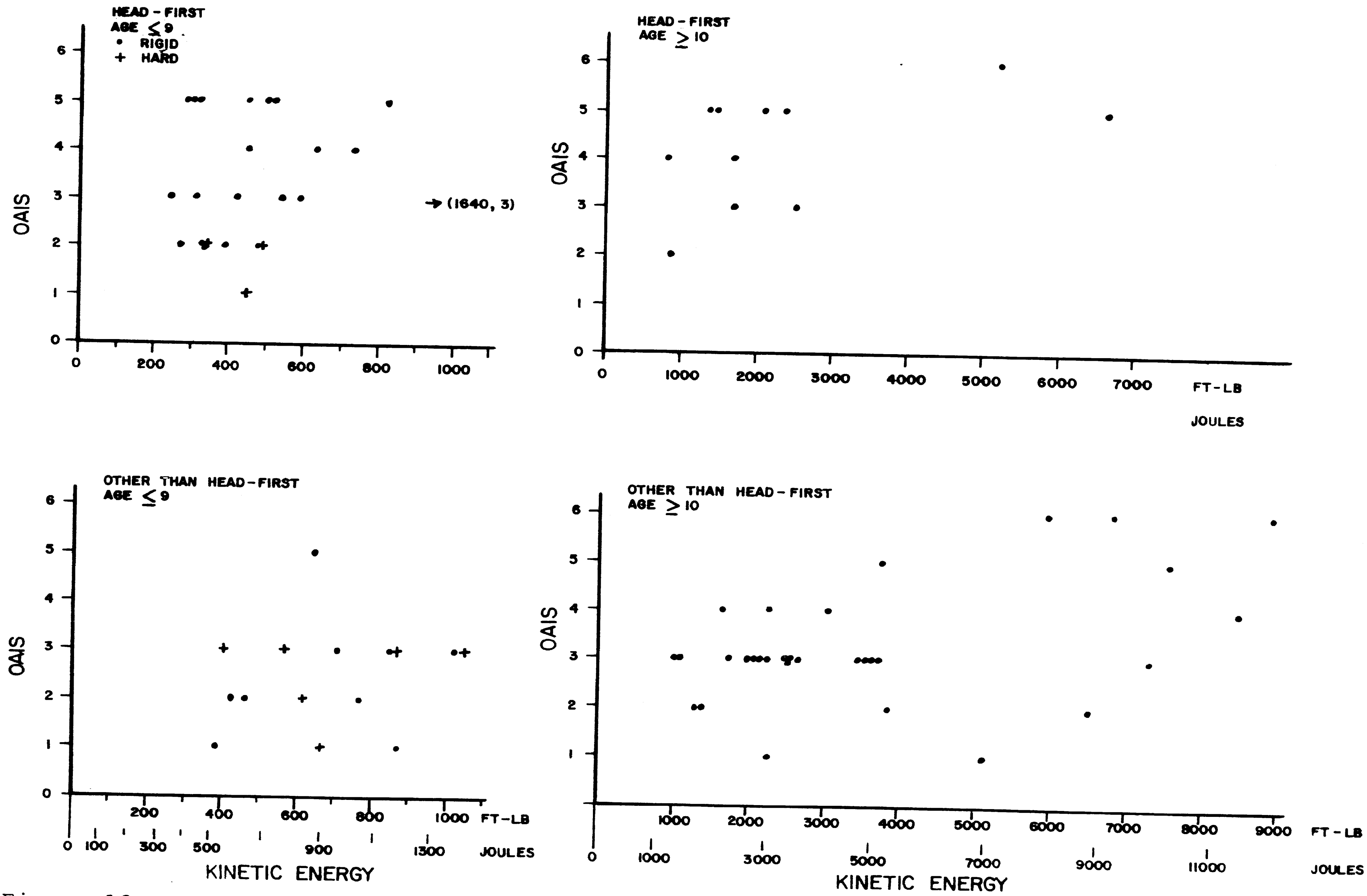


Figure 12a. Kinetic Energy and Overall Abbreviated Injury Scale.
12. Relationship between Kinetic Energy at Impact and Injury Codes. Kinetic energy is equivalent to whole-body absorbed energy for impacts to rigid surfaces.

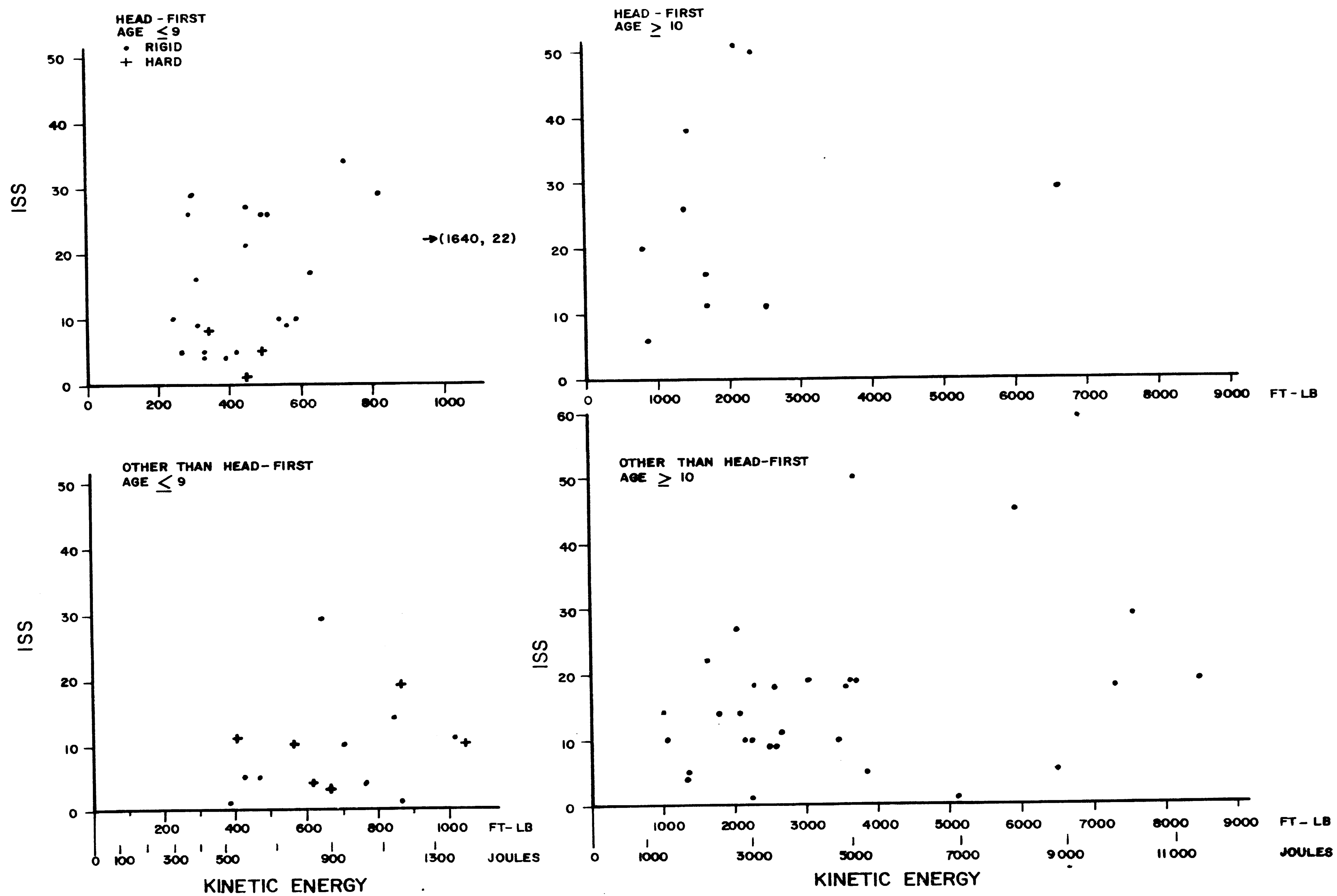


Figure 12b. Kinetic Energy and Injury Severity Score.

and consequently, in similar falls, the injuries sustained may be very different.

2) Impacts with hard surfaces as defined above produce injury results less severe than impacts with rigid surfaces. In most cases, hard-surface impacts resulted in OAIS of three or less and ISS of 20 or less regardless of impact velocity or energy. This analysis suggests that hard-surface impacts should not be grouped together with rigid-surface impacts for simplified analyses, since the hard surface apparently absorbs some of the impact energy.

3) Positive relationships between OAIS or ISS and the physical quantity were observed for only those quantities in which velocity was the dominant factor. Body mass apparently has less of a determining influence on injury in a fall than does impact velocity.

4) In only nine of the 24 graphs plotted do there appear to be any relationships between the level of injury and the magnitude of the physical parameter plotted. Of these, five were for head-first impacts, age 10 and above, three were for impacts other than head-first, age 10 and above, and one was for head-first impacts, age nine and younger. Only one of the observed relationships involved children age nine or younger. For a variety of reasons, some of which are probably related to growth and development, these simplified prediction methods apparently are not adequate for predicting injury to younger children.

5) Six of the nine observed relationships were for head-first impacts. This result is not surprising, since in head-first impacts the most severe injuries are usually to the head and prediction of injury severity should be somewhat easier. When some other part of the body bears the primary impact, injury mechanisms become more complicated and so

injury severities are less easy to predict. The observed relationships are generally weaker for non-head-first impacts than for head-first impacts. ISS and OAIS were found to be roughly equal indicators for both head-first and non-head-first impacts.

6) Figures 12a and 12b show that, in this sample of head-first falls onto rigid surfaces by eleven persons age 10-59, most people sustained an OAIS 5 or greater injury when the absorbed energy was 1500 ft-lbs or greater. The two subjects who sustained energy levels higher than 2500 ft-lbs were fatally injured. There are only two instances where less energy was absorbed and these individuals sustained less severe injuries. Because there were only two cases in this lower range, it is not possible to predict how frequently the more severe injuries might occur below 1500 ft-lbs of absorbed energy. It should be noted that 1000 ft-lbs of energy is exceeded by adults in all but the lowest-velocity falls. For example, an average-sized adult male (160 lbs) who falls six feet onto a rigid surface will absorb 1000 ft-lbs of energy.

From the foregoing discussion it is evident that relatively simple methods of predicting injury are usually not adequate. However, one additional technique was used to attempt prediction of injury to the head. For this approach, only head-first impacts onto rigid surfaces were included. Injury severity was described only by the maximum AIS value assigned to the head injury. The potential indicator used was the kinetic energy of the head "effective mass." Use of the "effective mass" method allowed a proportion of whole-body kinetic energy to be attributed to the head. This energy could then be compared to head injury as indicated by head AIS. Head effective mass is not merely a ratio of head mass to total body mass, and the method used to calculate it is described in

Appendix D. The results of the analysis are shown in Figure 13, with different age groups designated. Again, no overall positive relationship is observed. Also there is no relationship that appears to be age-related.

Perhaps the inclusion of additional factors, such as age-related material properties of the impacting mass, would point to a consistent relationship. However, the calculations become increasingly complicated with each additional factor, and the purpose of developing a simplified predictor of injury is defeated. The problem of injury prediction is apparently more complicated than can be successfully investigated using measures for impact severity that are easily defined in terms of impact velocity. Head injury prediction based on mathematical simulation was also attempted and is described in Section D.2.b. of this chapter.

D. Detailed Injury Results and Analysis

1. Introduction. The case investigations and the simulations produced detailed data about the effects of free-fall impacts on injury to specific parts of the body--especially the head and lower extremities. These detailed results will be presented in this section, together with an analysis that leads to conclusions about impact tolerance levels of children, for both reversible injury and survival. Part 1 of this section contains additional details about the simulations and description of the twelve cases selected for simulation. Part 2 is devoted to head injuries and includes results and analysis from the case investigations and the simulations. Part 3 contains similar results for other portions of the body such as the legs, spine, and chest.

In addition to those already mentioned, several more comments concerning the simulations should be noted. While it is recognized that aerodynamic drag affects the velocity of a falling body, it was also felt that drag would be both

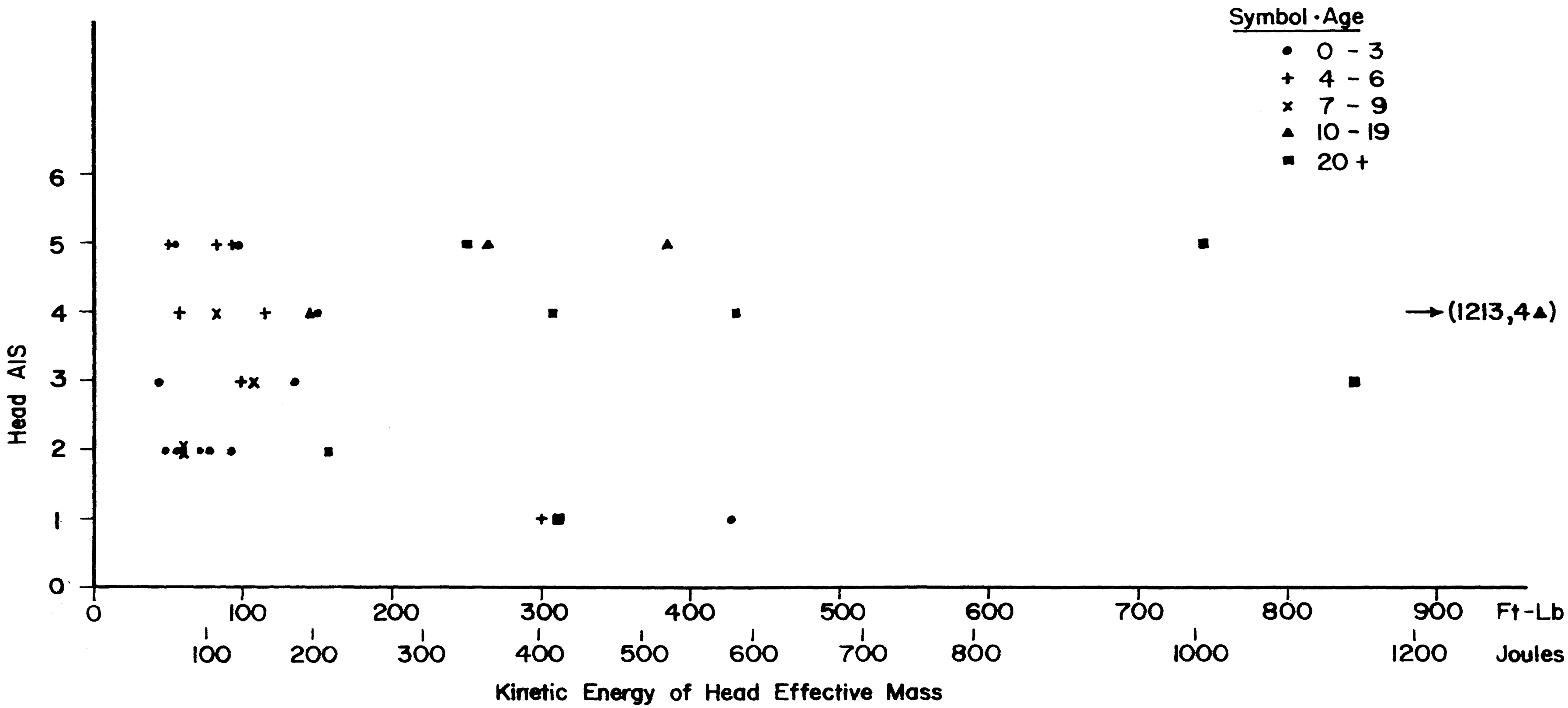


Figure 13. Relationship between Energy of Head "Effective Mass" and Head Injury.

minimal and very difficult to calculate for the subjects being simulated. Therefore, no adjustment was made in the calculation of impact velocity to account for aerodynamic drag. The fall distance used in determining impact velocity was, however, very carefully calculated. It was defined for the simulations as being the distance from the center of gravity of the subject at the start of the fall to the center of gravity at the moment of impact (including allowance for the angular position of the body at impact). Although the subjects were clothed when they fell, clothing weight was not included in the simulations (except for the feet-first fall of a heavily-clothed teenager).

Most of the emphasis was placed on simulating falls onto rigid surfaces, but falls onto soil were also of interest because injuries were generally less severe in these cases. Therefore, the head-first falls of four subjects were simulated as if they had landed on loose sand and on lawn soil instead of on a rigid surface. The force-deflection properties of sand were obtained from NASA data (see Appendix B) and the lawn soil data from on-site penetrometer readings. In the simulations for falls onto non-rigid surfaces, dynamic response results are meaningful only for the time that the head is the only body part in contact with the ground since the imput data were not modified to simulate soil impact by other body parts.

Twelve of the 110 cases were selected for simulation. These included seven head-first falls of subjects ranging in age from 13 months to 21 years, in body position from nearly prone through vertical to almost supine, and in center-of-gravity to center-of-gravity fall heights from 10 ft 8 in (3.3 m) through 33 ft 1 in (10.1 m). Three feet-first falls were simulated for three teenage subjects who fell from 12 ft 9 in (3.9 m) to 69 ft 7 in (21.2 m). Finally, two side-first falls were simulated, but in a simplified, somewhat stylized manner representing a child and an adult falling 9½ ft and 19½ ft (2.9 and 5.9 m).

The principal characteristics of the twelve subjects whose falls were simulated are shown in Table 10. More details about each of the falls are included in Appendix A.

2. Head Impact Results and Analysis

a. Investigated Cases. Forty of the 110 investigated cases were of head-first impacts onto various surfaces. The results presented in this section are analyzed for the effects of age, impact surface, and fall height on the injuries received in head-first falls.

Age Effects Among Children. Data for the analysis of age effects are contained in Table 11. Only children (except for one young adult) are included in this Table, since there were no investigated falls of older adults which had sufficiently similar fall distances and characteristics of impact. For this analysis, fall height and impact surface were fixed and the injuries to subjects of various ages were examined. The purpose of the analysis was to determine if a relationship existed between ages and injuries under otherwise similar fall conditions.

Every subject who impacted head-first onto a rigid surface, sustained skull fracture or concussion or both. Table 11 shows that seven of 10 falls at 11 feet resulted in skull fracture, the remaining three involved concussion. The seven falls averaging 17.5 feet all resulted in skull fracture. [There were several children who fell head-first from about 7 ft (2.1 m). The least serious injury was concussion after a fall of 6 feet (1.8 m), and the most serious a basilar skull fracture and fatality after falling 8 feet (2.4 m).] Even though the major injuries in each case were similar--skull fracture and concussion--the effects of the injuries did seem to increase somewhat with age. The youngest children tended to recover rapidly

Table 10

Twelve Cases Selected for Computer Simulation

Case No	Age	Sex	Wt (lb)	Ht (in)	Body Orientation At Start	Body Orientation At Impact	Measured Fall Ht	CG-CG Fall Ht	Body Rotation	Major Injuries	Recovery	Impact Angles	Surfaces Simulated Rigid	Surfaces Simulated Sand	Surfaces Simulated Soil
1. Head-First Falls															
21	3yr6mo	M	40	41	Seated	Semi-Prone	11'0"	10'8"	210°	Skull fx, concus	Complete	50°(N)* 60° 70°	X X X	X X	X X
59	21yr	M	160	70	Standing	Semi-Prone	11'0"	12'0"	120°	Skull fx, concus, Hemiparesis	Partial	50° 60°(N) 70°	X X X	 X	 X
87	6yr6mo	M	55	48	Standing	Supine	10'2"	11'8"	145°	Cerebral contusion, Hemiparesis	Partial Paralysis	25° 35°(N) 45°	X X X	 X	 X
110	3yr4mo	M	32	38	Standing	Prone	17'2"	16'8"	480°	Skull fx, coma	Fatal 6½ hrs	15° 25°(N) 35°	X X X		
61	1yr1mo	M	21	30	Prone	Prone	34'2"	33'1"	Rolled	Skull fx, femur fx, ruptured spleen	Probably Complete	25° 35°(N)	X X	 X	 X
9	2yr	M	25	35	Standing	Vertical	10'6"	11'0"	165°	Skull fx	Complete	65° 75°(N) 85°	X X X		
62	2yr1mo	F	23	32	Standing	Supine	13'3"	14'7"	100	Skull fx, severe concus, dural tear	Partial Paralysis	Supine 10°	X X		
2. Feet-First Falls															
74	13yr3mo	M	120	68	Standing	Standing Crouched	22'0"	22'0"	0°	Fx left lower leg, right ankle	Complete	65° 75°(N) 85°	X X X		
50	17yr6mo	M	158	73	Standing	Standing, One leg	16'3"	12'9"	0°	Fx left lower leg	Complete	75°(N) 85°	X X		
28	19yr4mo	M	125	63	Standing	Standing Crouched	75'4"	69'7"	0°	Fx both legs & feet, fx pelvis & ribs hemothorax	Partial	70° 80°(N) 90°	X X X		
3. Side-First Falls															
59	21yr	M	160	70	Standing	Hip First	10'0"; 20'0"	9'5"; 19'5"	0°	Simplified Fall		10°(N) 10°(N)	X X		
66	9yr10mo	M	60	51	Standing	Hip First	10'0"; 20'0"	9'7"; 19'5"	0°	Simplified Fall	Complete	10°(N) 10°(N)	X X		

Conversions: 1 lb = .4536 kg; 1 in = 2.54 cm; 1 ft = .3048 m

*(N) denotes nominal impact angle. This was the angle from the surface to the torso for head-first and side-first falls, and the angle from the surface to the lower legs for the feet-first falls. This was established by the investigator based on field observations and implications from injuries.

Table 11

Injuries as a Function of Age--Head-First-Impacts

Case No.	Age	Fall Height	Impact Surface	Primary Body Contact	Head AIS	Primary or Major Injuries
A. Falls averaging 11 feet (3.3 m), onto head						
9	2	10'6"	co	head	3	2 skull fxs, concus, subgal hematoma
57	2	12'	co	head	3	3 skull fxs, facial lac
16	3	12'	co	head	2	Skull fx, subgal hematoma
21	3	11'	slate	head	2	2 skull fxs, concus, head contus
101	4	11'12"	co	head	4	"cranio cerebral" injuries-fatal after 2 days
87	6	10'2"	co	head	5	concus, severe brain contus, hemi-paresis (no fx)
23	8	10'4"	co	head	3	Skull fx, concus, head lac
92	11	12'4"	co	head	4	Concus, intracerebral hematoma, gait problems
59	21	11'	co	head	4	Skull fx, concus, aphasia & hemiparesis
B. Falls averaging 17'6" (5.3 m), onto head						
29	1	18'2"	as	head	2	Skull fx
110	3	17'2"	co	head	5	Skull fx, coma, fatal after 6½ hrs.
80	4	17'6"	co	head	3	Skull fx, slight brain contus
78	5	17'6"	co	head	2	Skull fx
96	5	17'7"	as	head	4	Skull fx, cerebral contus
56	10	18'1"	co	head	2	Skull fx, fx arm
42	11	17'6"	co	head	5	Skull fx, concus, coma 5 days, fx forearm

Notes:

1. Abbreviations: For Impact Surface: co=concrete; as=asphalt; fs=frozen soil; hs=hard-packed bare soil; ls=lawn soil; ice=thick, rigid ice.
   For Injuries: fx=fracture; concus=concussion; contus=contusion; subgal=subgaleal; lac=lacerations; p-thorax=pneumothorax; compr=compression; bilat=bilateral

2. Fall height differences within categories represent less than 1.3 mph (2 kph) difference in impact velocity.

from their injuries and were outwardly normal just a few weeks after the fall. However, it should be noted that such head injuries can have long-term effects that are not immediately apparent. The 11-year-olds and the 21-year-old each had nervous system damage that required long convalescence, although each subject responded favorably to therapy. Injury severity, as described by the AIS score, does not show correlation to age. A comparison of head AIS values for the 17 cases showed only a slight trend to increasing severity of injury with increasing age of children for the 11-foot falls, and no pattern at all for the 17-foot falls. For these head-first falls, it was not possible to predict the seriousness of injury merely by specifying the fall distance and the victim's age.

Impact Surface Effects. When the head receives the primary impact in a fall, a skull fracture is likely to result unless the impact velocity is relatively low or the impact surface is very soft. Table 12, Parts A and B, show that falls of 12.5 feet onto grass-covered soil and of 16 feet onto gravel produced no injuries and minor facial injuries, respectively, for a pair of 3-year-olds. By contrast, a fall of 12 feet onto hard-packed bare soil resulted in a skull fracture typical of rigid-surface impacts, and falls onto concrete from the same height produced even greater injury. The greater the impact velocity, the softer the impacted surface must be for energy levels to remain below the skull-fracture threshold: a 3-year-old who fell 16 feet onto gravel (head-first) had no fracture (Table 12, Part B), but another 3-year-old who fell 25 feet sustained both skull fracture and concussion (Part D). In two 20-foot falls, a head-first impact onto an automobile hood did not cause significant injury, but a similar impact onto a wooden-plank porch fractured a child's skull. Part D of Table 12 shows that the rigidity of the impacted surface can be an important factor in injury severity. The two children, both age 3 and

Table 12

Injuries as a Function of Impact Surface--Head-First Impacts

Case No.	Impact Surface	Age	Fall Height	Primary Body Contact	Primary or Major Injuries
A. Falls of approximately 12' (3.7 m), young children, onto head					
85	ls	3	12'7"	head/back	None
79	hs	1	12'3"	head	Skull fx, concus
57	co	2	12'	head	3 skull fxs, facial lac
16	co	3	12'	head	Skull fx, subgal hematoma
B. Falls of approximately 16' (4.9 m), children, onto head					
83	gravel	3	16'3"	head	Facial bruises and lac, no fx
107	co	5	16'2"	head	Fx skull, coma 2½ weeks, hemiparesis
105	co	3	14'2"	head	2 skull fxs, cerebral concus and contus
C. Falls of approximately 20' (6.1 m), children, onto head					
25	auto hood	3	20'8"	head	Minor head injury, contus forehead
68	wood porch	2	21'	head	Skull fx, concus
110	co	3	17'2"	head	Fx skull, coma, fatal after 6½ hrs
31	co	5	21'	head	Fx skull, contus eye
D. Falls of approximately 25' (7.6 m), children, onto head					
81	gravel	3	25'4"	head	Fx skull, concus, fx leg
109	co	3	25'7"	head	Fx skull, intracerebral hemorrhage, fatal after 3½ hours

Notes: 1. Abbreviations same as Table 11
2. Fall height range represents impact velocity range of ± 1.3 mph (± 2 kph); age held constant ± one year.

of similar weight, fell identical distances of 25 feet (7.6 m) and landed with similar body orientations. The boy who landed on a gravel driveway suffered a fractured skull and concussion and was hospitalized for six weeks, but recovered. The boy who landed on a concrete driveway suffered a displaced fracture of the skull and intra-cerebral hemorrhage and expired 3½ hours later without regaining consciousness.

Fall Height Effects. Thirty-one head-first falls onto rigid surfaces are shown in Table 13. Each one is above the threshold of significant injury, since all subjects suffered skull fracture or concussion. No fatalities occurred in a sample of six children ages one and two in falls from 10.5 to 32.5 feet (3.2 - 9.9 m), but serious injuries were incurred in a fall from a lower height (3 ft 3 in), in case 62. Otherwise, the most serious injuries occurred in the longest falls. The response difference between- one- and two-year-olds is interesting - the injuries received by the one-year-old in falling 18 feet (5.5 m) were substantially less than the typical injuries of two-year-olds who fell from 10.5 to 15 feet.

In the eight falls of 3- and 4-year-olds, from 11 to 37.5 feet (3.4 - 11.4 m), severity of injury increased somewhat at higher fall distances. Although all suffered skull fractures, the incidences of cerebral contusion and hemorrhage and coma were found for the greater fall distances. There were three fatalities in this group, occurring two days after falling 11 feet, 6.5 hours after a 17-foot fall, and 3.5 hours after a 25-foot fall. Precise body position at impact may have made the difference between survival and non-survival for this group of children.

For the five- and six-year-old children, the trend was essentially the reverse of what might have been expected--injuries appeared to decrease as fall height increased. The two fatalities occurred at the lowest fall distances. Mixed results also are seen among the six older children in Table 13,

Table 13

Injuries as a Function of Fall Height--Head-First Impacts

	Case No.	Fall Height	Age	Impact Surface	Primary Body Contact	Primary or Major Injuries
A.	Falls of 1- and 2-year olds, onto head					
	9	10'6"	2	co	head	2 skull fxs, concus, subgal hematoma
	57	12'	2	co	head	3 skull fxs, head hematomas
	62	13'3"	2	co	head	2 skull fxs, severe concus, dural tear, subgal hematoma
	106	14'9"	2	co	head	Skull fx, concus, fx clavicle
	29	18'2"	1	as	head	Skull fx
	61	32'4"	1	co	head	Multiple skull fx, fx femur, ruptured spleen
B.	Falls of 3- and 4-year olds, onto head					
	21	11'	3	slate	head	2 skull fx, concus, head contus
	101	11'2"	4	co	head	"Craniocerebral" injuries, fatal after two days
	16	12'	3	co	head	Skull fx, subgal hematoma
	105	14'2"	3	co	head	2 skull fx, cerebral concus and contus
	110	17'2"	3	co	head	Skull fx, coma, fatal after 6½ hrs.
	80	17'6"	4	co	head	Skull fx, slight brain contus
	109	25'7"	3	co	head	Skull fx, intracerebral hemorrhage, fatal after 3½ hrs.
	45	37'5"	4	co	head	Skull fx, coma or semi-conscious 3 days, comp fxs T-3,4,5, possible paraparesis
C.	Falls of 5- and 6-year olds, onto head					
	71	8'4"	5	co	head	2 skull fxs, fatal after 5 days
	70	10'	6	co	head	Cerebral concus and contus, coma, no fx, fatal after 6½ hrs
	87	10'2"	6	co	head	Concus, severe brain contus, hemiparesis
	107	16'2"	5	co	head	Skull fx, coma 2½ weeks, partial hemiparesis
	78	17'6"	5	co	head	Skull fx
	96	17'7"	5	as	head	Skull fx, cerebral contus
	31	21'	5	co	head	Skull fx, contus eye
D.	Falls of older children, onto head					
	40	6'1"	8	co	head	Concus
	64	7'10"	7	co	head	Skull fx, concus
	23	10'4"	8	co	head	Skull fx, concus
	92	12'4"	11	co	head	Concus, intracerebral hematoma, no fx
	44	13'9"	8	co	head	Skull fx
	42	17'6"	11	co	head	Skull fx, coma 5 days, fx forearm
E.	Falls of adults, onto head					
	100	5'9"	40	co	head	Skull fx
	59	11'	21	co	head	Skull fx, concus, aphasia & hemiparesis
	48	15'1"	33	co	head	Skull fx, fx cervical vertebra, quadriplegia, fx femur, fatal after 5½ weeks

Notes:

1. Abbreviations same as Table 11.
2. Only falls to rigid surfaces are included; one ft ≈ .30 m.

Part D, although the least injury occurred at the lowest fall height, 8 feet (2.5 m), and the greatest injury at the greatest height (17.5 ft: 5.3 m).

Only three adults fell on their heads in a manner similar to the children included in Table 13, and those falls were of moderate height (6 - 15 ft; 1.8-4.5 m). Each increase in height resulted in more significant injury. The subject who survived 5½ weeks after falling 15 feet (4.6 m) finally succumbed to pneumonia as a complication of brain injury. For Subject 59, brain damage occurred after a fall of only 11 feet (3.4 m).

b. Results of Simulated Head Impacts. Head-first falls of seven subjects were simulated with the MVMA 2-D Model. The primary head response parameters -- peak resultant acceleration, 3-msec average acceleration, maximum skull deflection and peak normal force -- are shown in Table 14 for head-first falls onto rigid surfaces. The cases are arranged in order of increasing impact velocity.

In interpreting all response data in this table and in the rest of this chapter, it should be kept in mind that the force-deflection curves developed for the skull and other body parts (see Appendix B) do not account for fracture. Since fracture causes a reduction of load-bearing capacity, this means that predicted peak forces and accelerations are the maximum that could occur and peak deflections are minimum possible values. However, the following points should be noted:

1) The fall heights for four of the head-first impact simulations were not greatly above minimum heights for which fracture is expected. In fact, skull fracture did not occur for Subject 87, a six-year old that had an impact velocity very similar to three other simulation subjects (see Table 14).

2) Predicted peak deflections will have greater percentage error than predicted peak accelerations because a fracture-compensated load-deflection curve might result in large predicted deflections

Table 14

Peak Head Response Parameters

Head-first falls onto rigid surfaces, showing the effects of impact velocity, body mass, and body impact angle.

Case No, Age	Body Wt	Impact Velocity	Impact Angle, Head & Torso	Peak Head G's	3msec Avg G's	Max Defl	Peak Normal Force
	(lb)	(ft/sec)	(degrees)			(in)	(lbf)
21	40	26	50	372	283	.43	3597
3yr6mo			60	370	279	.45	3751
			70	374	279	.47	3878
9	25	27	65	489	356	.53	3284
2yr			75	418	312	.51	3214
			85	464	335	.49	3109
87	55	28	25	660	377	.50	4782
6yr6mo			35	622	355	.49	4774
			45	582	355	.50	4784
59	160	29	50	551	411	.80	10185*
21yr			60	514	ND	.75	9469*
			70	495	ND	.60	7679*
62	23	31	0**	640	413	.55	3452
2yr1mo			10	652	362	.55	3332
110	32	34	15	813	481	.59	4633
3yr4mo			25	791	474	.59	4619
			25 head 35 torso	782	500	.59	4622
61	21	46	25	751	535	1.01	4109
1yr1mo			35	696	546	1.02	4207

Conversions: 1 lb avoir = .4536 kg; 1 ft/sec = .3048 m/sec;
1 in = 25.4 mm; 1 lbf = 4.45 N.

*Loading history and, consequently, peak forces are suspect

**Supine position

beyond the fracture deflection in order to produce the necessary momentum transfer. Deflection values may be reasonably accurate, however, since observations from investigated cases did not suggest skull deflections grossly greater than those predicted. Predicted peak head deflections for rigid surface impacts range from 0.45 to 0.59 inches for children with fall heights between 10 and 18 feet. An adult with a fall height of 13.5 feet had a peak deflection of 0.72 inches and a child falling from 33 feet had a 1.01-inch predicted skull deflection.

3) Peak head accelerations are not particularly sensitive to peak head forces. For most of the cases (see Table 14), simulations for three body impact angles varying through a 20-degree range did not produce either greatly different accelerations or forces. For Case 59, however, peak forces varied by 33% while the peak accelerations varied by only 11%. This indicates that relative errors in predicted accelerations can be expected to be considerably less than errors in predicted forces.

Thus, while predicted head accelerations can be expected to be relatively nearer to fracture-compensated values than deflections, most predicted head responses are probably reasonable.

The results in Table 14 show that, for a given case, the angle at impact between the body and the surface has little effect on response of the head. With all other parameters held constant and the body impact angle varying over a 20 degree range, the peak and 3-msec average accelerations for a subject differed by no more than 17%, and deflection and forces differed by no more than 8% (except for Case 59, an adult, which had a 33% difference). In the simulations, the head loads increased to maximum and completely unloaded in a few milliseconds. This happened before forces could be fully transferred through the neck structures from the body to the head. Therefore, the position of the body relative to the head had little influence on the initial head response. Later in the simulation, body forces were more directly coupled through the neck and the head reloaded. Forces and accelerations during reloading never exceeded those at initial impact.

However, field investigation data cited earlier suggest that position at impact is more important than the simulations indicate. This discrepancy in the simulations may be due to the specification of skull force-deflection properties. The same force-deflection characteristics were assigned to all aspects of the skull, but the human skull does not respond identically to impacts from various directions. For example, while the modeled skull will have the same stiffness for both frontal and occipital impacts, the real skull may not. Also, brain motions in one direction may be more injurious than in another direction, and the model does not account for brain tissue dynamics. These factors may in part account for the large differences in injuries seen under otherwise similar fall circumstances.

Impact velocity (dependent on fall distance), body mass and age of the subject all have interrelated effects on impact responses. The graphs in Figure 14 show relationships between impact velocity and the response parameters of peak acceleration and maximum head deflection (averaged over two or three body impact angles). No such relationship is found for force as a function of impact velocity or for any of these parameters as a function of total body kinetic energy. Figure 14 suggests that impact velocity is most influential in determining the response to a head-first impact. However, the results in Table 14 show that other factors cannot be discounted. For example, in Cases 21 (age 3½) and 9 (age 2), the two children fell almost the same distance and landed with approximately the same impact angles. The smaller mass and lower head stiffness of the younger subject resulted in lower forces to the head despite higher accelerations. The lower head stiffness of Subject 9 also resulted in greater head deflections even though head mass was less. Both subjects

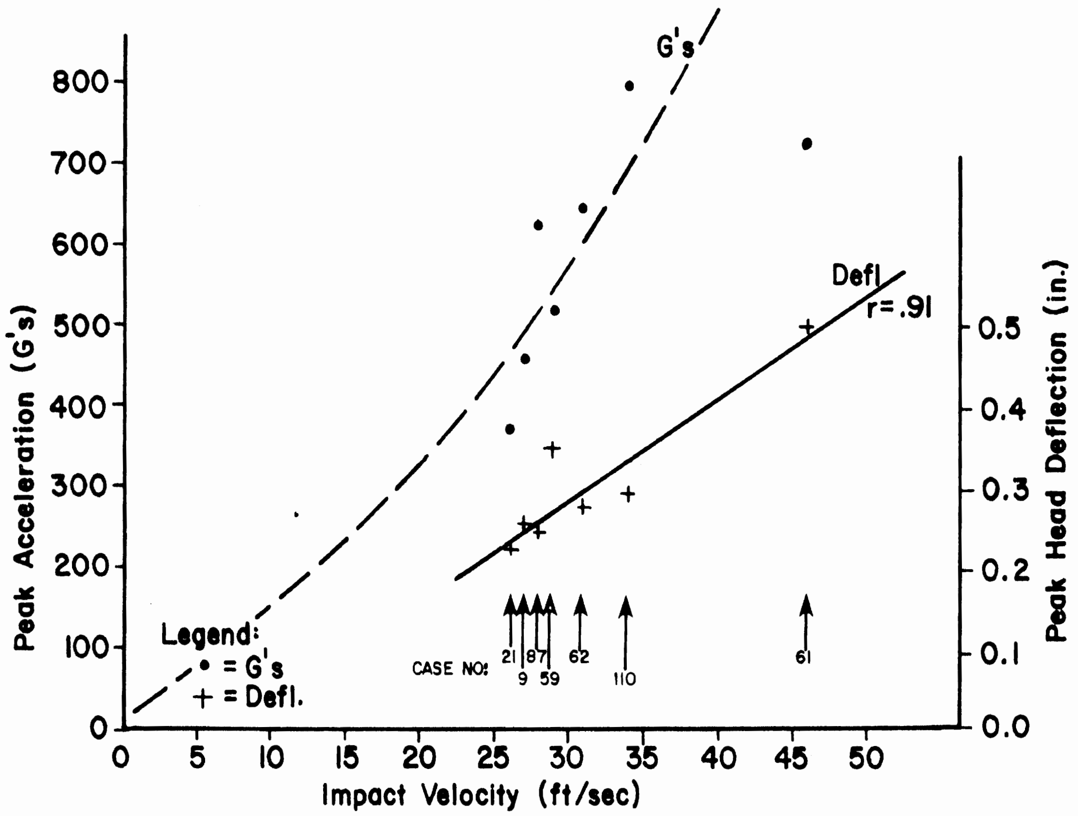


Figure 14. Head Acceleration and Deflection Responses as a Function of Impact Velocity.

received multiple skull fractures in their falls but recovered quickly, apparently with little or no permanent impairment. Subjects 21 (age 3½) and 59 (age 21) fell similar distances and at similar impact angles, but they differ in age and mass. The head stiffness calculated for Subject 59 was 1.6 times that of Subject 21, the body mass was four times greater, and the kinetic energy at impact was 4.9 times as large. The acceleration responses and head deflection of Subject 59 were 1.5 times and the peak head force 2.4 times as great as for Subject 21. Thus, in this instance, body mass and head stiffness were shown to have a significant influence on responses. The adult subject (Case 59) suffered much more severe injuries than the child (Case 21), with a prolonged recuperation and permanent brain damage.

c. Analysis of Head-Impact Simulation Results. In a report on the state-of-the-art in human impact tolerance, Snyder (1970) reported many results from tests with human volunteers and animals, and from other sources such as free-falls. These results suggested that the survival limit for adult humans under free-fall impact conditions was less than 240 G if applied for 12 msec. However, it is also generally accepted that portions of the body can survive much higher accelerations for much shorter periods of time. For survived falls simulated in this study, the predicted head resultant accelerations exceeded 475 G for time durations of up to two msec. Snyder (1970) also cites data which support an early head impact tolerance curve developed at Wayne State University. The Wayne State data are the acceleration-time combinations necessary to produce fracture in cadaver skulls which were impacted forehead-first onto a flat, rigid surface. Skull fractures occurred at about 450 G for one msec duration and 280-380 G for two msec duration with the potential for brain injury estimated to occur below those levels. Thus, neither the simulations nor the field observations are in gross disagreement with the published data. The simulations predicted peak head accelerations in the 370-800 G range for durations of 1-2 msec, and all simulation subjects did in fact have fractured skulls and/or substantial brain injuries.

Snyder (1970, 1973) presented a graph adapted from Roth (1967) which summarized impact experience to date as a function of deceleration distance and impact velocity, with impact acceleration and "stopping time" as determined parameters. This graph is included as Figure 15. The basis for the Roth graph is the assumption of constant deceleration over the stopping time. Therefore, accelerations shown in the graph should be considered "average," not peak. The simulated head-first free-falls have been plotted onto the graph using as coordinates the velocity at impact and the predicted maximum deflection of the head. All of the simulations fall beyond the survival limit estimated by Roth. Yet all but one of the subjects, including a young adult, survived the impacts, although most did suffer some brain damage. (Roth noted that uncertainties due to biophysical factors should cause the "approximate survival limit" values to be used with caution.) Acceleration and stopping time values for the simulations were determined from the graph and are compared with the values predicted by the model (Figure 15, tabular material).* The peak and 3-msec average accelerations for the graph are simple lumped-mass estimates for assumed linear systems.** Stopping times compare very favorably between the two methods - there is less than 0.7 msec difference for all but one case, the adult. Maximum head deflection for the adult occurred at 10.4 msec., about

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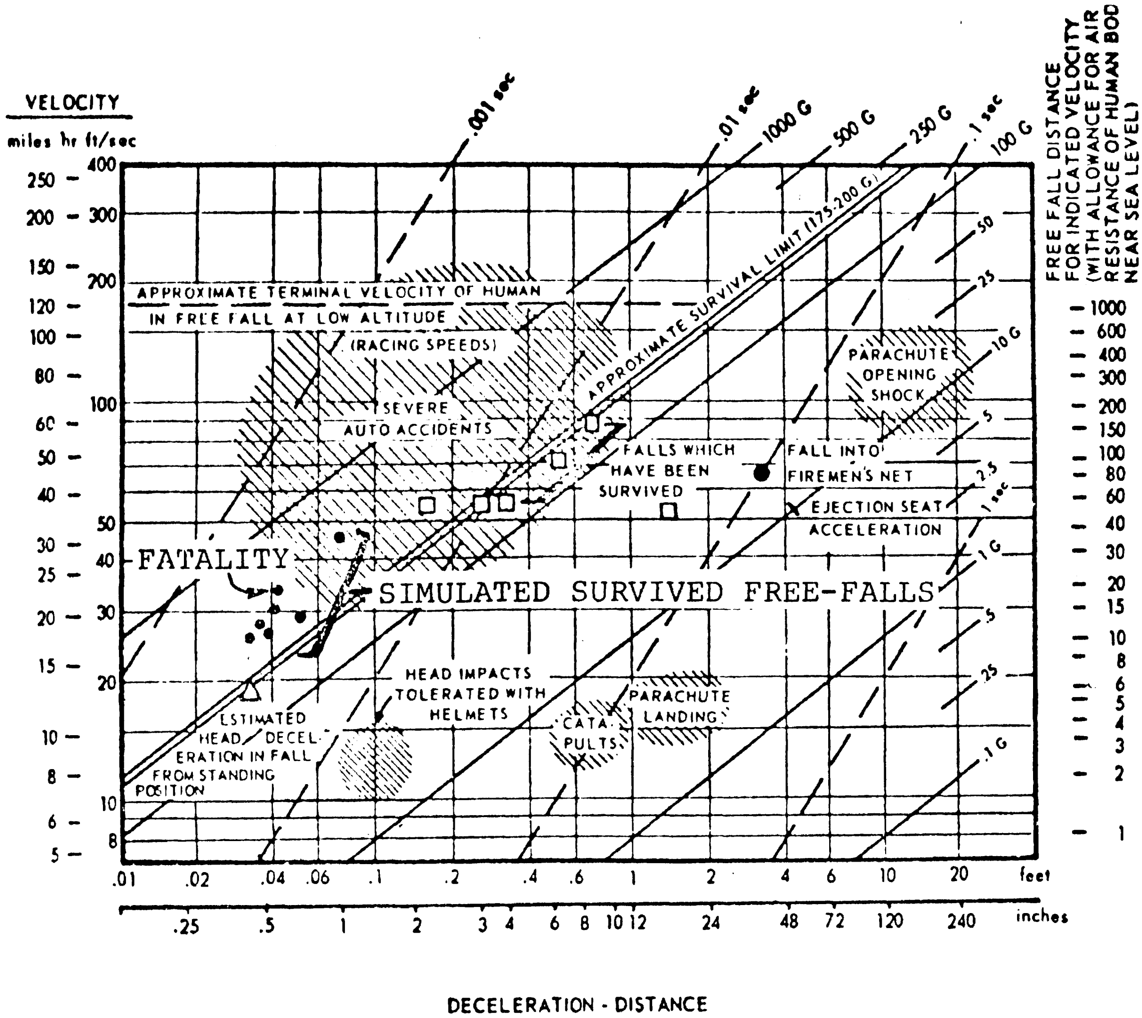
* Graphical results included in the table with Figure 15 are calculated, not read from the graph.

** The peak and 3-msec average accelerations for the graph are values derived from the previously-mentioned constant (or "average" deceleration by assuming that there is a fundamental natural frequency ($\sqrt{k/m}$) of the impacting body which does not vary with deflection for deflections less than the stopping distance.



Case No.	Peak Head Defl (in)	Impact Velocity (ft/sec)	Determined from Graph: Avg Accel. (G's)	Peak G's*	3 msec Avg G's*	Stopping Time (msec)	Avg Accel** (G's)	Predicted In Simulations: Peak G's	3 msec Avg G's	Stopping Time (avg) (msec)
21	.45	26	273	429	384	2.9	299	372	280	2.7
9	.51	27	264	415	377	3.2	306	457	334	2.7
87	.50	28	303	476	426	2.9	374	621	362	2.4
59	.72	29	228	358	338	4.1	89	520	411	10.4
62	.55	31	326	512	459	3.0	343	646	388	2.8
110	.59	34	369	580	517	2.9	464	795	485	2.3
61	1.01	46	392	616	575	3.7	474	742	541	3.0

Conversions: 1 in - 2.54 cm   1 foot - .3048 m

*Estimates: Peak = $\frac{\pi}{2}$ x Avg, 3-msec avg = $\frac{V}{.0015} \sin\left(\frac{.0015\,\pi}{2t_p}\right)$

[V = velocity, t_p = stopping time]

** Average acceleration = impact velocity/stopping time.

Figure 15. Simulated Head Impacts Compared with Other Impact Experience. After Roth, 1967.

8 msec later than for the children and 6 msec later than the graphical prediction. Although the adult simulation exhibits an initial peak in head deflection at 2.7 msec, a higher peak value occurs later, together with delayed inertial loading by the relatively large body mass of the adult, which acts through the neck. The degree of agreement between graphical and simulation results for accelerations and stopping times reflects the degree of similarity between lumped-mass and distributed-mass representations of the fall subject. It is clear that the adult behaved much less like a lumped mass than did the children. On the whole, acceleration values from the graph and the simulations are similar although simulation values are somewhat larger. The 3-msec average accelerations for the graph are probably unrealistically large since their calculation assumed no absorbed energy loss during rebound unloading.

The simulation results shown in Figure 15 do not include five cases which were not simulated, in which children fell 6-10 feet, landed on their heads on rigid surfaces with impact velocities of 19-25 ft/sec, and suffered concussion, skull fracture, and (in three cases) death. These three cases were specifically investigated because it seemed unusual that death had occurred in falls from such low heights. A detailed comparison of fall heights, impact velocities, and body masses between these five cases and very similar simulation cases indicated that these cases would also have been above the survival limit designated by Roth.

The results shown in Figure 15 and discussed above lend support to a possible generalization concerning head impacts. Considering that the survival limit indicated by Roth is the level above which survival is rare, Roth's value of 175-200 G is probably below the actual survival limit for many children under 7-8 years of age. With Roth's definition of survival limit, the graphical data suggest that a constant acceleration of 350 G for 2.5 to 3 msec stopping time might be more appropriate for this age group. A corresponding survival limit for peak acceleration can be estimated by multiplying the constant acceleration by a factor of $\pi/2$. This factor is conservative compared to the model predictions and gives a value of 550 G peak acceleration.

The above conclusion, of course, depends on a reasonably accurate estimate of deceleration distance, and this question was addressed indirectly in several simulations. Errors of 30% were assumed in the technique used to make age adjustments for skull force-deflection characteristics. The resulting simulation data showed differences in deceleration distance of less than 10% (+ .02 to -.04 inches), which produced virtually no change in the graphical results. Therefore, errors of at least 10% in predicting head deformation do not affect the results enough to change the basic conclusions noted above.

No conclusions could be drawn from the results in Figure 15 concerning tolerance limits for reversible injury.

The availability of simulation results afforded another opportunity to determine if a reliable injury indicator could be developed. Eleven potential indicators were calculated and were examined for their ability to predict the maximum AIS value for the head. Only five, as described below, were thought to be potentially good indicators of head injury. These were peak and 3-msec average accelerations, Head Injury Criterion (HIC), rate of onset of acceleration, and head absorbed energy per unit of head mass. A "good" indicator is one for which there is a positive correlation between the indicator and the AIS value. The existence of such correlation does not distinguish between factors which are primarily and secondarily involved in the injury mechanism.

The Abbreviated Injury Scaling system uses a discrete injury scale of magnitude 0-6, zero being no injury at all and 6 being maximum and currently untreatable (invariably fatal) (AAAM, 1976). Therefore, any predictor of AIS may be expected to produce results which fit a sigmoid curve of the type shown in Figure 16. If the predictor has no magnitude, there can be no injury, so the curve passes through the origin. The curve remains at AIS = 0 until the magnitude of the predictor is such that injury starts to occur. Thereafter, the severity of injury will increase as the magnitude of the predictor increases until that magnitude becomes very large. The curve must later become asymptotic to AIS = 6 since the AIS value cannot exceed 6 regardless of the magnitude of the predictor. The slope in the central portion of the curve and the shape of the curve near AIS = 0 and AIS = 6 will change with various indicators, but the basic shape of the curve must be satisfied.

Peak head acceleration and 3-msec average acceleration are two parameters that were found to produce a good fit to the required curve. Figure 17 shows the relationship between the head acceleration and the maximum AIS value for the head (the plotted point for each subject is the average for two or three simulations at different body angles). The fit for six of the seven simulated cases is excellent through the AIS = 2 - 5 range. It is also noteworthy that the greatest peak acceleration was associated with the only fatality which was simulated. Peak and 3-msec accelerations were consistent indicators in all but one case. The exception (Case 61) was the 13-month old child who fell 34 feet (9.9 m), but suffered little or no known permanent brain damage. Unlike most of the other falls, this child received extensive injuries to other portions of the body as well as the head and some of the impact energy may have been dissipated through the other body parts. The curves included in Figure 17 were constructed using a subjective judgement of best fit based both on the simulation data points and on case investigation experience.

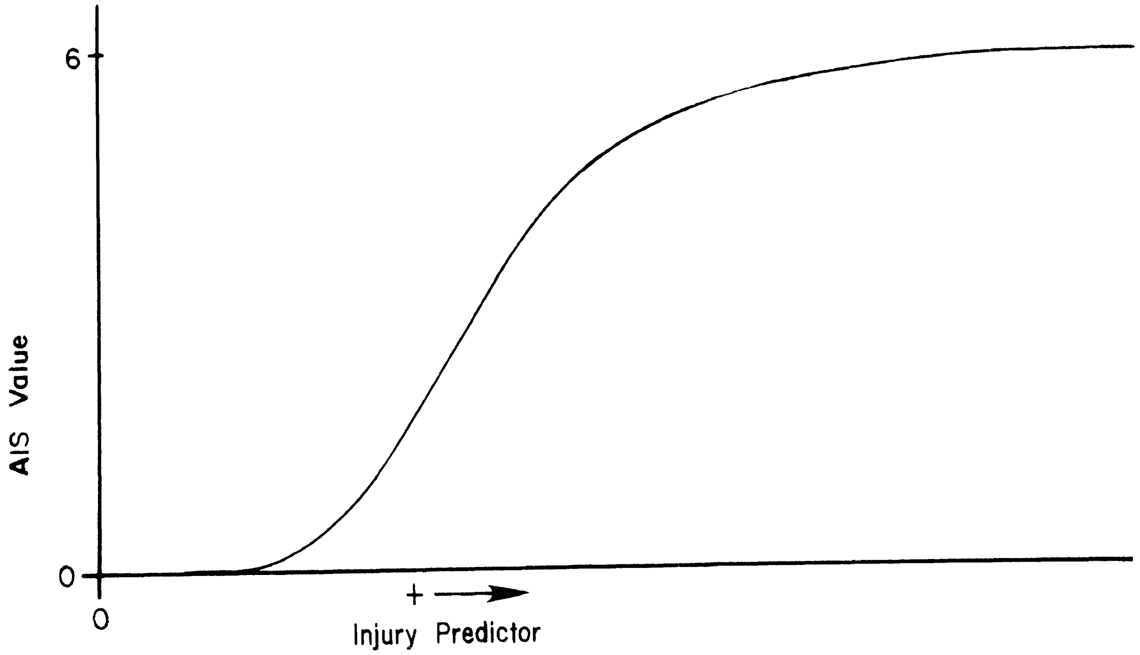


Figure 16. General Shape of Curve for Predicting AIS.

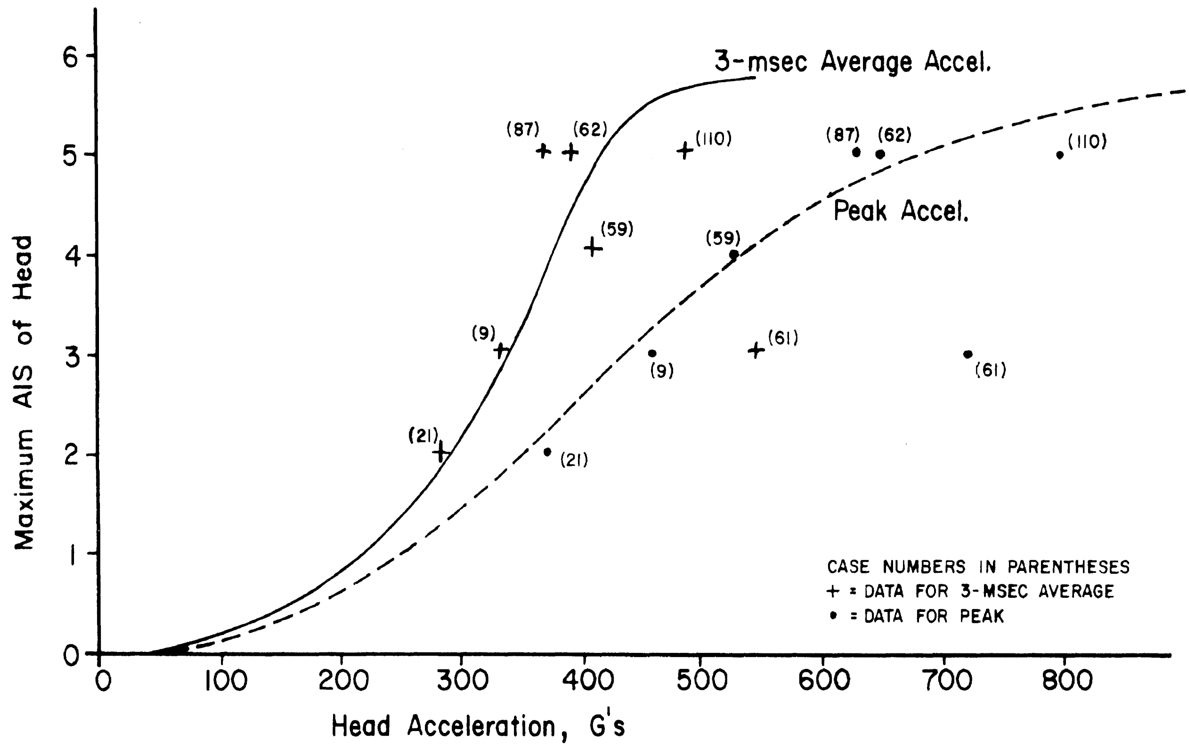


Figure 17. Peak and 3-msec Average Head Accelerations as Indicators of Head Injury. In each case, peak acceleration was reached within 3 msec after initial impact.

The slope of the curve for 3 msec average acceleration is steeper, as expected, since the consequences of sustained acceleration are more severe. The curve for 3-msec average accelerations, though approximate,suggests a 350-400 G survival limit for young children. At 400 G the curve is approaching AIS = 5 which is defined as a critical injury with survival uncertain. This curve also indicates that a reversible injury tolerance limit (AIS = 2 or 3) could be as high as 275-325 G for 3-msec average accelerations. The curve for peak acceleration indicates that the survival and reversible injury tolerance limits for young children may be as high as 600 G peak and 350-400 G peak, respectively. It should also be noted that four of the investigated cases involved children falling onto their heads from heights less than the lowest simulated height. Head injuries of AIS 4-5 level severity were received in three of those four cases. For those three, peak head accelerations were probably less than would be indicated by the curve in Figure 17.

The Head Injury Criterion (HIC) was also found to have a relationship to observed injuries. The HIC results for the six child subjects are shown in Figure 18 (incorrect reloading in the model prevented accurate calculation of HIC for the adult). Again, Case 61 lies outside the expected grouping. The dashed curve illustrates a correlation of head AIS to HIC. This is an encouraging result, since HIC and AIS are both intended to be related to the severity of actual head injuries. However, the curve also suggests that HIC values of up to 3000 could be expected to reflect only moderate injury. There will be more discussion related to these observations later in this section.

Snyder (1973) stressed that rate of onset of acceleration is a determining factor in whole-body tolerance to impact. This parameter was calculated as the average slope (rate of change) of the acceleration curve from time t = 0 to the time at peak acceleration (generally 2 msec)(Figure 19). This is

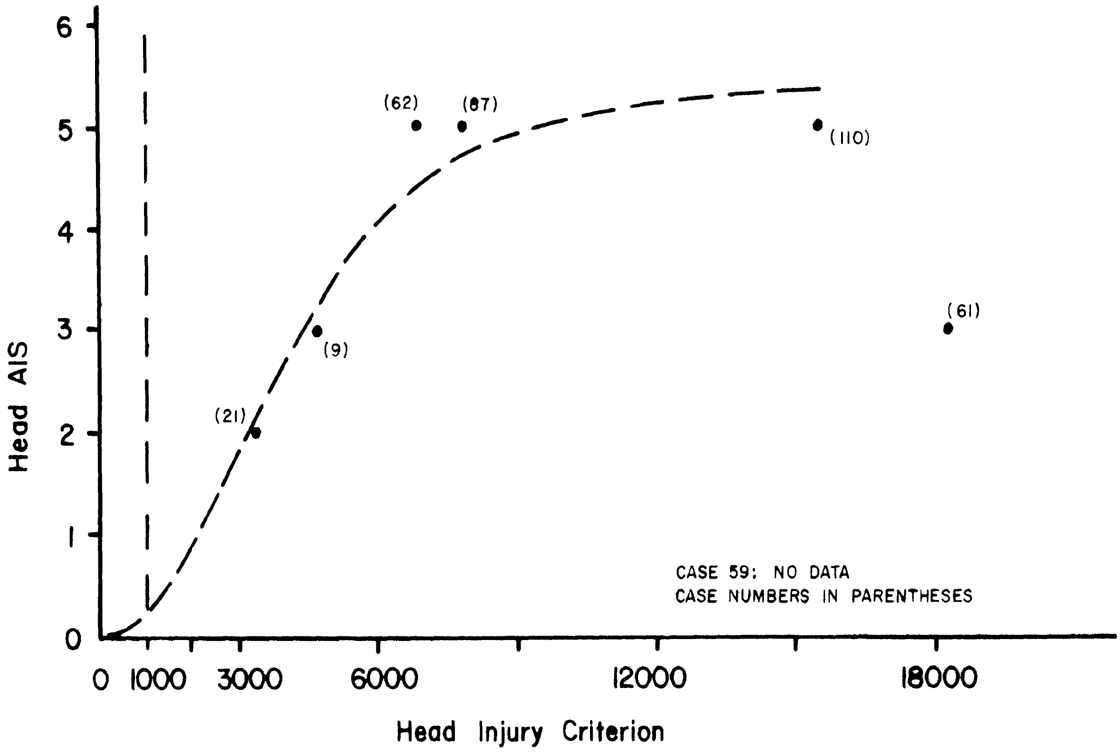


Figure 18. HIC as an Indicator of Head Injury

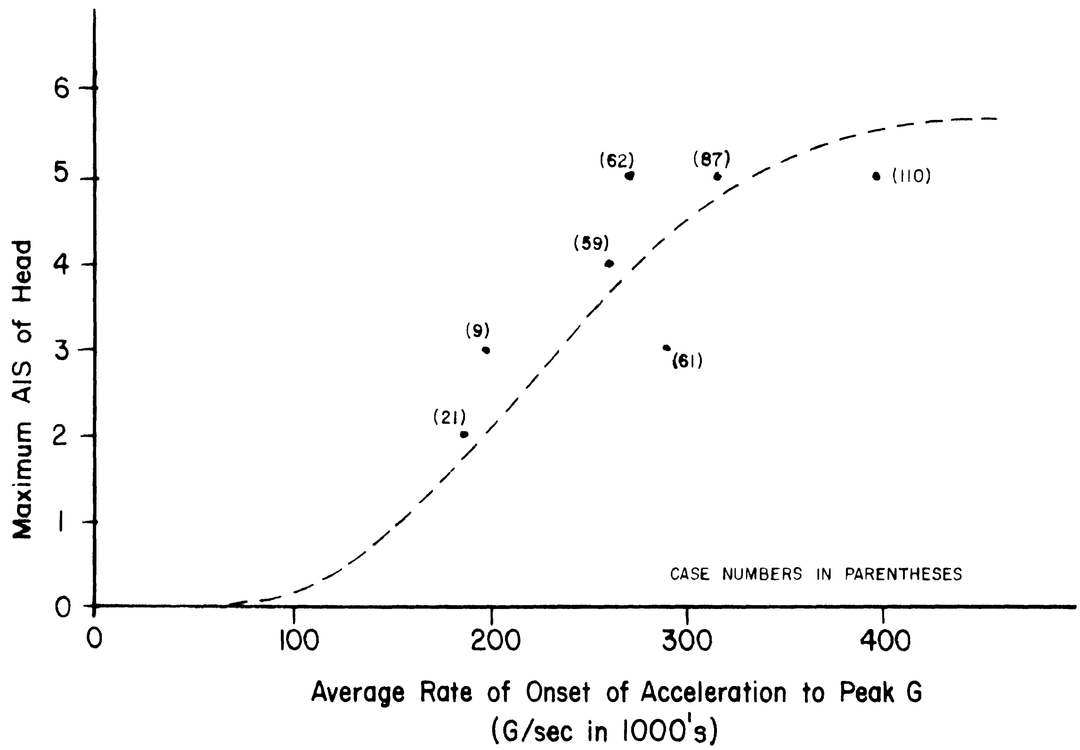


Figure 19. Rate of Onset of Peak Acceleration as an Indicator of Head Injury. These rates were sustained for a maximum of three msec.

the standard method of expressing rate of onset of acceleration. Another method would have been to use the initial slope of the acceleration curve. This would have given a higher value for rate of onset, but the duration of this rate was always 0.5 msec or less. The sigmoid curve shape would not differ for this definition of rate of onset as it was noted that the initial and average rates of onset were nearly proportional for the head-first impact simulations.* Again, curve has been constructed to fit the data in Figure 19. Snyder's (1970) data were examined for possible application to the lower portion of the curve. However, only data for whole-body response were reported and they were not applicable. The simulation results suggest a reversible-injury tolerance (AIS = 1) for rate-of-onset, as defined above, of up to 200,000 G/sec for as much as 2 msec of onset and a survival tolerance (AIS > 5) of about 300,000 G/sec. These predicted tolerance levels pertain primarily to young children.

The fifth potential indicator was developed based on energy considerations. Of the several energy-related indicators that were examined, only one - energy absorbed per unit volume - tended to support the required curve shape. Head volume was, of course, not known for any subject. However, volume, mass and density of the head are related through the expression $V_h = m_h/\rho_h$. If the assumption is made that the average material density, ρ_h, of the head is relatively constant from individual to individual, then ρ_h becomes constant and volume is proportional to head mass. The head mass was calculated as part of the input data for each simulation, so the parameter of interest was energy absorbed by the head divided by head mass. Absorbed energy was calculated to be 0.9 times the area under the impact loading curve of the head (see Appendix B). Figure 20 shows energy absorbed per

* The proportionality factor is about 1.9.

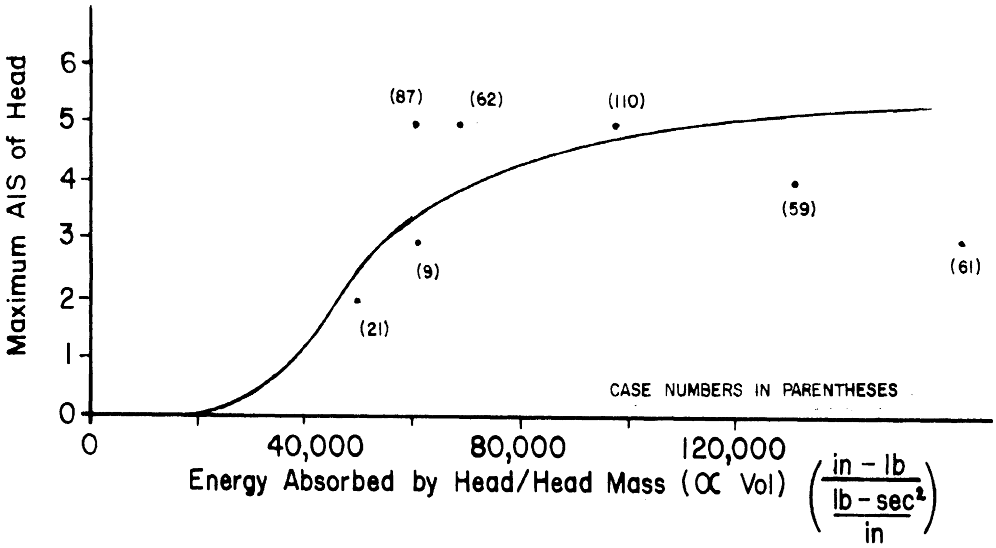


Figure 20. Energy Absorbed per Unit of Head Volume as an Indicator of Head Injury

unit volume of the head vs AIS score. An approximate best-fit curve is shown in Figure 20, but more data points would be needed to establish its shape or validity, especially since two cases lie well outside the expected grouping.

It should be emphasized that the five potential indicators of head injury just discussed do not identify a mechanism for head injury. Nor has any one of them been established as a "best" indicator. It is not unexpected that more than one of them demonstrates a relationship to head AIS, for the indicators themselves are related through their definitions and through the laws of mechanics. All of the curves should be of value since no specific indicator will always be the one of primary interest.

The other simulation parameters that were examined in relation to head AIS as potential indicators of injury are as follows:

a) Peak normal force in the head during impact;
b) Peak head deflection as a percentage of the total head length, on the supposition that the greater the percentage of head deformation, the greater the injury might be;
c) Effective mass of the head as a percentage of the total body mass;
d) Rate of onset to 3-msec average acceleration (time used in the calculation was the mid-point of the 3-msec range);
e) Total energy absorbed by the head during initial impact;
f) Energy absorbed by the head per unit of head cross-sectional area (calculated using ${m_h}^{3/2}$ as proportional to area).

None of the above demonstrated a correlation to AIS values.

The simulations in this study produced some interesting results related to the Head Injury Criterion (HIC). A HIC value of 1000 is intended to reflect the combination of impact acceleration and pulse duration which will cause most people to sustain concussion injury (U.S. DOT, 1969). This type of concussion would normally be rated AIS = 2. The MVMA 2-D model calculates HIC during simulations and has been shown to accurately predict HIC values for tests of unrestrained dummies impacting the windshield in a severe auto crash environment. Since all of the cases simulated had at least a concussion and/or a skull fracture it is not possible to determine the validity of a threshold value of 1000, but it is interesting to note the computed HIC values in these cases.

One fall was simulated in which the child received a concussion and skull fracture with a head AIS rating of 2. The model calculated a HIC value of 3200 in this 100-MSEC simulation. For more severe injuries in survived impacts, HIC values of up to 19,600 were calculated for children. The child who did not survive had a HIC value of 15,000, and the survived fall in which no skull fracture was diagnosed had a HIC = 7500.

Fayon et al (1976) have recently published results of rigid surface impact testing with cadavers that are in general agreement with the simulation results. In free-fall tests of lateral impact to the skull in which accelerometers were positioned to calculate HIC at approximately the head center of gravity, Fayon reported HIC of "> 7000" for a 6 ft (1.8 m) drop and "> 5000" for an 8.3 ft (2.5 m) drop. Fayon found that skull fractures and brain vasculature lesions had occurred in each of these lateral impacts (the brain vascular system was pressurized during the tests). They judged that the "injuries" would have been minor in the six-foot drop but probably fatal in the 8.3-foot drop.

HIC values may be estimated by specifying a waveform shape for the acceleration response pulse, a peak acceleration, and a pulse duration. The simulations predicted pulse durations of about 3 msec and waveforms that were basically either triangular or half-sine in shape. Calculations using idealized triangular and half-sine waveforms and the predicted peak acceleration values from Figure 17 indicate that HIC values of as much as 6500-11,000 may be survivable by some children, and HIC values of 1700-2800 may reflect only moderate injury.

While these results do not reflect on the validity of HIC = 1000 as a minimum tolerance level, they show that some individuals can survive impacts which would produce HIC values ten times greater than the minimum tolerance value.

d. Age Factor and Impact Surface Effects. Several other interesting results were obtained from the head-first impact simulations. The first involved varying the age factor curve (Figure B-8) that was used to derive child head stiffness curves from adult head stiffness (Figure B-7). The development of these curves is discussed in detail in Appendix B. Since the age factor curve was developed based on generalized bone growth patterns, there was some uncertainty about the shape of the curve, particularly to age 6. Therefore, the sensitivity of the model to "incorrect" force-deflection characteristics was investigated using the data set for Case 21, age 3½. The appropriate age factor was determined from the curve shown in Figure B-8. This was then varied by ± 30% and the head force-deflection curves were adjusted accordingly to reflect a greater and lesser head stiffness. These simulations were then run under identical conditions except for head stiffness variations. The results showed that a 60% range of "error" in specifying early growth characteristics produced only 12-15% range of difference in the response values. Four of the important responses are summarized in Table 15.

Table 15

Effects of Head Stiffness Variations on Simulated Responses

Case 21 Conditions	Peak Head Accel. (G's)	3-msec Avg Head Accel. (G's)	Peak Normal Head Force (lbf)	Peak Head Defl. (in)
Low head stiffness	337 (9.4%)*	242 (14.5%)	3311 (8.0%)	.47 (9.3%)
Nominal head stiff.	372	283	3597	.43
High head stiffness	391 (5.1%)	282 (0.3%)	3741 (4.0%)	.41 (4.7%)

*Percent difference from nominal value.
1 lbf = 4.448 N ; 1 in. = 25.4 mm

These results demonstrate that the responses as predicted by the model were not extremely sensitive to substantial uncertainties in the portion of the growth factor curve used for five of the seven simulations of head-first impact. To have confidence that the child simulation results are reasonably close to real-life conditions, it is only necessary to have confidence in the nominal adult head stiffness curve. As discussed in Appendix B, this curve is based on experimental results, with logical modifications for application to simulation of impact.

The simulation results reported thus far for head-first impacts relate to impacts with rigid surfaces. However, the field investigations showed that impacts with non-rigid surfaces, even hard-packed ground, usually resulted in much less severe injury. Cases 2, 25, 79, 81 and 83 are all good examples of this type of fall. To investigate the extent to which soil might mitigate impact effects, simulations were run to contrast head responses from impacts with rigid surfaces, sand, and hard-packed soil. The effects of impacting different surfaces under otherwise identical conditions are shown in Table 16. Peak accelerations and normal forces are reduced considerably by impact with even a hard-packed soil, their magnitudes being only about 1/3 to 1/2 of the rigid-impact values. Impact with soft sand reduces these forces even more, to 15-22% of rigid surface values (25-50% for Case 59, the adult). Head deflections are reduced substantially when soil or sand are impacted. Head deflections from soil impacts are only about 28% of those from rigid-surface impacts, and when sand is impacted, head deflection values are only 12% of rigid-surface values. The time necessary to reach peak acceleration also increases considerably with impacts to softer surfaces, implying a lower rate of onset of acceleration. Finally, inertial "spiking" was reduced, so that the 3-msec average acceleration was very nearly the same magnitude as peak acceleration for all non-rigid impacts.

3. Impacts to Body Parts Other Than the Head. Although head impacts accounted for the largest percentage of investigated falls (36%), more than half (55%) of the case investigations involved primary contact to body parts other than the head. In this portion of the report, results and analysis for impacts of the back, chest, hip, spine, and extremities are presented. The detailed field investigation results are included for all of these body parts, followed by results of feet-first and side-first impact simulations.

a. Investigated Cases. The following results are presented in a format similar to that used for head-first falls in Part 2a. Age, impact surface, and fall height variables are examined for their effect on injuries received in impacts to body parts other than the head.

Age Effects. Table 17 contains data for a number of different impact conditions. The table compares injuries received in rigid surface impacts of similar body

Table 16

Head Response from Impact with Rigid and Non-Rigid Surfaces

Case No. Age	Body Wt (lb)	Impact Velocity (ft/sec)	Impact Angle (deg)	Surface	Peak Head (Gs)	Msec to Peak Head (Gs)	3msec Avg (Gs)	Max Head Defl. (in)	Max Soil Penetr (in)	Peak Normal Force (lbf)
21 3yr6mo	40	26	50	Rigid	372	2.0	283	.43	0.	3597
				Soil	125	4.0	121	.12	1.12	1842
				Sand	76	20.0	65	.05	3.92	805
			60	Rigid	370	2.0	279	.45	0.	3751
				Soil	122	4.0	118	.13	1.19	1969
				Sand	71	24.0	70	.06	4.28	881
87 6yr6mo	55	28	35	Rigid	622	2.0	355	.48	0.	4774
				Soil	255	5.0	266	.11	1.17	1992
				Sand	99	17.0	ND	.04	3.58	764
59 21yr	160	30	60	Rigid	514	2.0	ND	.75	0.	9469
				Soil	299	16.0	280	.22	2.58	5212
				Sand	261	44.0	210	.09	8.19	2066
61 1yr1mo	21	46	25	Rigid	250	2.7	535	1.01	0.	4109
				Soil	386	6.0	364	.29	1.77	2281
				Sand	163	16.0	157	.12	5.77	928

Conversions: 1 lb avoir - .4536 kg; 1 ft/sec - .3048 m/sec; 1 in - 25.4 mm;
1 lbf - 4.45 N.

Table 17

Injuries as a Function of Age—
Non-Head Impacts

Case No.	Age	Fall Height	Impact Surface	Primary Body Contact	Primary or Major Injuries
A. Falls averaging 13'9" (4.2 m), onto head and back (illustrating effect of slight difference in body position					
62	2	13'3"	co	back/head	2 skull fxs, severe concus, dural tear
82	16	11'10"	as	back	Mild concus, contus shoulder and back
90	19	14'2"	co	back	Severe concus, fx T-7, paraplegia
91	21	14'2"	co	back	Skull fx, coma, fatal after 4 days
48	33	15'1"	co	back/head	Skull fx, fx cervical vertebra, quadriplegia, fx femur, fatal after 5½ weeks
B. Falls averaging 12' (3.7 m), onto feet, then to sitting position					
89	1	13'6"	co	seat	Contus buttock, swollen foot
38	43	12'5"	co	seat	Compr fx L-1, fx foot, fx elbow
73	47	10'7"	as	seat	Compr fxs T-7, L-1, L-2, S-3,4,5 (buckled sacrum), fx and disloc of wrist
19	59	11'	co	seat	Compr fxs L-1 and L-4, soreness upper back
C. Falls of approximately 17' (5 m), onto feet					
50	17	16'6"	co	foot (one)	Complex bimalleolar fx ankle
53	50	17'	co	feet	Compr fxs L-1 and L-2, fxs wrist, knee, foot
D. Falls of approximately 22' (6.7 m), onto feet					
74	13	22'	ice	feet	Fx left tibia and fibula, right ankle
54	18	20'8"	co	feet	Fx nose, lac face and extremities
63	26	20'7"	co	feet	Bilat fxs of feet, fx pelvis
55	40	22'4"	as	feet	Fx pelvis, "internal injuries," no leg fx
108	46	22'	fs	feet	Bilat fxs ankles, compr fx L-1
E. Falls of approx 18½' (5.6 m), onto side or arm and side					
35	1	17'3"	co	side	Possible sprain hip, bruise elbow
37	4	20'3"	co	side	Contus and lac hand, no fx
51	7	17'3"	co	side	Fx femur, lost 3 teeth
66	9	17'3"	co	side	Fx forearm, lac ear and face
39	20	19'	co	side	Compound fx ulna, fxs radius and elbow, 3 fxs pelvis, p-thorax

Notes:

1. Abbreviations: For Impact Surface: co=concrete; as=asphalt; fs=frozen soil; ls=lawn soil; ice=thick, rigid ice.
   For Injuries: fx=fracture; concus=concussion; contus=contusion; lac=lacerations; p-thorax=pneumothorax; compr=compression; bilat=bilateral; disloc=dislocation
2. Fall height differences within categories represent less than 1.3 mph (2 kph) difference in impact velocity.

parts for persons of different age. Included are several falls in a supine or nearly supine position from about 14 feet (Part A); many feet-first impacts grouped at approximately 12, 17, and 22 feet (Parts B, C, and D); and several side-first falls from an average of 18 feet (Part E).

Table 17, Part A, illustrates that very serious injury is likely if a person strikes a rigid surface "flat on his back." Five subjects impacted in this supine position after falling about 14 feet (4 m)—four were very seriously injured. The fifth— case 82— landed on a slightly sloped surface with his head somewhat lower than his back, and he had only minor injuries. Subjects 90 and 91 provide a contrast, since they fell side-by-side under indentical circumstances. Their injuries were apparently very near the survival limits for both, but one survived (with permanent impairment) and one did not. Some age effects may be present, since the child, although injured seriously, was not injured as critically as the oldest subjects, two of whom died. Probably more influential than age for this type of fall, however, are slight differences in body position at time of impact. Review of the case summaries shows slight differences in estimated impact position—some subjects, though supine, probably contacted first with their head, and they seemed to incur the more serious injuries.

Falls in which the subject landed on the feet, or in a sitting position, are summarized in Table 17, Parts B, C, and D. It is apparent from these 11 cases that, on the whole, the older subjects suffered the more serious injuries. Compression fractures of the lumbar spine were the most common injury to persons over forty who fell to a sitting position after landing on their feet. Both teenagers and adults often landed on their feet, then fell to all fours or to the side. In these circumstances, fractures of the lumbar spine and pelvis were common among older adults but were not seen in teenagers.

Rather fine injury vs age distinctions are seen in five falls onto the side from about 18 feet (Table 17, Part E). Although the sample size is small, the age groupings are distinct and the levels of injury increase with each age increase. The one- and four-year olds received only slight injuries and no fractures when they landed on their sides. Older children (age 7 and 9) had simple fractures and other moderate injuries. The adult, however, suffered major injuries to his arm and pelvis and may have permanent impairment of wrist function.

Impact Surface Effects. Only limited data were available to contrast impact surface effects for falls other than onto the head. Table 18, Part A shows two cases of males of the same age falling the same distance and impacting differing surfaces feet-first. The one who fell onto soil pitched forward and received a concussion but no fractures; the other, who landed on concrete, suffered a fractured ankle.

Table 18, Part B, shows that the automobile, under certain circumstances, is an excellent impact attenuator. Two case investigations involved subjects who had landed on autos after falling more than 100 feet. The flat steel roof panels collapsed and partially absorbed the impact energy, minimizing injury. In a fall of 105 feet (32 m), the subject in Case 1 landed on his back, causing 7 inches (18 cm) of permanent roof deformation, and walked away with virtually no injury. The longest fall that was investigated in which the subject survived was 166 feet (50.6 m), in which the subject in Case 12 landed on the roof of a four-door hardtop, crushing part of the roof to below the level of the windowsills. He remained conscious and could have left the scene without assistance except for severe lacerations to his legs from broken windshield glass. A basic principle of crash victim protection is that dissipating impact energy over

Table 18

Injuries as a Function of Impact Surface--
Non-Head Impacts

Case No.	Impact Surface	Age	Fall Height	Primary Body Contact	Primary or Major Injuries
A. Falls of approximately 25' (7.6 m), teens, onto feet					
33	ls	19	28'1"	feet	Concus, back pain, facial abrasions
99	co	20	25'	feet	Fx ankle
B. Falls onto automobiles					
25	auto hood	3	20'8"	head	Minor head injury, contus forehead
1	auto roof	23	105'	back	Bump on head, ankle sprain
12	auto roof	30	166'	back	Mild concus, fx disloc a rib

Note:

Abbreviations same as Table 17

long times and distances will minimize deceleration of the impacting body and reduce injury. This principle was dramatically demonstrated in these two cases.

Fall Height Effects. The data in Table 19 show the effects of increasing fall distance on injuries for persons of approximately the same age in comparable types of falls.

Nine subjects between the ages of 12 and 26 landed on their feet on rigid surfaces (Table 19, Part B). These falls ranged from 16.5 feet (5.0 m) to 75.5 feet (23.0 m). None of the feet-first falls that were investigated resulted in fatalities, and for fall distances of less than 30 feet (9.1 m), the injuries tended to be similar—usually fractures of one or both feet or ankles. It may be significant that the only fractured pelvis for a fall of less than 30 feet was suffered by the oldest subject. In the four cases of falls from heights greater than 30 feet, fractures of the spine and pelvis were seen in addition to fractures of the ankles and feet. The severest injuries resulted from the most extreme falls—two teenagers who survived falls of more than 70 feet (21 m). An 18-year old had some limited neurological damage that was expected to respond to therapy; the 19-year old suffered neither neurological damage nor any loss of consciousness. The benefits of decelerating the body through longer time and greater distance are apparent in foot-first impacts. The body has more deceleration distance when it impacts feet-first, and the long bones absorb a large amount of the impact energy before fracturing.

Six falls were investigated in which adults over 40 years landed off-balance on their feet and then fell immediately to a sitting position (Table 19, Part C). The five falls of greater than 10 feet (3 m) involved fracture

Table 19

Injuries as a Function of Fall Height—
Non-Head Impacts

Case No.	Fall Height	Age	Impact Surface	Primary Body Contact	Primary or Major Injuries
A. Falls of adults, onto side					
52	12'	45	co	side	Fxs wrist, humerus, pelvis
39	19'	20	co	side	Compound fx ulna, fxs radius and elbow 3 fxs pelvis, p-thorax
58	28'3"	20	flat roof	side	fx pelvis, chest and lung contus
B. Falls of teens and young adults, onto feet					
50	16'6"	17	co	one foot	Complex bimalleolar fx ankle
63	20'7"	26	co	feet	Bilat fxs feet, fx pelvis, rib cage injury
54	20'8"	18	co	feet	Fx nose, lac face & extremities
74	22'	13	ice	feet	Fx left tibia & fibula, fx right ankle
99	25'	20	co	feet	Fx ankle
104	33'10"	12	co	feet	Fx foot, fx pelvis, emphysema
17	49'10"	21	co	feet	Bilat fxs feet, 2 fxs thoracic spine, fx wrist
60	72'6"	18	ice	feet	Fxs neck, clavicle, pelvis, both legs, both ankles
28	75'4"	19	as	feet	Bilat fxs feet, fxs femur, pelvis, rib, p-thorax
C. Falls of adults over 40, onto feet, then to sitting position					
86	9'6"	61	as	seat	Bilat fxs ankles and feet
73	10'7"	47	as	seat	Compr fxs T-7, L-1, L-2, S-3,4,5, fx and disloc wrist
19	11'	59	co	seat	Compr fxs L-1 and L-4, soreness upper back
38	12'5"	43	co	seat	Compr fx L-1, fxs elbow and foot
53	17'	50	co	seat	Compr fxs L-1 and L-2, fxs wrist, knee, foot
108	22'	46	fs	seat	Compr fx L-1, bilat fxs ankles

Notes:

1. Abbreviations same as Table 17
2. Only falls to rigid surfaces are included
3. One ft ≈ .30 m

of the first lumbar vertebra, and wrist or elbow fractures were also common as the subject tried to support himself while coming to rest. Other than for the 9.5-foot fall (the subject anticipated it and was trying to balance himself), the injuries were similar regardless of fall distance. There were no fatalities and no diagnosed neurological injuries as a result of these falls (all spinal fractures were compression fractures of the anterior portion of the vertebral body). However, each subject had long periods of hospitalization and convalescence, much loss of work, and some permanent disability.

b. Simulations of Feet-First Impacts. As described in Table 10, three of the computer simulations were for cases in which the subject landed feet-first on a rigid surface. All three subjects were teenagers, since neither of the children in investigated cases who landed feet-first satisfied the criteria for simulation. Simulation of foot-first impact is difficult with the MVMA 2-D model, since it has only one leg and no joint at the ankle. Also, the complex reactions of a flexed human knee under impact are difficult to simplify for modeling. The techniques used to develop force-deflection characteristics for the lower extremity are explained in Appendix B. As explained near the beginning of Section D.2, body part force-deflection curves used in the simulations do not account for fracture. Therefore, predicted peak forces and accelerations are the maximum that could have occurred for the subject. Each simulation was repeated for different lower-leg-to-impact-surface angles to account for uncertainties in exact position at impact.

The results of the feet-first impact simulations are shown in Table 20. Forces in the foot and the leg accelerations of the hips are included in the table. The axial forces

Table 20

Results of Feet-First Impact Simulations

Case No, Age	Body Wt (lb)	Impact Velocity (ft/sec)	Lower Leg Impact Angle (deg)	Hip Peak Res. G's	Femur Forces* Peak Axial-Thigh (lbf)	Femur Forces* Peak Axial-Knee (lbf)	Femur Forces* Peak Shear-Knee (lbf)	Peak Axial Tibia Force* at Foot (lbf)	Foot-Peak Contact Force* (lbf)
50	158	29	75	97	4665	6632	1847	10428	6475
17yr6mo			85	96	5335	7629	857	10140	7489
74	120	38	65	84	1756	2355	835	4454	4752
13yr3mo			75	110	2364	3166	1002	5784	5816
			85	131	2818	3829	1102	6728	6654
28	125	67	70	293	4185	6431	2809	12914	8094
19yr4mo			80	312	4796	7674	2799	14103	9236
			90 (knees locked)	438	11196	15298	2366	19096	16062

All contacts are to rigid surfaces; Responses do not represent fracture effects.

* All forces are values for one leg. Case 50 was a fall to only one leg - all impact forces were absorbed by one leg.

Conversions: 1 lb avoir. = .4536 kg; 1 ft/sec = .3048 m/sec; 1 lbf = 4.45 N noted would tend to bow the long bones and cause bending or compression fractures, while shear forces at the knee would bend to dislocate the joint or destroy the ligament capsule. It is apparent that the body position at impact substantially affects the forces in the legs. In all simulations, axial forces in the foot, tibia and femur increased as the subject landed with greater knee extension. Shear forces also follow a consistent pattern, decreasing as the leg becomes straighter and transfers more force axially through the bones. In two cases, these force transfers were also reflected in increased hip acceleration. The simulations demonstrate that compressive forces vary along the length of the long bones. In each simulation, a greater distance from the foot contact point results in lower forces.

The subject in Case 50 landed on only one foot. A comparison of his results at 29 ft/sec with those of Subject 74 at 38 ft/sec shows the advantage of landing on both feet. The tibial forces for two legs are only 50-60% of those for one leg, despite the fact that Subject 74 absorbed 50% more kinetic energy (3000 ft-lbs compared to 2000 ft-lbs). Actual injuries to both of these subjects were confined to fractures of the lower leg bones just above the ankle or to bones in the ankle. Therefore, the simulations indicate that, for these teenage subjects, the forces were great enough to cause fracture of the tibia at the ankle, but not great enough to fracture the femur. Also, the predicted accelerations in the hip were not sufficient to cause injury to the pelvic regions. The results show that an average of 5650 ft-lbs (25,000 N) did not fracture the femur of Subject 50. The explanation probably lies in the maturity of the two subjects. The 13-year old (Case 74) was probably still growing and therefore had a somewhat weaker bony structure than the 17½-year old (Case 50). Also, though both subjects were of slim build, the younger one was wearing approximately 17 lb

(7.7 kg) of clothing, which is 14% of his body weight. This additional weight may also have caused more stress on the bones.

When the subject in Case 28 was interviewed, he indicated he had tried to throw himself forward and roll as he landed. This type of movement cannot be simulated by the model, but the impact velocity was so great that the initial few milliseconds of simulation probably produced realistic results. The results for the falls with knees bent appear consistent with the other two subjects in terms of injuries. This subject suffered fractures of a foot, the lower bones of both legs, the left femur and right hip. The femur axial forces are nearly identical for subjects 50 and 28. One did not sustain injury, the other did, but these results are not inconsistent with the circumstances. The loading direction was different for the subjects (Subject 50 remained upright while Subject 28 went to his knees). Predicted shear forces for Subject 28 were roughly twice those for Subject 50, so those forces were probably the determining factor causing the femur fracture. Subject 28 sustained a pelvic fracture at the hip joint (predicted hip acceleration = 300 G), but the other subjects did not (predicted hip acceleration = 100 G). The results also demonstrate that locking the knees would cause significantly higher forces and accelerations to be transmitted through the body. These could be expected to cause much greater injury than the subject actually received, so it is likely that he fell with bent knees and threw himself forward as he claimed.

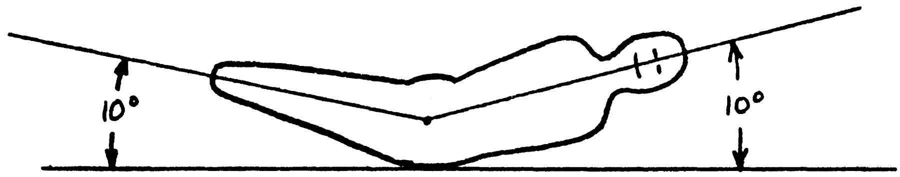
Comparison of the predicted femur forces with experimental results is possible using data published recently by Melvin and Stalnaker (1976). Fresh cadavers in a sitting position were impacted on the patella so that the force was transmitted axially through the femur. The lower torso was not restrained. In seven experiments an unpadded rigid striker was used to impact the knee. The cadavers were 57 to 74 years old. Fractures of the patella or the distal shaft of the femur occurred in four tests with axial forces of 4050 to 5330 lb (18,015 to 23,720 N), at striker impact velocities of 34-38 ft/sec. No fractures occurred in three tests with forces of 3640 to 5100 lb (16,190 and 22,685 N) at striker impact velocities of 27-31 ft/sec. Corresponding predicted values from the simulations are in the range of 6400-7600 lb (28,500-33,800 N) for impact velocities of 29 and 67 ft/sec. No fractures typical of axial loading were seen in these subjects, so either the simulation predictions are somewhat high, or the teenagers have stronger femurs than the elderly test subjects, or both.

c. Simulations of Side-First Impacts. An age-dependent pattern of arm and pelvic injury had been noted in the case investigations. Since pelvic fractures often occur in lateral-impact auto crashes, simulation of this type of fall was thought to be desirable. Two cases were selected for simulation, one child and one adult. However, it was found that not enough human biomechanical data exist to adequately simulate a fall onto an outstretched arm with subsequent collapse onto the hip. Force-deformation characteristics for the shoulder girdle and for lateral loading of the hip were critical to accurate simulation, and these were not available. A different simulation technique was therefore adopted for the side-first falls. A stylized representation of a child (Case 66) and an adult (Case 59) was developed. No arms were modeled, the characteristics of both legs were represented in one leg, and the individual was positioned to strike hip first (see diagram at top of Table 21.) Two fall heights, 10 and 30 feet (3.0 and 6.1 m), were simulated for falls onto rigid surfaces.

The hip and shoulder contacts were of primary interest, and those responses are shown in Table 21. Hip and shoulder accelerations for the child were predicted to be higher than for the adult, but the adult had greater peak forces at

Table 21

Results of Side-First Impact Simulations



Case No. (Age)	Body Weight (lb)	Impact Velocity (ft/sec)	Peak Acceleration (G's) Hip	Peak Acceleration (G's) Shoulder	Peak Force (lbf) Hip	Peak Force (lbf) Shoulder	Peak Hip Defl. (in)
66	60	25	157	79	1422	970	1.26
(9 yr 0 mo)		35	214	107	1520	1374	3.09
59	160	25	84	47	2987	2011	1.80
(21 yr)		35	94	71	3243	2705	2.93

Conversions: 1 lb = .4536 kg   1 ft/sec = .3048 m/sec

1 lbf = 4.45 N   1 in = 2.54 cm

both hip and shoulder. Hip accelerations appear too low in comparison with other bony-structure impacts with similar impact velocity, such as head-first falls. Also, the hip deflections appear too large—at 20 feet, the hip deflection is 36% of total hip breadth for the child and 22% for the adult. It is likely that this much deformation would cause severe pelvic fractures, yet child pelves were not fractured in falls from this height and adults did not sustain severe fractures. It is apparent that the hip stiffness characteristics used in the simulations were too "soft." However, since there were no available experimental data from which to develop a loading curve, no further adjustments to hip stiffness were attempted.

The shoulder contacted the surface within 4 msec after initial hip contact. The shoulder therefore sustained a large force almost simultaneously with the hip and may have been responsible for diminishing hip responses. There are no known biomechanical data from which to draw conclusions about the accuracy of the simulation values.

Head contacts were noted in each of the simulations. The head rotated into a position of extreme lateral hyperflexion before contacting the surface. Unfortunately, an incorrect head stiffness curve was used for the child, so no comparisons can be made regarding head response.

Finally, since these two simulations were not of actual cases, there can be no comparison of the simulations with observed injuries. The side-first simulations were of interest primarily in establishing some of the necessary parameters that should be developed through experimentation.

d. <u>Chest Responses</u>. The force-deflection characteristics used to model the chest were developed from experimental data, so chest responses were of interest. Some chest response data were available from the head impact simulations, since the chest sustained both deceleration forces (at initial head impact) and direct impact forces when the surface was contacted. Chest impact occurred in about 70% of the simulations, the extent of contact depending upon how vertical the body was at impact and the time duration of the computer run. Peak acceleration of the chest ranged from about 50 G to 140 G, with the average at about 80 G. The highest accelerations in the chest were consistently found to be associated with head impact, not chest impact. The time during which acceleration was greater than 50% of its maximum value was usually less than seven msec, although in one case acceleration remained above half the maximum value for 16 msec. When contact occurred, chest forces ranged from 250-1500 pounds (1100-67,000 N), and remained greater than half of maximum value for 15-40 msec (depending on body position at impact). Snyder (1970) reports chest tolerances to blunt forces at magnitudes greater than those simulated, and in fact, none of the simulation subjects had significant thoracic injury as a result of their falls.

E. General Discussion

The analysis of case investigation data indicates that age effects may be seen for all types of falls, with the least injury variation occurring in head-first and back-first impacts and the greatest variation in feet- and side-first impacts. How much these differences depend on body maturity and how much on body mass remains largely unanswered from these data. Since the skull bones of children mature rather early in life, child responses to head impact would be expected to be more adult-like if bone strength were the only important factor. The fact that adults still tend to receive somewhat greater injuries than children in similar head-first falls suggests that the increased body mass of adults is responsible for what age effect is seen in head-first falls.

By contrast, teenagers are often significantly less injured than adults in similar feet-first impacts, yet there is not a great difference in body mass between the two groups. In these instances, it is probable that bone maturation is responsible for the observed age effects on injury. The bones of teenagers are less brittle than those of adults and are thus better able to absorb impact energy.

A review of the attempts to predict whole-body injury on the basis of fall height shows that impact velocity can be correlated with injury severity. However, this observation is subject to restrictions of age and fall circumstances. The lack of reliable whole-body injury predictors demonstrates that many details need to be known about the specific circumstances surrounding a group of falls before any predictions about injuries can be made. However, it is possible to make some general statements concerning expected injuries. The results indicate that virtually any head-first fall of greater than 10 feet (3 m) onto a rigid surface may be expected to cause skull fracture or concussion and injuries of at least AIS=2 for adult or child. Neurological damage and AIS=3-4 injuries are probable if fall heights exceed about 15 feet (4.6 m) for children and about 10 feet for adults. For fall distances of 10 feet or greater, landing in a sitting position on a rigid surface will probably cause fracture of the lumbar spine of adults. Landing on the feet after falling more than 30 feet (9.1 m) and landing on the side after falling more than 12 feet (3.7 m) will probably cause pelvic fractures in adults if a rigid surface is impacted.

Data from the present study indicate an upper bound for child tolerance for head-first impacts to rigid surfaces in that fracture and/or concussion are almost always to be expected from falls of 10 feet or greater. For very young children (up to 18 months) a lower bound in which skull fracture rarely occurs may be estimated from recent data published in Accident Facts (National Safety Council, 1976).

The Consumer Product Safety Commission (CPSC) found that falls from high chairs resulted in fractures of all types for only about 7 percent of 7000 children who were seen in hospital emergency rooms. (Half of these were between 7 and 18 months of age.) About 5200 of these children suffered head injuries (not necessarily fractures). The most severe fall situation cited by CPSC was of children standing up on the seat and toppling over the side [a fall distance of approximately four feet]. Since it may be assumed that only the more severe cases of high chair falls will result in a hospital visit, these data suggest that only a very small percentage of head-first falls from four feet or less are likely to cause skull fracture in very young children. Thus, for young children, the threshold for skull fracture resulting from free-falls is estimated to be in the range of four to ten feet.

While these general observations may be accurate, case investigation data still cannot provide a means of quantifying impact tolerance limits for either moderate injury or for survival. By contrast, the simulations were intended to provide predictions of the force, acceleration, and deflection quantities which might be produced in a rigid surface impact, but the model cannot predict the expected injuries. For this reason, an important part of the simulation analysis was devoted to establishing correlation between the predicted response values and the observed injuries.

The results suggest that for head-first impacts, children may have higher limits of survival tolerance than adults. The simulation results compare favorably with the impact experience presented by Roth (1967), but indicate the survival limit for impulsive loading of the child skull could be above that specified by Roth for adults.

The results suggest that children may also have a slightly higher level of tolerance for reversible injury (if one assumes that AIS=2-3 defines reversible injury), since under similar fall circumstances, children were usually injured less severely than adults.

The greatest limitation in interpretation of simulation results was the absence of fracture prediction. Appropriate force-deflection data for fractures of the skull and extremities do not exist, so the simulation model could not be accurate in an absolute sense. However, the model did predict response values that were in logical agreement with observed injuries. These simulations demonstrated that, with careful attention to establishing initial parameters and conditions, whole-body-motion models can be used successfully to simulate actual individual events and predict the responses expected in those events. For simulations of both head-first and feet-first falls, several of the predicted responses correlated well with injury severities to the degree that greater response magnitudes were associated with more severe observed injuries.

Additional research is needed to establish better values for parameters to which the model is especially sensitive (such as material properties of the head, lower leg complex, and hip). This would increase the value of the model as a tool in predicting response of humans. Other research is also needed to develop in more detail model response parameters which are reliable predictors of injury, such as those which were explored in this Chapter. Especially valuable would be the establishment of loading curves which incorporate fracture characteristics. Success in those two areas of research would permit the attainment of a long-sought goal—the use of a model to predict specific injuries under prescribed impact circumstances.

Computerized simulations are believed to have been a useful method of studying free-fall impacts under a variety of conditions. The results were in conceptual agreement with published experimental data for appropriate segments of the population. By extension, they provided previously unavailable data for segments of the population for which there are no published data. They predicted that survived rigid-surface impacts involved higher forces and accelerations than were previously believed survivable. They thus provide the basis for indications that new human tolerance values may be warranted and the baseline against which new experimental values may be compared.

CHAPTER 4
SUMMARY AND CONCLUSIONS

This study has demonstrated that the combined techniques of detailed investigation of selected human free-fall impacts and computer simulation of representative falls are an effective means of expanding the knowledge of human impact tolerance.

Experience with the various methods used to study human response and tolerance has shown that volunteers, animals, cadavers, anthropomorphic dummies and auto crash investigations all have distinct limitations. Free-falls, while also subject to limitations, are among the few impact situations which can at the same time be well-described in terms of conditions at impact, be effectively investigated post-impact, and be structured to include different segments of the population (especially children) for which little tolerance data exist. Because some free-falls could be described in enough detail to provide input data for a gross-motion computer model, we believed that simulations of free-falls could provide quantitative information related to human tolerance. Therefore, the study objectives were to identify specific types of free-falls, investigate them in sufficient detail to permit reconstruction of the fall, simulate a selected number of free-falls to estimate impact response, and compare the predicted responses with observed injuries as a means of estimating human tolerance levels.

To accomplish the initial objectives, a system was established to obtain newspaper clippings of free-falls in the United States and Canada. Certain falls were selected from the clippings and were investigated on-site. Measurements, interview data, and injury descriptions were obtained, and a summary of the investigation was prepared which attempted to provide a reconstruction of the fall sequence and described the effects of the fall.

In all, 2257 individual free-falls were reported. From these, 110 falls were selected for investigation on-site during the course of the study. The investigated falls were selected according to special criteria of interest--the age and sex of the individual, the circumstances of the fall, and the nature of the surface that was struck. Fifty-nine of the 110 investigated falls (54%) involved children 12 years or younger and nine (11%) involved teenagers. The investigations concentrated on falls of less than 25 feet (7.6 m) (68%) and falls onto rigid surfaces (69%).

A limited number of falls were selected from the total of those investigated for simulation with the MVMA 2-D Crash Victim Simulator. Successful simulation of laboratory falls of an instrumented dummy demonstrated that the model could predict dummy responses accurately in both prone and feet-first falls. Twelve human free-falls were then simulated for impacts with rigid surfaces (7 head-first, 3 feet-first and 2 side-first).

Simulation results showed that body position at impact had little effect on head response parameters for head-first falls, but had substantial effect on leg response for feet-first impacts. The magnitudes of head response parameters such as peak acceleration, peak deflection, and peak normal force all tended to be larger than those obtained from experiments with surrogates, and they would probably not have been substantially lower even if the model had been capable of including fracture-related loading effects. Analysis of some of these responses compared to other impact experience indicated that survival limits for children may be higher than previously believed. For head-first impacts, a number of potential indicators of injury were examined to determine if relationships existed between predicted response values and observed injuries. Accelerations, HIC, rate of onset of acceleration, and energy absorbed by the head as a percentage of head mass were found to show positive relationships to maximum head AIS. For feet-first impacts, the simulations predicted forces that were consistent with observed injuries and experimental data.

Analyses of data from the reported free-falls, the case investigations, and the simulations have led to the following conclusions:

1) During a one-year period, males were reported to fall under free-fall conditions six times as frequently as females (1830 vs 304 falls). From birth to age 6, males were involved in 65% of all reported free-falls. During the "working years" from ages 20-69, males accounted for 90% of falls, and males were the victims in 99% of occupational falls. Falls relating to occupational hazards were 35.5% of all falls.

Youths and young adults (ages 20-39) were involved in 39% of reported free-falls. Youths in the 13-19 age range fell 1.4 times as often as children in the 0-12 age range. Young adults (20-29) fell twice as often as children. Data from news reports indicated that persons in the 13-29 age range took on more hazardous recreational and occupational activities and therefore constituted the population segment most at risk of being involved in a free-fall accident.

2) The most frequently mentioned fall hazards for young children were open windows and open-railing balconies. Sliding type windows and non-load-bearing screens were found to be particularly hazardous. These findings demonstrated the need to design new buildings or modify older ones to prevent falls if possible and minimize the consequences of falls if they do occur.

3) This study has provided evidence that children were injured less severely than adults under similar impact conditions. Children and adults also showed different injury patterns under similar fall circumstances. Children suffered

a greater proportion of head injuries because they tended to land head-first regardless of fall distance or position at the start of the fall. Adults, however, tended to land on their sides or feet, probably because of a better-developed sense of balance. Children under 12 years were killed in free-falls only 25% of the time, while adults over age 50 died from fall injuries 65% of the time. Increased injury severities among adults were thought to be caused by a combination of increased body mass and less flexible bony structures.

4) The field investigations indicated that body position at the moment of impact had a very great effect on resulting injuries. For several nearly identical falls (such as cases 23, 70 and 87), impacts to slightly different areas of the head resulted in a range of injuries from moderate to fatal. However, the model used for the simulations predicted very little change in impact response over a range of 20 degrees difference in body position. This type of model is not yet capable of accounting for the subtle differences in position or internal response that may affect overall injury patterns.

5) The case investigations indicated that in falls to rigid surfaces certain general kinds of injury can be predicted on the basis of age and fall distance. Virtually any fall from greater than 10 feet (3.0 m) with head-first impact may be expected to cause skull fracture for adult or child. Adults landing in a sitting position after falling from greater than 10 feet will almost always incur lumbar spine fractures, especially of the first lumbar vertebra. Feet-first falls from greater than 15 feet (4.5 m) will probably result in leg and ankle fractures, and in falls from 30 feet and above (9.0 m), pelvic fractures are likely to occur. Several analyses of the case investigation data for rigid-surface impacts revealed no correlation between standard injury scales (ISS and AIS) and potential injury predictors such as impact

velocity and kinetic energy at impact. The only tolerance data suggested by this prediction analysis was that survival was uncertain if more than 2500 ft-lbs of energy were absorbed in a free-fall. As a basis for further analysis, response parameters from the simulations were used. For head impacts with rigid surfaces, peak head acceleration, 3-msec average head acceleration, HIC, and rate of onset of acceleration all were found to correlate reasonably well with AIS of the head. Analysis of curves fitted to these data suggest that the survival limit for children age 8 and younger, as indicated by AIS level 5 injury, may be as high as 600 G peak acceleration with an onset rate of up to 300,000 G/sec and a pulse duration of up to 3 msec. This is approximately equivalent to HIC values of up to 11,000. For some children, the curves predict that the tolerance limit for moderate to severe (but reversible) injury, as indicated by AIS 2 or 3, could be as high as 350-400 G peak acceleration with a rate of onset of up to 200,000 G/sec for up to 3 msec pulse duration (approximate HIC of 1700-2800).

6) Comparison of simulation data with other reported impact experience showed that children often survived impact accelerations at levels beyond the estimated survival limits for adults. For children under age 8, this comparison supports a conclusion that a constant acceleration of up to 350 G for 2.5 - 3 msec approaches the survival limit for head impacts. No conclusion about survival limits could be reached for adults, since only one adult head impact was simulated.

Impact experience data were too limited to allow a conclusion about minimum tolerance levels or tolerance levels for reversible injury. The observation may be made, however, on the basis of CPSC data, that for children younger than 18 months, the minimum tolerance level for reversible head injury may be reached when fall distance is somewhat greater than four feet.

7) Finally, the MVMA 2-D model appeared to be a useful tool for simulating human dynamic responses in free-fall impacts. The results were in conceptual agreement with published data and could logically be extended to include age groups for which there were no published data. The simulations also predicted higher forces and accelerations than were previously considered to be survivable and thus tentatively support new conclusions regarding human tolerance to impact.

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APPENDIX A

SUMMARIES OF INDIVIDUAL CASES

APPENDIX A

SUMMARIES OF INDIVIDUAL CASES

This appendix contains a one-page summary for each of the 110 cases that was investigated on-site. The summaries are presented in a consistent format, as described below.

1) The General Summary contains a brief description of the most pertinent facts of the case. This includes: a description of the subject by sex, age, height, and weight; the measured fall distance; the beginning and ending points of the fall; significant injuries received in the fall; and a description of the situation leading to the fall, the fall sequence, injuries received, length of hospitalization and degree of recovery.

2) The Fall Chronology includes details about the position of the subject just prior to the fall, the probable contact sequence for various parts of the body, the surface that was impacted, and the subject's position at rest. The impact sequence is either as observed by a witness or as reconstructed from interview data and injury patterns. The sketch included with the summary shows the subject's estimated body orientation at the start of the fall and at impact, as determined by the investigator. The sketch also shows the fall height measurement and the type of clothing worn by the subject at the time of the fall.

3) The Specific Injuries summary contains detailed injury information--in most cases from the hospital medical records. The information is given in medical/anatomical terms, rather than in common usage terms, to reflect the known injuries as accurately as possible.

Also included in the Injury Summary is a series of codes to designate the injury and its severity. These codes constitute an application of the combined Occupant Injury Code (OIC) and the Abbreviated Injury Scale (AIS).[1,2] This coding system is currently in use nationwide by automobile accident investigation teams. The code is oriented toward injuries caused by contact with specific objects, and each separate injury caused by a specific contact is coded. For most cases in this study, injuries are caused by contact with a flat rigid or semi-rigid surface. Exceptions are noted in the Fall Chronology.

The OIC describes each injury by a four-letter, one-number code, consisting of body region (head, chest, etc), aspect or location (right, anterior, etc), type of lesion (laceration, fracture, etc), system or organ involved (skeletal, heart, etc), and the appropriate AIS code for severity. A summary of all the OIC and AIS codes is included as Figure A-1, so that the reader may decode the injuries. Fatalities are not automatically assigned the maximum severity AIS value (AIS=6). Values are assigned according to the nature of the injuries, without regard to whether the victim survives or not. The occurence of death is noted separately in the Injury Summary.

4) The Recovery category reflects the status of the subject at the time of the on-site investigation. If recovery was not complete at the time, the prognosis for complete recovery is given. Recovery data is primarily based upon the subject's own assessment and the investigator's observations.

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1 "Multidisciplinary Accident Investigation File. Editing Manual and Reference Information. Volume I - 1976 Editing Manual." Prepared for NHTSA by Highway Safety Research Institute, The University of Michigan, March 1976.

2 "The Abbreviated Injury Scale (1976 Revision)." Prepared by Joint Committee on Injury Scaling of the AMA, SAE, and AAAM, 1976.

1 BODY REGION

- H Head-Skull
- F Face
- N Neck
- S Shoulder
- X Upper Extremities
  - A Arm (Upper)
  - E Elbow
  - R Forearm
  - W Wrist-Hand
- C Chest
- M Abdomen
- B Back
- P Pelvic-Hip
- Y Lower Extremities
  - T Thigh
  - K Knee
  - L Leg (Lower)
  - Q Ankle-Foot
- O Whole Body
- U Unknown

2 ASPECT

- R Right
- L Left
- B Bilateral
- C Central
- A Anterior/Front
- P Posterior/Back
- S Superior/Upper
- I Inferior/Lower
- W Whole Region
- U Unknown

3 LESION

- L Laceration
- C Contusion
- A Abrasion
- F Fracture
- P Pain
- K Concussion
- H Hemorrhage
- V Avulsion
- R Rupture
- S Sprain
- D Dislocation
- N Crushing
- M Amputation
- B Burn
- X Asphyxia
- O Other
- U Unknown

4 SYSTEM/ORGAN

- S Skeletal
  - V Vertebrae
  - J Joints
- D Digestive
  - L Liver
- N Nervous System
  - B Brain
  - C Spinal Cord
  - E Eyes, Ears
- Cardiovascular
  - A Arteries
  - H Heart
  - Q Spleen
- G Urogenital
  - K Kidneys
- R Respiratory
  - P Pulmonary, Lungs
- M Muscles
- I Integmentary
- W All Systems in Region
- U Unknown

5 AIS

- 0 No Injury
- 1 Minor
- 2 Moderate
- 3 Severe (Not life-threatening)
- 4 Serious (Life-threatening, survival probable)
- 5 Critical (Survival uncertain)
- 6 Maximum (Currently untreatable)
- 9 Unknown

Occurrence of death is noted separately.

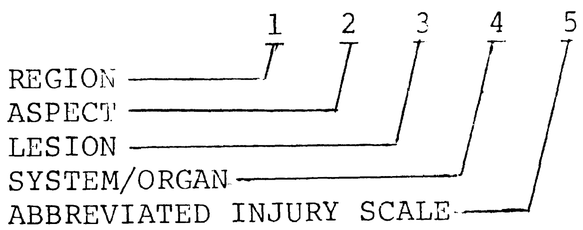

Figure A-1. Occupant Injury Classification (OIC) Codes

5) Sources of Data refer only to those sources from who useful information was obtained. In the case of a child subject, the "subject" category was checked even if the subject was only observed and not directly interviewed. "Hospital" is checked only if the medical records of the fall were reviewed, thereby implying that a medical release was signed by or for the subject. Occasionally, law enforcement agencies or other potential sources were contacted but did not provide the information. The "Police" category will not be checked in those cases. A "newspaper" source is cited only if it is different from the clipping that formed the basis of the investigation.

6) The Other Comments section contains additional information pertinent to the on-site investigation or follow-up. Factors preventing a complete investigation are also noted in this section.

7) Calculated Data, for most cases, will be limited to an estimate of impact velocity, adjusted for air drag as reported by Snyder,[3] an assignment of Overall Abbreviated Injury Scale (OAIS), which is based on the AIS described above,[2] and the Injury Severity Score, a technique for assessing the overall severity of a group of injuries.[4,5] Cases that were used for computer simulations will have a synopsis of the data calculated from the simulation.

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[3] Snyder, R. G., "Human Tolerances to Extreme Impacts in Free-Fall." <u>Aerospace Medicine</u>, Vol 34, No 8, August 1963.

[4] Baker, S. P., B. O'Neill, W. Haddon, Jr., and W. B. Long, "Injury Severity Score: A Method for Describing Patients with Multiple Injuries and Evaluating Emergency Care." <u>Journal of Trauma</u>, Vol 14: 187-196, 1974.

[5] Baker, S. P., and B. O'Neill, "The Injury Severity Score: An Update." <u>Journal of Trauma</u>, Vol 16 No. 11, November, 1976.

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 1

SUBJECT: Male, 23 yrs, 6 ft (1.8 m), 190 lbs. (86.2 kg)

FALL DISTANCE: 105 ft (32.0 m)

ENVIRONMENT: Window washer's bosun's chair to car roof

MAJOR INJURIES: None

SUMMARY: Window washer was in bosun's chair at 12th floor level of apartment house. Knot slipped, subject fell free of chair, 105 ft., and impacted the roof of a parked car. He bounced off the roof to the concrete driveway. Injuries were minor - a sprained ankle - and the subject returned to work washing windows at the same location the next day.

FALL CHRONOLOGY: Subject was sitting in bosun's chair. When rope slipped, he fell out of chair. Subject claimed in newspaper interview that he pushed himself away from building with his feet. He impacted the roof of a 1971 full-size 2-dr sedan, probably landing on his back. Roof was permanently dented about 7 in (17.8 cm), 12-15 in (30.5-38.1 cm) behind windshield.

SPECIFIC INJURIES: Minor head laceration [HULI-1]; sprained ankle (probably from striking the driveway) [QUSJ-2]; possible shock. Claims to have felt nothing during the impact. Treated briefly by a physician. No medical records to review.

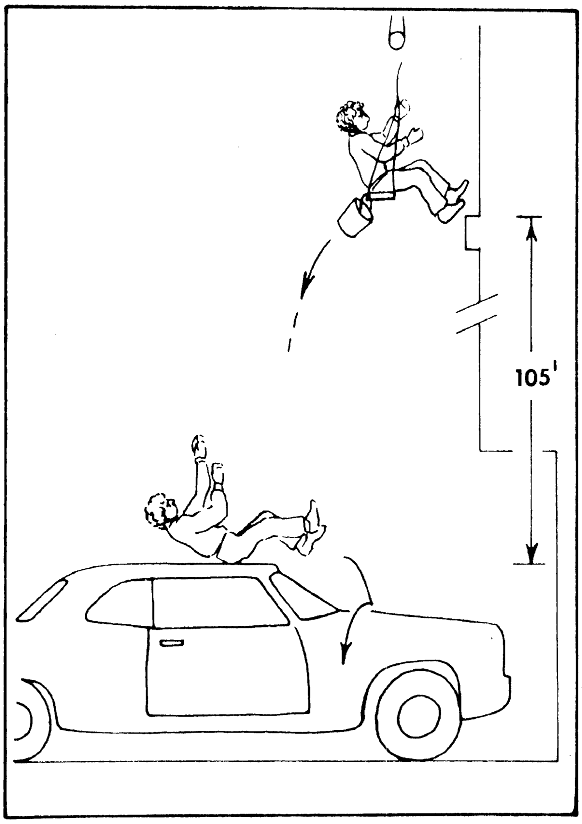
RECOVERY: Immediate and complete. Returned to work the next day.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;

__ POLICE; __ HOSPITAL; __ WITNESSES;

X OTHER: Apartment manager, newspaper, Auto manufacturer

OTHER COMMENTS: Fall occurred approximately one year before investigation. Subject had left area and could not be located. Newspaper accounts very complete. Automobile manufacturer had studied this case also.



CALCULATED DATA:

IMPACT VELOCITY: 78 ft/sec (23.8 m/sec)

OAIS: 2

ISS: 5

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 2

SUBJECT: Female, 3 yr 1 mo, Ht and wt unknown

FALL DISTANCE: 17 ft 5 in (5.3m)

ENVIRONMENT: Windowsill to damp lawn

MAJOR INJURIES: Left parietal skull fracture

SUMMARY: Child was playing with friends, sitting on windowsill. She leaned against the screen, which came loose. Subject fell from windowsill to a sodded lawn. Injuries included a linear fracture of the left parietal bone and mild swelling of left side of head. Hospitalized overnight for observation. Acting nearly normal three days after fall.

FALL CHRONOLOGY: Subject fell from sitting position on windowsill, although whether facing in or out is unknown. She free-fell 17'5", landing probably on her left side, on a flat sodded lawn over clay soil. Final resting position was on left side.

SPECIFIC INJURIES: Subject was initially stunned but not unconscious. The only external injury noted was a slight swelling over left parietal region [HLLI-1]. This did not develop into a bruise. Xrays showed a linear skull fracture, undisplaced, in the left parietal bone posteriorly [HLFS-2]. Complained of neck pain [NPPM-1].

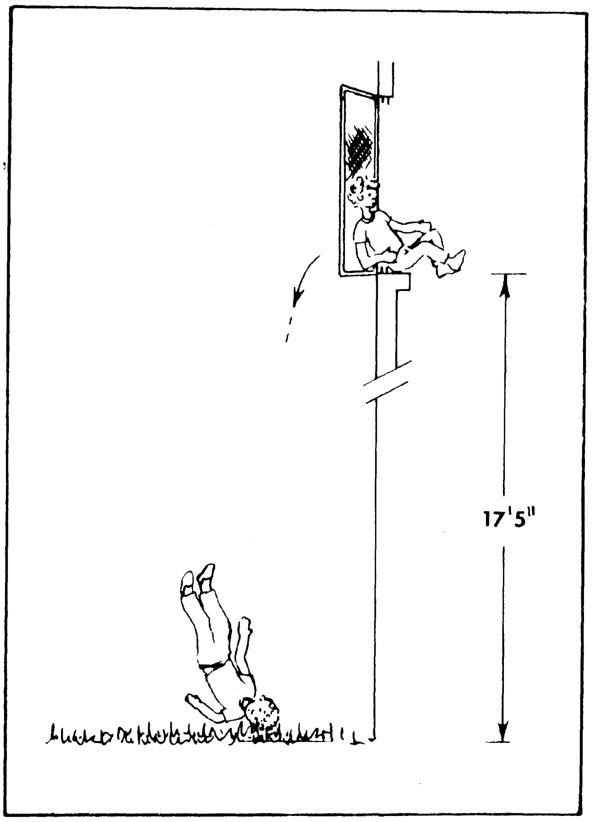
RECOVERY: Neck pain persisted after 3 days. Recovery apparently will be complete.

SOURCES OF DATA: __ SUBJECT; X PARENTS;

__ POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: Friend at Scene

OTHER COMMENTS: Friend was not direct witness, but arrived on scene very quickly.



CALCULATED DATA:

IMPACT VELOCITY: 33 ft/sec (10.0m/sec)

OAIS: 2

ISS: 5

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 3

SUBJECT: Female, 19 yrs, height and weight unknown.

FALL DISTANCE: 49 ft (14.9 m)

ENVIRONMENT: Fifth floor fire escape to brick pavement

MAJOR INJURIES: "Multiple head and body trauma" - fatal

SUMMARY: Subject was baby-sitting 2 year old child (Case #4) when flames from fire in tenement building forced them onto the fifth floor rear fire escape. Although a fireman reached the fire escape, the fire escape collapsed before the ladder could be positioned for the rescue. The subject fell head-first onto brick pavement in the alley at the rear. Due to her falling behind a 10 ft. high fence, no one actually observed the impact. Exact injuries are unknown, but head trauma is indicated, and the subject died several hours after the fall.

FALL CHRONOLOGY: Since a news photographer took 4 photos of the fall using a motor-drive camera, the exact sequence of body positions prior to impact was documented. Immediately prior to the fire-escape collapse the subject was crouched on the fire escape with one arm on the rail and one arm holding the 2 year old child, who was standing in front of her. As it collapsed, she fell feet first, arms over head, then her body rotated so that she was falling with arms and legs outspread, face downwards, parallel to the ground. She continued rotating into the head first position, arms spread out ahead of her and presumably landed in this position.

SPECIFIC INJURIES: Multiple head and body trauma. Autopsy was performed but report was unavailable. Some injuries may have resulted when falling child (Case #4) landed on her.

RECOVERY: Fatal

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
X POLICE; __ HOSPITAL; X WITNESSES;
X OTHER: Neighbor, news photographer

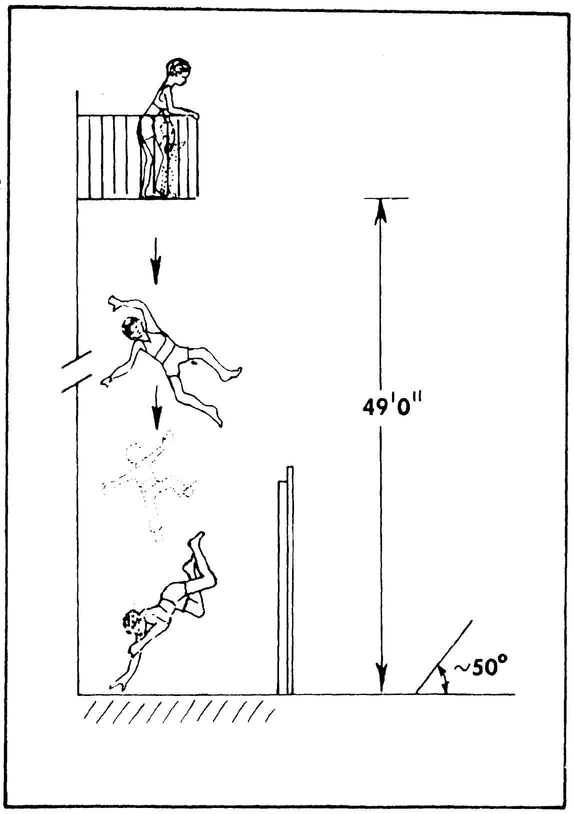
OTHER COMMENTS: Due to intensive investigation by some 15 agencies and possible homicide charges relative to the tenement fire, it was not possible to obtain any official records. Efforts to contact subject's relatives for interview were also not successful.

CALCULATED DATA:

IMPACT VELOCITY: 54 ft/sec (16.5 m/sec)

OAIS: 6

ISS: N/A



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 4

SUBJECT: Female, 2 yrs, height and weight unknown

FALL DISTANCE: 49 ft (14.9 m)

ENVIRONMENT: Fire escape, probably to body of subject in Case #3, then to pavement.

MAJOR INJURIES: Mild concussion, possible internal injuries.

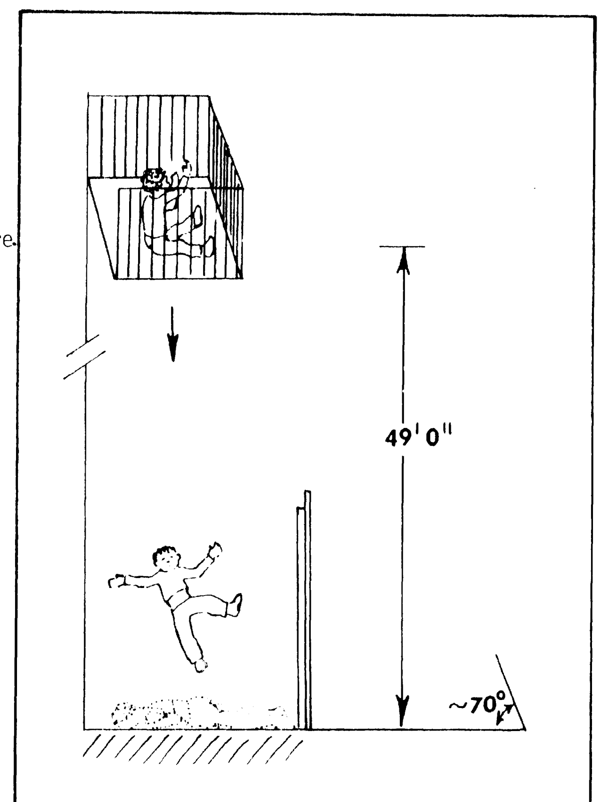
SUMMARY: Subject brought by babysitter to fire escape at rear of apartment. While standing on fire escape awaiting rescue, the fire escape collapsed, and subject fell to brick-paved alley below, probably landing on body of babysitter. She received a mild concussion and other "minor" injuries. Recovery probably complete.

FALL CHRONOLOGY: The actual fall was documented by 4 photos taken by a news photographer using a motor drive camera. At the collapse the child appeared to fall backwards, then feet first, right leg down, left leg out to side (almost 90°), and arms outstretched to the side. No one observed the impact as it occurred in the alley on a brick surface behind a 10 ft high fence, but it is believed the child landed on the body of the babysitter (Case #3) who is shown in the photos to have landed first.
SPECIFIC INJURIES: Mild concussion [HUKB-2]; "a few scratches and bruises" [UULI-1] and, possible internal injuries. Due to law enforcement investigation, no medical records were available.

RECOVERY: Extent of any permanent injury unknown.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
X POLICE; __ HOSPITAL; X WITNESSES;
X OTHER: Neighbor, news photographer

OTHER COMMENTS: It was not possible to obtain any official records due to intensive investigation by some 15 agencies and possible homicide charges relative to the tenement fire. Efforts to contact the subject or her mother were unsuccessful.



CALCULATED DATA:

IMPACT VELOCITY: 54 ft/sec (16.5 m/sec)

OAIS: 2

ISS: 5

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 5

SUBJECT: Male, 34 yrs, height and weight unknown

FALL DISTANCE: 36 ft 11 in (11.3 m)

ENVIRONMENT: Flat roof to street and curbing

MAJOR INJURIES: Blunt trauma to heart, lacerations of spleen, liver, and mesentery. Fatal.

SUMMARY: Subject paced along edge of flat roof for several minutes, then fell 37 feet to street below. His injuries included lacerations of the spleen and liver, a large hematoma of the small bowel mesentery, and loss of spontaneous cardiac and respiratory activity. The injuries proved fatal after 2 hours.

FALL CHRONOLOGY: Subject stood on ledge of roof, facing the street, with arms outstretched. He fell forward and landed, probably face down, with his head and chest impacting the concrete sidewalk and the remainder of the body impacting the asphalt street. Subject was found lying on his back with his head and neck on the curb.

SPECIFIC INJURIES: Immediate loss of spontaneous cardiac activity; cardio-pulmonary resuscitation was begun at the scene. Minimal blood pressure reestablished for approximately one hour. No obvious damage to cardiac tissue [CCLH-5]; Small laceration, hilum of spleen [MLLQ-4]; Small laceration, right lobe of liver [MRLL-4]; Large hematoma, mesentery of small intestine [MILD-4]; Suspected fracture of left scapula at glenoid fossa [SLFS-2].

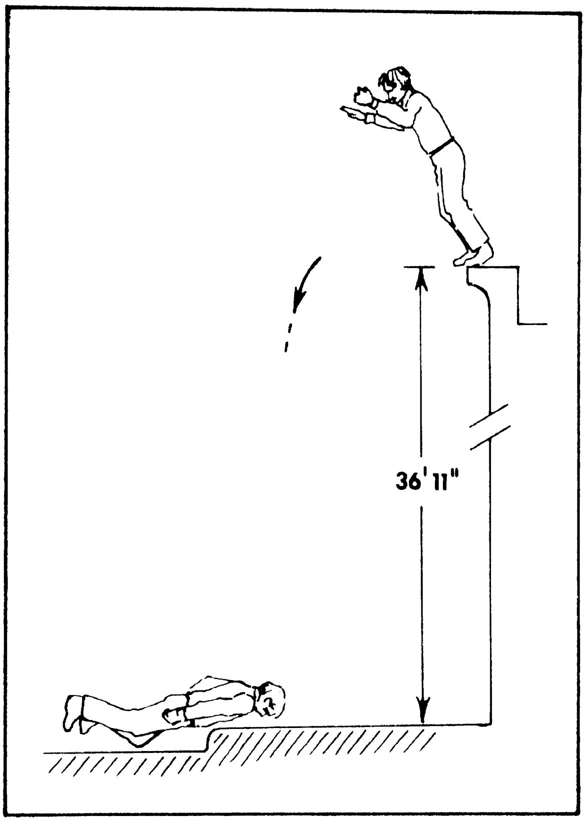
RECOVERY: Subject was alive, though unconscious, at scene. Heart stopped beating during emergency surgery. Resuscitation efforts were unsuccessful. Subject expired two hours after fall.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;

X POLICE; X HOSPITAL; X WITNESSES;

__ OTHER:

OTHER COMMENTS: Hospital record indicated no obvious head or neck injuries or fractures.



CALCULATED DATA:

IMPACT VELOCITY: 48 ft/sec (14.6m/sec)

OAIS: 6

ISS: 45

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 6

SUBJECT: Male, 37 yrs, height and weight unknown

FALL DISTANCE: 45 ft (13.7 m)

ENVIRONMENT: Mine shaft entrance to sandy bottom of vertical shaft

MAJOR INJURIES: Fractured left radius and left scapula

SUMMARY: Subject had been sitting on edge of cliff, drinking alcohol. At approximately 2 am, he stood and slipped into a vertical mine shaft. He fell 45 feet landing on his left shoulder on the sandy bottom of the shaft. He was not discovered until 13 hours later. His injuries included fractures of the distal left radius and the left scapula. He was hospitalized overnight. Recovery is apparently complete.

FALL CHRONOLOGY: Subject probably slipped on loose gravel at edge of mine shaft and slid into the shaft feet-first. The brunt of the impact was taken on the left shoulder and left wrist. However, the bottom of the shaft was composed of loose sandy soil and sloped at approximately a 30° angle, and this probably acted to absorb some of the energy.

SPECIFIC INJURIES: Displaced comminuted fracture of distal left radius [RLFS-3]; comminuted, minimally displaced fracture of left scapula at glenoid fossa [SLFS-2]; laceration of forehead [FSLI-1]; right adductor muscle strain [TRSM-1].

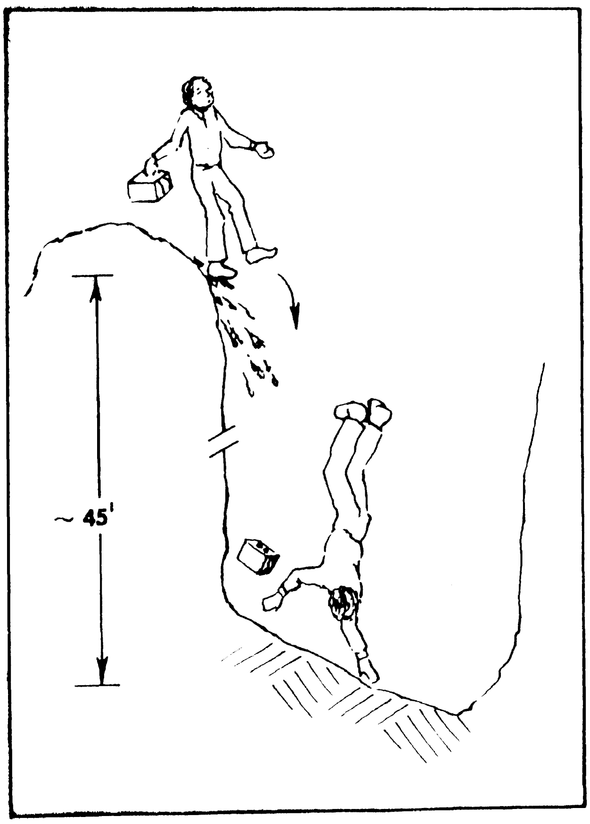
RECOVERY: Apparently complete.

SOURCES OF DATA: X SUBJECT; __ PARENTS;

X POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: Rescue squad

OTHER COMMENTS: A road had to be bulldozed to shaft entrance for rescue unit winch truck. Rescue took 4 hours.



CALCULATED DATA:

IMPACT VELOCITY: 52 ft/sec (15.8 m/sec)

0 AIS: 3

ISS: 10

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 7

SUBJECT: Male, 28 yrs 11 mo, height and weight unknown

FALL DISTANCE: Approx 147 ft (44.8 m)

ENVIRONMENT: Microwave tower to sandy soil

MAJOR INJURIES: Fractures of right radius and right patella.

SUMMARY: While working on maintenance on a 200 ft (61 m) microwave tower, the subject fell from the 147 ft level, landing on grass covered soil below on his right knee and right forearm. He suffered fractures of the right radius and right patella, and multiple abrasions and contusions of the right chest and abdomen. He was hospitalized 11 days. He has partially recovered, but is still in physical therapy.

FALL CHRONOLOGY: Subject was climbing the tower with his safety harness temporarily disconnected when he slipped. While falling he attempted to reach for a steel cable which hung to within 20 ft of the ground. He apparently missed the cable since he had no burns on hands. He landed on his right hand and right knee, 5 ft (1.5 m) from the base of the tower. Five weeks later, a depression was still observed that was 42 inches long, 7 inches wide and 3/4 inch deep (106 x 18 x 2 cm) and shaped like a bent arm or leg.

SPECIFIC INJURIES: Displaced fracture of distal right radius [RRFS-3]; comminuted fracture of right patella [KRFJ-3]; multiple contusions and abrasions over lateral right side of chest and abdomen [CRAI-1, MRAI-1].

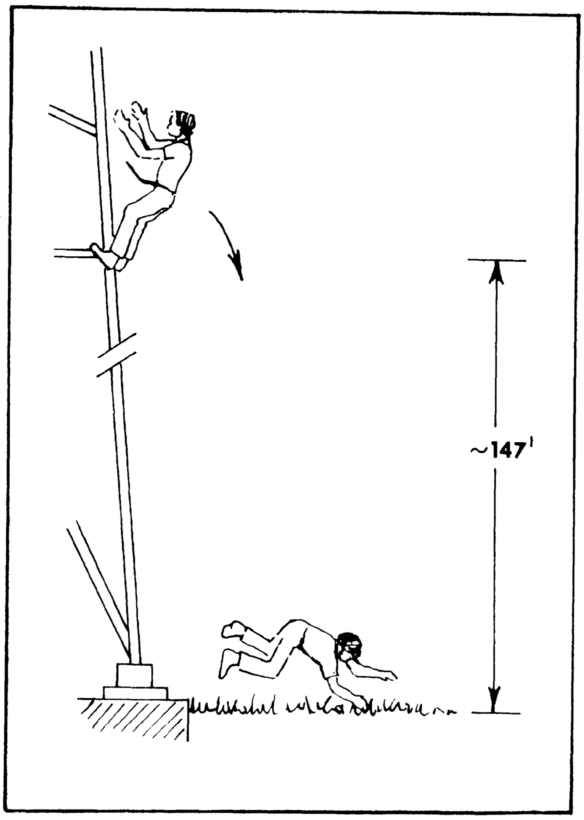
RECOVERY: Still undergoing physical therapy 4 months after fall. Additional surgery was anticipated.

SOURCES OF DATA: X SUBJECT; __ PARENTS;

X POLICE; X HOSPITAL; X WITNESSES;

X OTHER: Company representatives, wife, neighbor

OTHER COMMENTS: It required many months to trace the subject, since he had returned to another state after release from the hospital.



CALCULATED DATA:

IMPACT VELOCITY: 89 ft/sec (27.1 m/sec)

OAIS: 3

ISS: 10

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 8

SUBJECT: Male, 3 yrs., height and weight unknown

FALL DISTANCE: 70 ft 0 in (21.3 m)

ENVIRONMENT: Windowsill to grass-covered soil

MAJOR INJURIES: Fracture of left arm, fractured rib, chest laceration

SUMMARY: Child was playing ball with brother in their 9th floor apartment residence when the ball fell through a hole in the window screen. Subject apparently climbed onto a radiator and leaned out of the window to see where the ball had gone. He tumbled out of the window some 70 ft. to the grass covered soil below. Child was hospitalized 9 days with a fractured left arm, fractured rib, and chest laceration. He has apparently recovered.

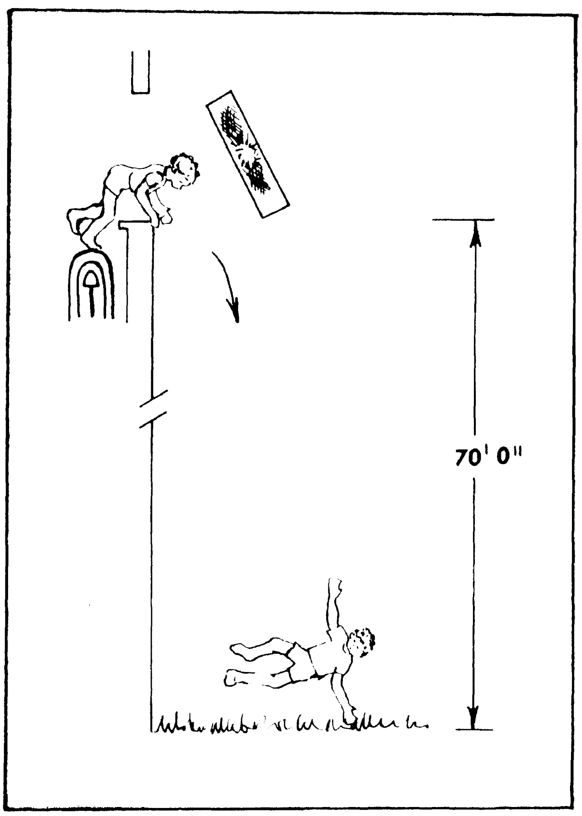
FALL CHRONOLOGY: When the ball he was playing with fell through a hole in a window screen, child climbed onto radiator and leaned out window to search for it. He tumbled from windowsill to the rain-soaked, grass-covered soil below. Child landed on his back with one arm (left) behind him approximately 5-6 ft (2 m) from building.

SPECIFIC INJURIES: Fracture left arm [XLFS-2]; fracture rib [CUFS-2]; chest laceration [CULI-1].

RECOVERY: Released after 9 days in hospital, apparently recovered.

SOURCES OF DATA: __ SUBJECT; __ PARENTS; __ POLICE; __ HOSPITAL; X WITNESSES; X OTHER: apartment management

OTHER COMMENTS: Soil impacted was littered with garbage and debris.



CALCULATED DATA:

IMPACT VELOCITY: 64 ft/sec(19.5 m/sec)

OAIS: 2

ISS: 9

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 9

SUBJECT: Male, 2 yrs, 34.5 in (.87 m), 25 lbs (11.3 kg)

FALL DISTANCE: 10 ft 6 in (3.2 m)

ENVIRONMENT: Hay loft doorway to smooth concrete

MAJOR INJURIES: Multiple skull fractures, concussion

SUMMARY: Subject was playing in barn while father was working. He went to an open hay loft door and fell 10 ½ feet to the concrete cattle yard beneath, landing on his head. Unconscious at the scene; injuries include a linear fracture of the left parietal bone and a diastatic coronal fracture, a small left subgaleal parietal hematoma, and cerebral concussion. He was hospitalized seven days. Recovery is essentially complete.

FALL CHRONOLOGY: Subject was probably in standing position, facing out, in the open doorway of the hayloft. He probably fell forward out of the door, falling to a smooth 6"-thick concrete cattle yard. The yard was clear of manure at the time. Subject landed on top of head slightly to left side.

SPECIFIC INJURIES: Subject was initially unconscious and semi-conscious, then drowsy and irritable at the scene and for first two hospital days. Xrays showed a linear skull fracture in left parietal area and a diastatic (separation) coronal fracture [HLFS-2,HSFS-2]. Neurological exam normal except for small left subgaleal parietal hematoma [HLCI-1]. Cerebral concussion [HLKB-3]. No other injuries.

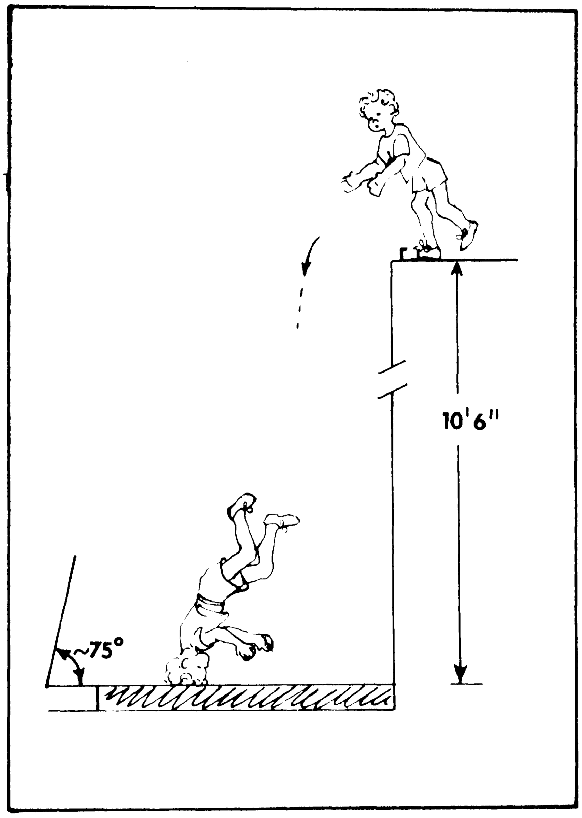
RECOVERY: Medical records indicate subject alert by 3rd hospital day. Mother reported only that he had "not been himself" since the fall. No motor difficulties observed.

SOURCES OF DATA: X SUBJECT; X PARENTS;

__ POLICE; __ HOSPITAL; __ WITNESSES;

X OTHER: Attending Physician

OTHER COMMENTS: There were no direct witnesses, but father reached subject while still unconscious. Would not sign release, but authorized doctor to release injury information.



CALCULATED DATA:

IMPACT VELOCITY: 25 ft/sec (7.6m/sec)

OAIS: 3

ISS: 10

Case was simulated. Responses do not account for fracture effects (see Chapter 3)

1st. peak head accel: 418-489 g's

1st. peak normal force: 3100-3300 lb (13,800-14,700N)

1st. peak head deflection: .49-.53in. (1.24-1.35 cm)

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 10

SUBJECT: Male, 1 yr 8 mo, height and weight unknown

FALL DISTANCE: 97 ft (29.6 m)

ENVIRONMENT: Windowsill of 11th floor bedroom to ground

MAJOR INJURIES: Fractured right clavicle and left scapula, three fractured ribs, bilateral pneumothoraces, avulsion of buttocks.

SUMMARY: Child was playing in bedroom, climbed up on windowsill and fell out upper half of window 14 inches above sill, striking branches of tree, and landing on grass 97 ft below. The child was discharged after 15 days of hospitalization. He has apparently recovered completely.

FALL CHRONOLOGY: The child climbed on wide windowsill 32 in (81 cm) and fell out top half of window 14 in (36 cm) above sill. He was observed by grandfather on ground below to hit branches of a small tree and impact buttocks-first on the lawn.

SPECIFIC INJURIES: Avulsion of soft tissues of both buttocks from lumbosacral to coccygeal area [PPVM-3]; fracture of right clavicle [SLFS-2]; fractures of 8th right rib, 1st and 11th left ribs [CBFS-3]; bilateral pneumothoraces [CBOP-4], non-displaced fracture of ischium [PUFS-2], 2 cm laceration of tongue [FILD-1].

RECOVERY: Apparently complete.

SOURCES OF DATA: __ SUBJECT; X PARENTS;
X POLICE; X HOSPITAL; X WITNESSES;
X OTHER: Neighbors

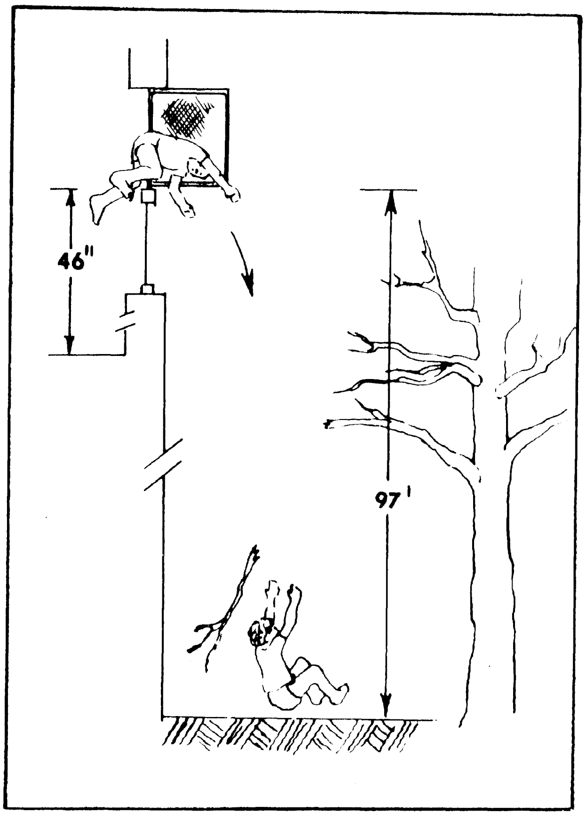
OTHER COMMENTS: This fall occurred in a rough neighborhood. The investigator was robbed at gunpoint during this investigation.

CALCULATED DATA:

IMPACT VELOCITY: 75 ft/sec (22.9 m/sec)

OAIS: 4

ISS: 29



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 11

SUBJECT: Male, 37 yr., 6 ft. (1.8 m), 185 lbs. (84.1 kg)

FALL DISTANCE: 1900 ft. (579 m)

ENVIRONMENT: Airplane to freshly plowed field

MAJOR INJURIES: Fatal - fractured neck.

SUMMARY: Subject was skydiving and his parachute didn't open. He fell 1900 feet onto a freshly plowed field of thick topsoil, landing on his feet. Subject was fatally injured at impact.

FALL CHRONOLOGY: Subject apparently was in a standing position as he descended to a very irregular, freshly plowed field of topsoil. Subject landed in a standing position with his left boot, helmet, right leg and body leaving very distinct impressions in the soil in the final resting position. His impact created a roughly circular and nearly uniform depression approximately 4 ft (1.2 m) diameter and 9-10 in (22-25 cm) deep in the soft soil.

SPECIFIC INJURIES: Subject received fatal injuries. The medical examiner listed probable cause of death as a fractured neck [NPFV-6]. Left upper and lower legs were completely shattered [TBFS-4;LBFS-4]. Head was not deformed, as jumper was wearing helmet, but blood noted from nose and left ear. Possibly right hip broken.

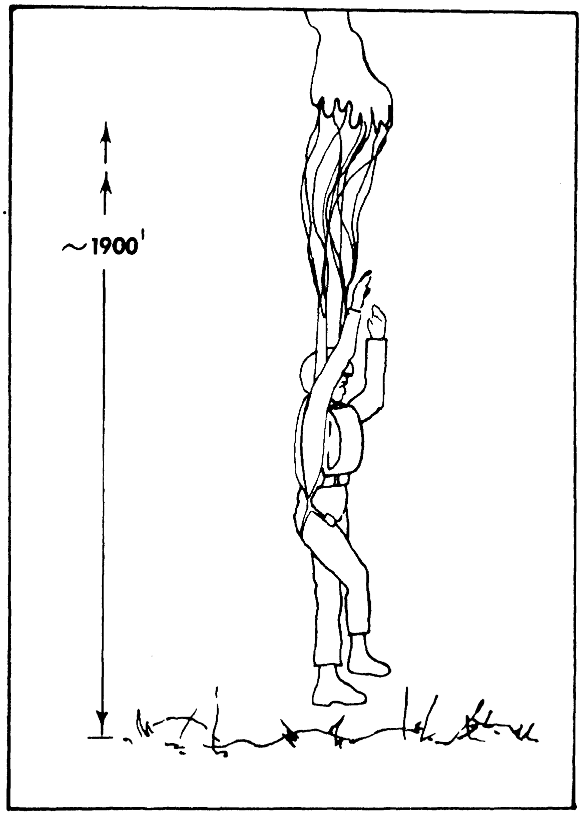
RECOVERY: Fatal.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;

X POLICE; __ HOSPITAL; __ WITNESSES;

X OTHER: Medical Examiner

OTHER COMMENTS: This was parachutist's first jump. Chute streamer came out, but sleeve snagged and there was no parachute deployment. The reserve chute was not deployed. No medical release was sought.



CALCULATED DATA:

IMPACT VELOCITY: *

OAIS: 6

ISS: N/A

* Probably terminal velocity, although there was a streamer from the main chute which may have slowed the descent.

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 12

SUBJECT: Male, 30 yr, approx 6 ft 4 in (1.93 m), weight unknown

FALL DISTANCE: 166 ft (50.6 m)

ENVIRONMENT: 14 th floor windowsill to roof of parked car

MAJOR INJURIES: Mild concussion, contused kidney, fractured rib, severe leg laceration.

SUMMARY: Subject climbed onto windowsill at 14th floor level of office building. In an attempted suicide, he jumped off the sill, fell 166 feet, and landed, back-first, crosswise on a parked automobile. The roof collapsed and the subject became wedged in the windshield opening. He was stunned and sustained a severe laceration to his left thigh, a fractured 4th right rib, a kidney contusion, and abrasions of his back. Length of hospitalization and degree of recovery are unknown.

FALL CHRONOLOGY: Subject stood on a narrow ledge outside his 14th floor office window, facing outward, and jumped. He impacted the roof of a four-door hardtop sedan, just behind the top of the windshield and 12 in (30 cm) right of center. At impact, his body was crosswise to the auto, supine and slightly buttocks-down. The roof and windshield collapsed and the subject passed through the windshield opening, crushed the instrument panel, and came to rest wedged in the front seat, with his legs dangling over the windowsill of the right front door.

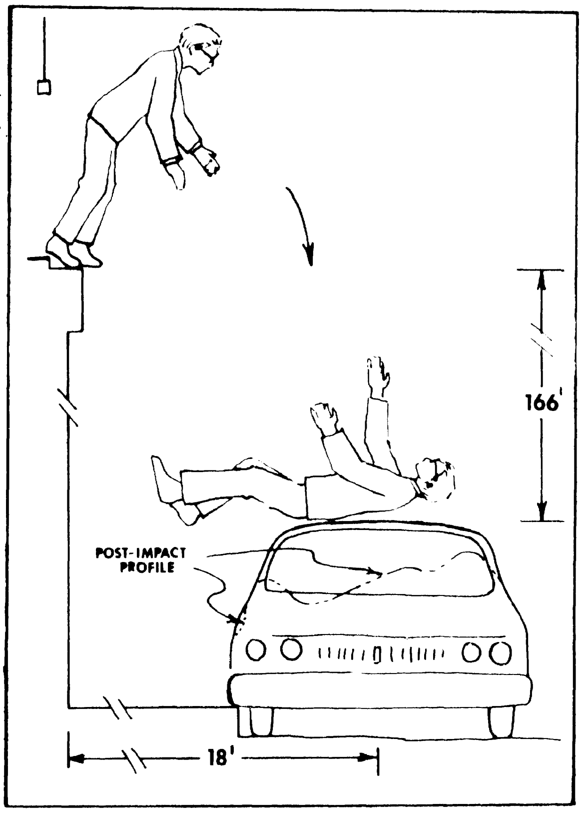
SPECIFIC INJURIES: Stunned, possible mild concussion [HPKB-2], deep laceration of soft tissue of left thigh, with ligament damage behind knee [TLLI-2]; displaced fracture, with dislocation, of 4th right rib [CRFS-3]; retroperitoneal hemorrhage, mild kidney contusion [MVHD-3, MUCK-3] laceration of tendon in right thumb [WRLI-1]; superficial glass abrasions and ecchymosis over entire back [BWAI-1].

RECOVERY: Unknown, but physician anticipated no complications.

SOURCES OF DATA: __ SUBJECT; __ PARENTS; __ POLICE; __ HOSPITAL; X WITNESSES;

X OTHER: Office building security, owner of auto, physicians, fire dept rescue, newspaper

OTHER COMMENTS: Greatest roof crush was 18 in (45 cm), top of right "A" pillar was deformed to below windowsills, instrument panel had 1" (2.5 cm) crush. Steering assembly was bent downward. Head and buttocks made depressions in roof, shoe heels dented right car doors.



CALCULATED DATA:

IMPACT VELOCITY: 95 ft/sec (28.6 m/sec)

0 AIS: 3

ISS: 22

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 13

SUBJECT: Male, 62 yrs 4 mo, height and weight unknown

FALL DISTANCE: 44 ft (13.4 m) with partial intermediate contact after 26 ft (7.9 m)

ENVIRONMENT: Top of grain elevator tower to wooden platform

MAJOR INJURIES: Severe concussion, internal injuries, fractures of facial bones, pelvis and lower leg. Fatal.

SUMMARY: Subject was freeing motor drive belt at top of tower. He lost balance and fell off the ladder, impacting his face on the edge of a shed roof and landing on a wooden platform at the base of the tower. He had multiple facial lacerations, a basilar skull fracture, renal contusion, ruptured spleen, and fractures of facial bones and the nose, left pelvis, left tibia and left fibula. He remained comatose until he died six weeks later.

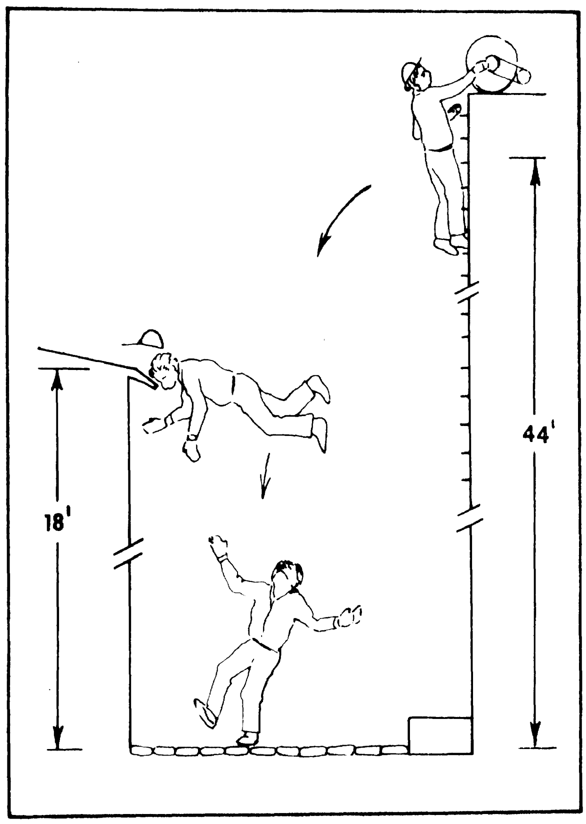
FALL CHRONOLOGY: Subject probably fell back away from top of tower and rotated as he fell. He hit unsupported overhang of corrugated steel shed roof 18 ft (5.5 m) above platform, then landed on wooden platform [boards 6 in. wide by 2¼ in thick (15 x 6 cm)] impacting first with his left leg. He came to rest in supine position on platform.

SPECIFIC INJURIES: Probable basilar skull fracture, with severe cerebral concussion and subdural hematoma [HWKB-5]; fractures of left zygoma, lateral wall of left orbit (displaced), and nose [FLFS-3, FCFR-2]; contusion of left lung [CLCP-3]; ruptured spleen [MLRQ-4]; severe bilateral retroperitoneal hemorrhage [MBHD-5]; fracture of left pubis [PAFS-2]; 3 fractures of left tibia (one comminuted), fracture left fibula [LLFS-3]; severe facial lacerations [FCLI-2].

RECOVERY: Remained in coma continuously and expired six weeks after fall.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
X POLICE; X HOSPITAL; __ WITNESSES;
X OTHER: Son, fire department

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 52 ft/sec (15.8 m/sec)

OAIS: 5

ISS: 59

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 14

SUBJECT: Male, 3 yrs 8 mo, 3 ft 4 in (1.02 m), 36 lbs (16.3 kg)

FALL DISTANCE: 74 ft 8 in (22.8 m)

ENVIRONMENT: 9th floor bedroom window to small bushes and soil

MAJOR INJURIES: Fractured right femur, fractured right arm

SUMMARY: Child climbed onto radiator, pushed out screen and fell nine stories. He landed on bushes and soft soil. He did not lose consciousness, and was observed by mother to be crawling on all fours immediately after the fall. He was hospitalized about 6 weeks with a fractured right arm and leg, and has apparently completely recovered.

FALL CHRONOLOGY: Subject reported by mother to have climbed onto radiator to window sill and pushed out screen. He fell straight down from window, through some 30 in (76 cm) juniper bushes, to soil which was a rain-soaked mixture of earth and gravel. He landed on his right side, about 3 ft (.9 m) from building. Remnants of a depression 8 in (20 cm) long and 24 in (61 cm) wide were present in the soil.

SPECIFIC INJURIES: Fractured right femur [TRFS-2]; fractured right "arm" [XRFS-2], contused right eye [FRCE-1]; concussion [HUKB-2].

RECOVERY: Apparently complete

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; __ HOSPITAL; __ WITNESSES; __ OTHER:

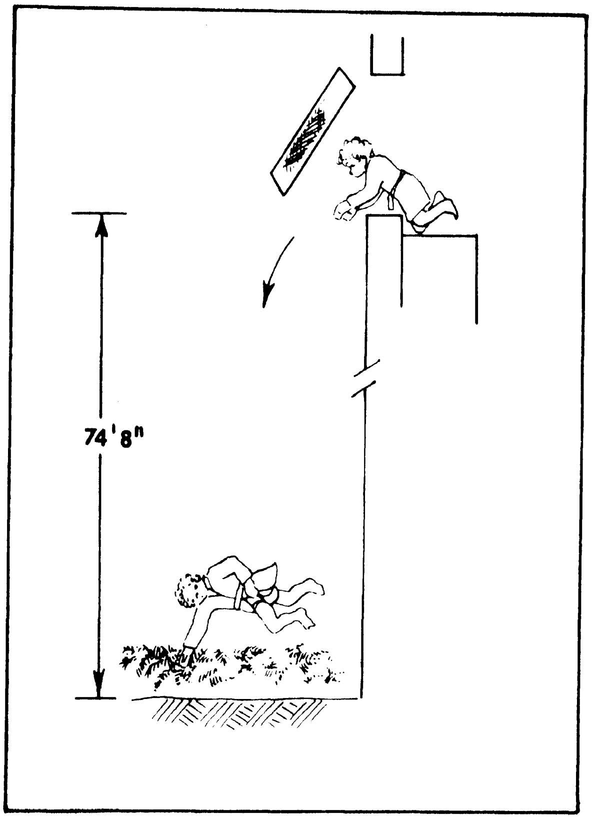
OTHER COMMENTS: Case in litigation; medical release unavailable.

CALCULATED DATA:

IMPACT VELOCITY: 66 ft/sec (20.1 m/sec)

OAIS: 2

ISS: 9



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 15

SUBJECT: Female, 2 yrs 2 mo., height and weight unknown

FALL DISTANCE: 26 ft 0 in (7.9 m)

ENVIRONMENT: Windowsill to soil

MAJOR INJURIES: No injuries

SUMMARY: Child was playing on couch and attempted to grasp a lamp on a table beside the couch. The lamp fell and the child fell against the window screen. She broke through screen and tumbled 26 ft from windowsill to bare soil below. She suffered no injuries (not even bruises), was examined and released from hospital.

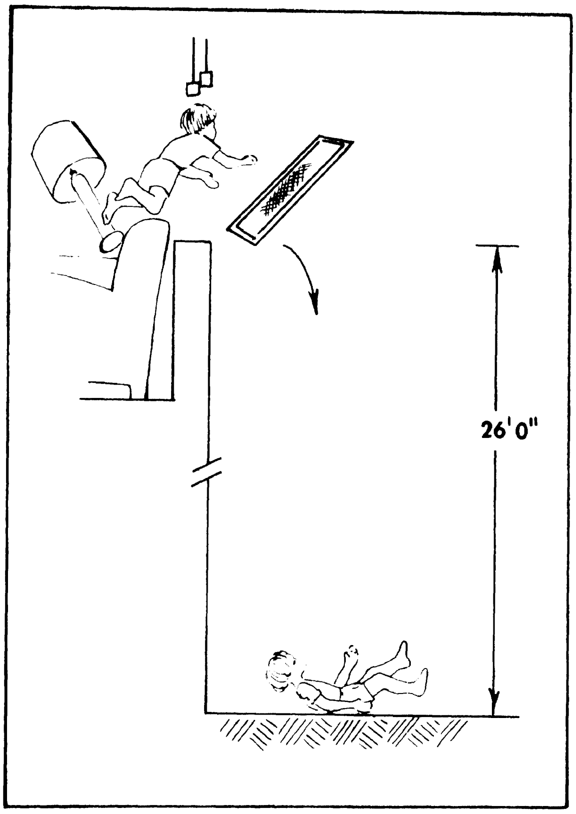
FALL CHRONOLOGY: Child lost her balance when she leaned against screen and it gave way. She tumbled from window facing forward, turned a half somersault and landed to rest on her back on bare soil. The soil had probably been softened somewhat by rains four days earlier, but was not wet or muddy.

SPECIFIC INJURIES: None

RECOVERY: No injuries. Child was examined at local hospital. No bruises or fractures or other injuries observed, so child was released.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
X POLICE; __ HOSPITAL; __ WITNESSES;
X OTHER: weather service

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 40 ft/sec (12.2 m/sec)

OAIS: 0

ISS: 0

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 16

SUBJECT: Female, 3 yrs 8 mo, 3 ft 1 in (0.97 m), 26 lbs (11.8 kg)

FALL DISTANCE: 11 ft 0 in (3.4 m)

ENVIRONMENT: Roof to concrete

MAJOR INJURIES: Subgaleal hematoma, linear skull fracture, black eye.

SUMMARY: Child was pursuing a cat on a flat roof which was readily accessible from some outside stairs. Child fell from roof, 12 ft, landing on a concrete walkway. Injuries sustained were two nondepressed linear skull fractures, subgaleal hematoma and blackened left eye. Child was hospitalized for 4 days and appears fully recovered.

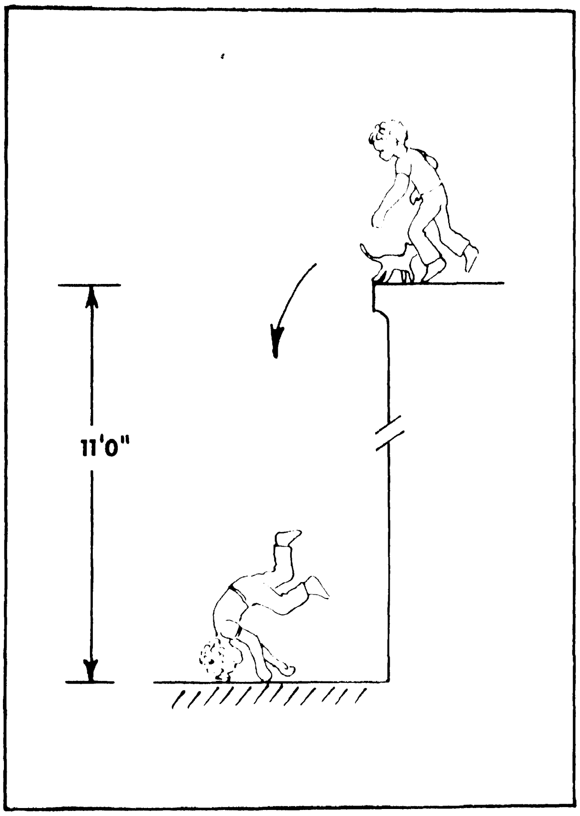
FALL CHRONOLOGY: Child probably stumbled off roof while moving forward. She landed on the top of her head on a concrete walkway.

SPECIFIC INJURIES: Subgaleal hematoma across top of head [HSCI-1]; nondepressed linear skull fracture that extended from right to left temporoparietal areas over top of head, with small linear fracture adjoining [HSFS-2]; contused left eye [FLCE-1].

RECOVERY: Complete, according to parents.

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; X HOSPITAL; __ WITNESSES; __ OTHER:

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 26 ft/sec (7.9 m/sec)

OAIS: 2

ISS: 5

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 17

SUBJECT: Male, 21 yrs, height and weight unknown

FALL DISTANCE: 49 ft 10 in (15.2 m)

ENVIRONMENT: Window to concrete sidewalk

MAJOR INJURIES: Two fractured thoracic vertebrae, fracture left wrist, fractures of both heels.

SUMMARY: Prisoner attempted to escape by breaking a window on the 4th floor of a court building lockup and lowering himself on a rope made out of pieces of blanket. Apparently, he slipped from the rope and fell to the concrete sidewalk below. Subject was hospitalized 11 days for treatment of a fractured left wrist, compression fractures of two thoracic vertebrae, and bilateral fractures of the calcaneus bones of the heel. He was expected to recover after 9-15 weeks of convalescence.

FALL CHRONOLOGY: During an escape attempt, prisoner broke a 4th floor window and began to lower self on a 20 ft makeshift rope. He slipped from rope and fell to concrete sidewalk. Subject was found lying on his left side in a fetal position though injuries indicate that the subject landed feet first.

SPECIFIC INJURIES: Compression fractures of T-10 and T-11 [BSFV-3]; bilateral fractures of calcaneus, with probable displacement [QBFS-3]; fracture left wrist [WLFS-2].

RECOVERY: Not expected to walk for 9-15 weeks.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
X POLICE; __ HOSPITAL; __ WITNESSES;
X OTHER: attorneys; physician

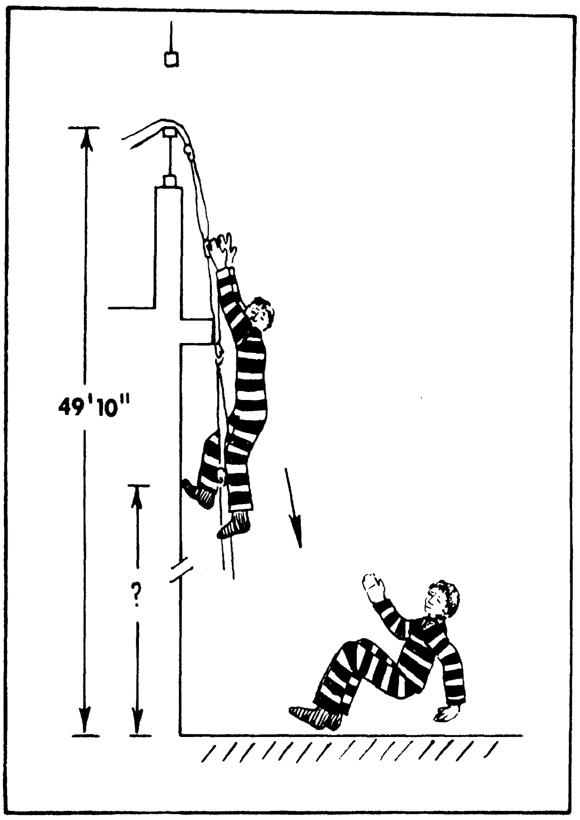
OTHER COMMENTS: Precise fall distance unknown, since it is not known if he had climbed part way down rope.

CALCULATED DATA:

IMPACT VELOCITY: 55 ft/sec (16.8 m/sec)

OAIS: 3

ISS: 18



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 18

SUBJECT: Male, 71 yrs, height and weight unknown

FALL DISTANCE: 49 ft 0 in (14.9 m)

ENVIRONMENT: Window to grass-covered soil

MAJOR INJURIES: "Critical" condition after fall.

SUMMARY: Subject was eating when a piece of food became lodged in his throat. He got up from the table, went over to the window, and leaned his head out apparently with the idea of dislodging the food. Subject lost his balance, knocked out screen, and fell through the open window, 49 ft, to the grass-covered soil below. Subject was hospitalized in critical condition. Recovery unknown, but he was still in hospital (stable condition) 16 days after the fall.

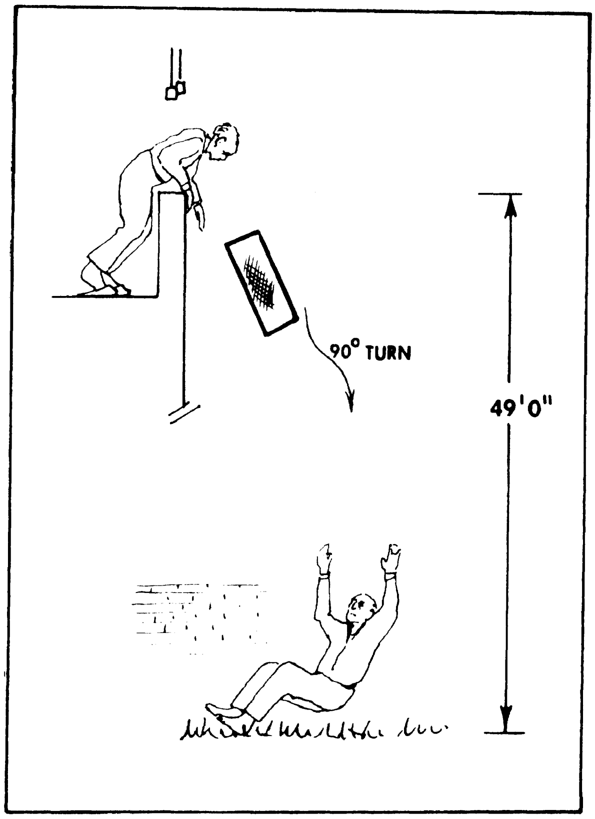
FALL CHRONOLOGY: Subject was leaning out of open window of fifth-floor apartment, possibly choking. He lost his balance and fell through the window. He was found lying on his back in a grassy section of the yard.

SPECIFIC INJURIES: Conscious and able to move arms after fall. Listed in critical condition after admission to hospital. 16 days later was in stable condition, in traction. Traction suggests lower spinal or lower extremity injuries.

RECOVERY: In hospital at least 6 weeks, but final condition not known.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
X POLICE; __ HOSPITAL; X WITNESSES;
X OTHER: Sister, age 73

OTHER COMMENTS: Subject in too critical condition for initial interview, and subsequently sister refused medical release.



CALCULATED DATA:

IMPACT VELOCITY: 54.5 ft/sec

OAIS: Unknown

ISS: Unknown

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 19

SUBJECT: Male, 59 yrs., 5 ft. 10 in. (1.77 m.), 160 lbs. (72.6 kg.)

FALL DISTANCE: 11 ft. 0 in. (3.4 m.)

ENVIRONMENT: Scaffolding to concrete slab floor

MAJOR INJURIES: Laceration of left rear scalp; compressed fracture of L1 and L4 vertebrae

SUMMARY: Sheet metal worker fell 11 ft. while installing ductwork at a supermarket construction site. He fell from scaffolding, head first, onto a concrete slab floor. Subject was hospitalized for 9 days and expects to be off the job for 5-6 months.

FALL CHRONOLOGY: Subject was working atop two sections of scaffolding with wheels. Wheels were locked and planks were in place. Scaffold had railing except for end from which subject fell. Subject believes he was turning around to pick up some ductwork at the time of his fall. He knows he hit head first on concrete and rolled somewhat. Hard hat came off during fall as the chin strap was not fastened.

SPECIFIC INJURIES: Laceration of left rear scalp requiring several stitches [HLLI-1]; compressed fracture of L1 and L4 vertebrae [BIFV-3]; bilateral soreness across upper back and lower neck [BSPM-1].

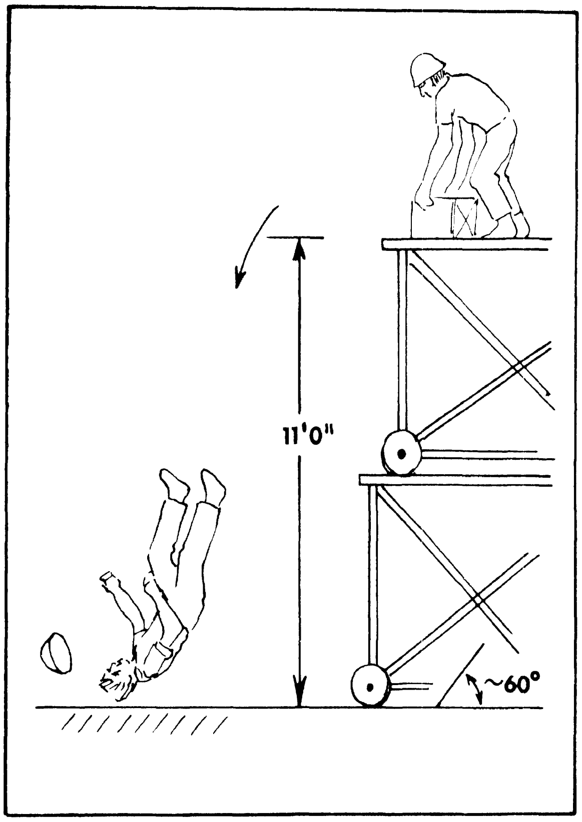
RECOVERY: Not allowed, nor capable of, work, though gets around well. Expects to be out of work 5-6 months. Wears back brace when up. Was told "healing satisfactorily".

SOURCES OF DATA: X SUBJECT; __ PARENTS;

__ POLICE; __ HOSPITAL; X WITNESSES;

__ OTHER:

OTHER COMMENTS: Subject's son was witness to the fall. Subject refused to sign medical release.



CALCULATED DATA:

IMPACT VELOCITY: 26 ft./sec. (7.9 m./sec.)

OAIS: 3

ISS: 11

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 20

SUBJECT: Male, 53 yrs., height and weight unknown

FALL DISTANCE: Unknown

ENVIRONMENT: Down elevator shaft to concrete

MAJOR INJURIES: Broken sternum; multiple fractures

SUMMARY: Worker fell into open elevator shaft. Subject pushed handcart into elevator opening and fell in after it. Safety gate had malfunctioned and was open. Elevator was one floor above. Knowledge of details of fall are limited by legal repercussions of the fall.

FALL CHRONOLOGY: Worker fell down an elevator shaft. The subject probably fell from the second floor level, though it was thought that he was talking with a fellow worker on the third floor when he fell. Subject impacted "the elevator pit". It was not possible to examine the site.

SPECIFIC INJURIES: Neither hospital nor newspaper reported extent of injuries. Possible fractured sternum [CCFS-2]; multiple fractures, "back trouble".

RECOVERY: Subject was at home recuperating, but had not yet recovered.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;

__ POLICE; __ HOSPITAL; __ WITNESSES;

_X_ OTHER: Newspaper, owner of building, insurance company representative

OTHER COMMENTS:
Litigation prevented any detailed investigation of this fall.

Unknown

CALCULATED DATA:

IMPACT VELOCITY: Unknown

OAIS: Unknown

ISS: Unknown

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 21

SUBJECT: Male, 3 yrs 6 mos, 3 ft 5 in (1.04 m), 40 lbs (18.1 kg)

FALL DISTANCE: 11 ft. 0 in. (3.4 m.)

ENVIRONMENT: Windowsill to slate floor

MAJOR INJURIES: Concussion; possible cerebral contusion

SUMMARY: Child fell from second floor window of his room to slate stone floor of foyer inside house. Subject fell head first, 11 feet, sustaining multiple head injuries including concussion and various contusions. Parents transported subject to hospital after his fall. He was discharged 7 days later and has

FALL CHRONOLOGY: Child was sitting on windowsill of opening which overlooks foyer, facing into the room. He fell backward through the opening, landing head first on a slate floor and narrowly missing a metal ventilation grate in the floor. He was crying and starting to stand up when his mother arrived a few seconds after she heard him land.

SPECIFIC INJURIES: Linear skull fracture of left frontal, parietal and temporal bones down to anterior fossa and orbit [FSFS-2, HLFS-2]; cerebral concussion [HLKB-2]; "huge" contusion and hematoma of left side of head [HLCI-1].

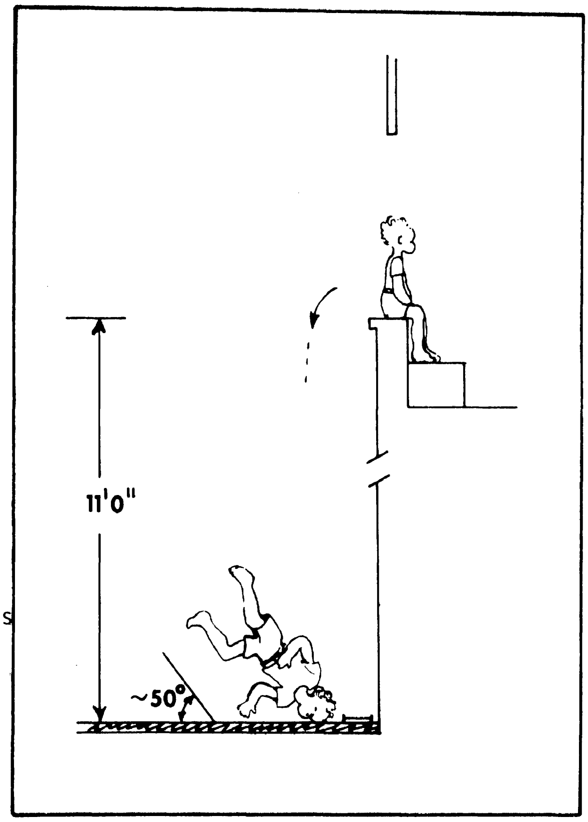
RECOVERY: Apparently complete. Mother reports no ill effects or lingering problems as a result of his fall.

SOURCES OF DATA: __ SUBJECT; _X_ PARENTS;

__ POLICE; _X_ HOSPITAL; _X_ WITNESSES;

__ OTHER:

OTHER COMMENTS: Family had occupied house for only 2 weeks prior to fall.



CALCULATED DATA:

IMPACT VELOCITY: 26 ft./sec. (7.9 m./sec)

OAIS: 3

ISS: 5

This case was extensively simulated. Responses do not account for fracture effects.
(See Chapter 3)

Est. peak head accel: 370-391 g's

Est. peak head normal force: 3300-3900 lbs. (14,680-17,350N)

Est. peak head deflection: .41-.47 in (1.04-1.19 cm)

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 22

SUBJECT: Female, 10 yrs., 1/2 month, 4 ft. 6 1/2 in. (1.38 m.), 63 lbs. (28.5 kg.)

FALL DISTANCE: 35-37 ft. (10.7-11.3 m.)

ENVIRONMENT: Tree to hard ground

MAJOR INJURIES: Concussion, cortical contusion, other contusions

SUMMARY: Subject fell while climbing a tree with friends. She fell approximately 35 ft. landing on her back on hard ground. Subject was unconscious immediately upon impact and slowly came out of coma over a two week period of hospitalization. Not functioning normally at time of investigation, but later follow up indicated minimal residual effects.

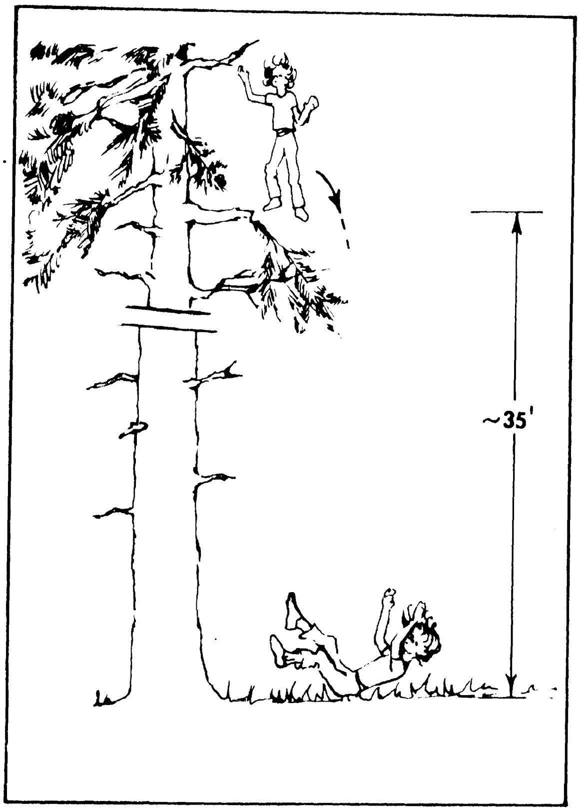
FALL CHRONOLOGY: Subject was climbing a pine tree in a park near her home. Branch apparently snapped underfoot, throwing her free of tree. She landed on her back, buttocks slightly down--on rather hard ground covered thinly by grass and pine needles.

SPECIFIC INJURIES: Concussion, unconscious then semiconscious for two weeks [HLKB-4]; left fronto-parietal cortical contusion [HLKB-4]; corneal abrasion of right eye [FRAE-1]; no fractures; contusions on left side of head [HLCI-1] and on lower back [BLCI-1].

RECOVERY: Not completely recovered. Has good memory, slightly-abnormal - but-improving EEG. Has regained most normal functions, but slight speech and motor problems yet. Doing OK in school.

SOURCES OF DATA: __ SUBJECT; X PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES; __ OTHER:

OTHER COMMENTS: Two playmates witnessed fall. However, both children were regarded as unreliable witnesses. Fall height was estimated using rangefinder, since tree could not be climbed.



CALCULATED DATA:

IMPACT VELOCITY: 47-48 ft./sec. (14.3-14.6 m./sec.)

OAIS: 4

ISS: 18

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 23

SUBJECT: Male, 9 yrs., 4 ft. 2 1/2 in. (1.28 m.), 61 lbs. (27.6 kg)

FALL DISTANCE: 10 ft. 4 in. (3.2 m)

ENVIRONMENT: Second story window to concrete slab

MAJOR INJURIES: Skull fracture, concussion

SUMMARY: Child was jumping on bed situated beside a second story window of his residence. Subject fell 10 feet, head first, to a small concrete patio. He was hospitalized for 10 days with a fractured skull. Recovery is complete except for some problems in comprehension.

FALL CHRONOLOGY: Child was playing by jumping on his bed when he lost his balance and his momentum carried him through a second story window. The window was open and the screen was dislodged by his fall. The subject fell head first onto a 4 inch thick concrete slab patio. He was found lying chest down with legs drawn up under him. Subject's head and chest were on the concrete while legs were on the grass.

SPECIFIC INJURIES: Linear fracture of frontal skull bone (not depressed), cerebral concussion [HRKB-3]; laceration of right knee [KRLJ-1].

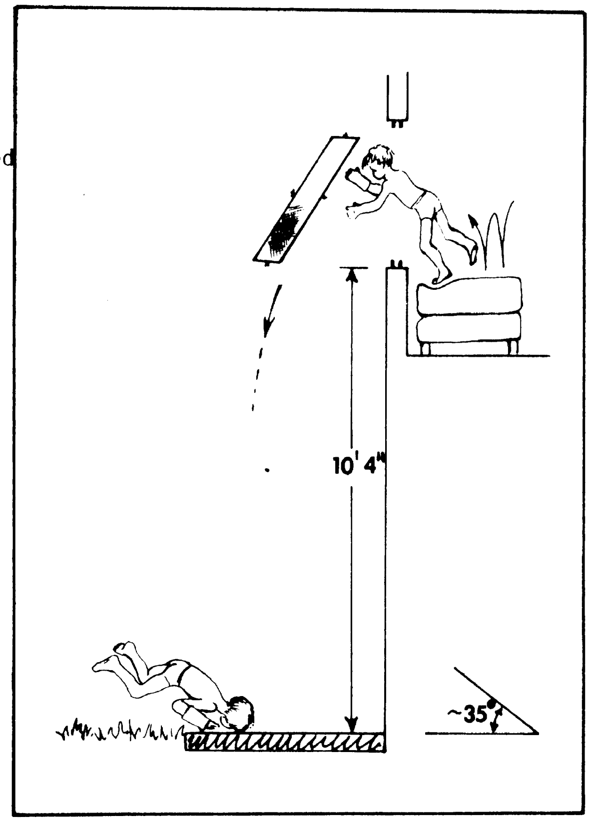
RECOVERY: Not quite complete. Parents feel he is slower, less bright in school.

SOURCES OF DATA: __ SUBJECT; X PARENTS;

__ POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: Apt. manager, ambulance service.

OTHER COMMENTS: Townhouse where fall occurred was vacant at the time of investigation. At the time of fall, the subject had a cast on his right arm from a previous injury.



CALCULATED DATA:

IMPACT VELOCITY: 25 ft./sec. (7.6 m./sec.)

OAIS: 3

ISS: 10

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 24

SUBJECT: Female, 3 yrs. 5 mos., 3 ft. 1 in. (.94 m.), 31 lbs. (14 kg)

FALL DISTANCE: 49 ft. 0 in. (14.9 m.)

ENVIRONMENT: Sixth floor balcony railing to damp, grass-covered soil.

MAJOR INJURIES: Mild concussion, pulmonary contusion with hemothorax, multiple rib fractures, right elbow fracture.

SUMMARY: Subject was playing alone on balcony, climbed onto balcony rail and fell 49 feet to damp ground below, landing on her back. Injuries include unconsciousness at the scene, a broken right elbow and right hemothorax. She was hospitalized seven days. Recovery is essentially complete.

FALL CHRONOLOGY: Subject probably climbed onto a folded lawn chair near balcony railing, lost balance and fell forward over railing. She landed on her back, on grass-covered soil that had been dampened by recent rains.

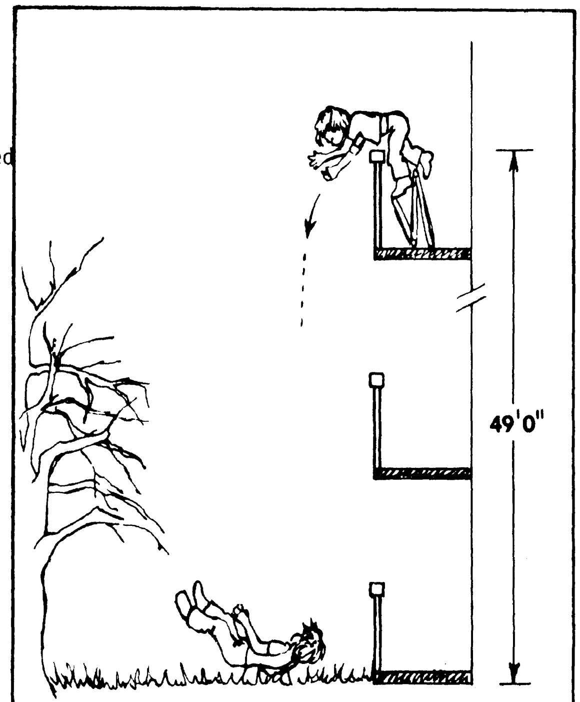
SPECIFIC INJURIES: Unconscious at scene, but fully awake within 24 hours [HWKB-3]. Multiple fractures of ribs on right side [CRFS-3]. Right pulmonary contusion with right pneumohemothorax [CRCP-3, CRHP-3]. Right elbow had comminuted supercondylar fracture with displacement of distal fragment [ERFJ-3].

RECOVERY: Apparently complete. There were no complications noted by the parents.

SOURCES OF DATA: __ SUBJECT; X PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: Newspaper

OTHER COMMENTS: A witness had been identified but could not be located. Lawn was strewn with apples from nearby tree, but there were no specific bruises attributable to them.



CALCULATED DATA:

IMPACT VELOCITY: 54 ft./sec. (16.5 m/sec)

OAIS: 4

ISS: 27

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 25

SUBJECT: Male, 3 yrs. 4 mos., 3 ft. 5 in. (1.04 m.), 35 lbs. (15.9 kg)

FALL DISTANCE: 20 ft. 8 in. (6.3 m.)

ENVIRONMENT: Windowsill to hood of car to asphalt surface

MAJOR INJURIES: No major injuries

SUMMARY: Child fell nearly 21 feet from third floor windowsill to hood of parked subcompact car, striking his head. He was found lying on the asphalt parking lot. Subject did not lose consciousness and his only injury was a bruise in the right parietal region. He was hospitalized three days for observation and is fully recovered.

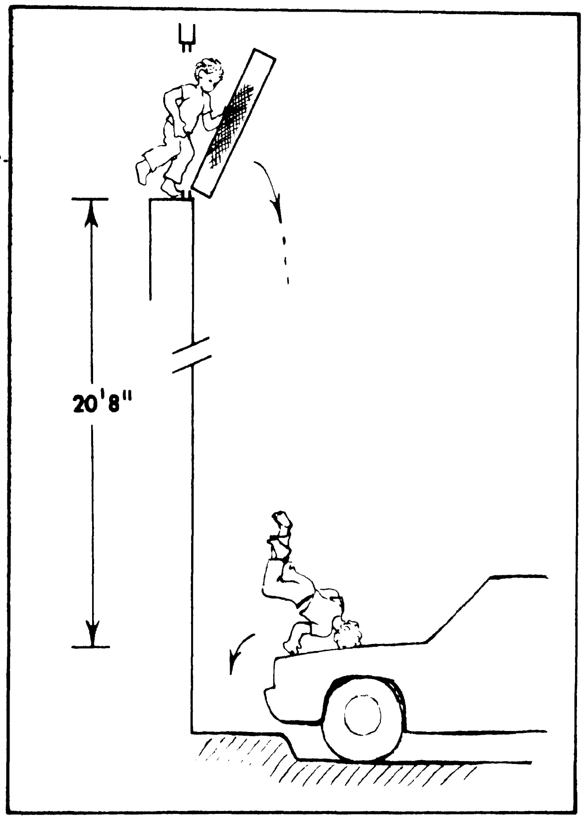
FALL CHRONOLOGY: Child was playing on wide windowsill of third floor bedroom at time of the fall. The window was open. The child fell against the screen, dislodging it, and toppled out of the window. He landed on the hood of a parked car, striking the right parietal skull area. He then rolled off hood onto the paved surface in front of vehicle where he was found by mother.

SPECIFIC INJURIES: Swelling in right parietal skull area [HRCI-1]. No other injuries.

RECOVERY: He "favored" his right upper arm and shoulder for a few days. Completely recovered.

SOURCES OF DATA: _X_ SUBJECT; _X_ PARENTS;
__ POLICE; _X_ HOSPITAL; __ WITNESSES;
_X_ OTHER: Apartment manager

OTHER COMMENTS: There was no permanent deformation to the hood of the car, and no indications of damage due to impact from above.



CALCULATED DATA:

IMPACT VELOCITY: 36 ft./sec (11.0 m./sec.)

OAIS: 1

ISS: 1

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 26

SUBJECT: Female, 3 yrs. 4 mos., 3 ft. 5 in. (1.06 m.), 30 lbs. (13.6 kg.)

FALL DISTANCE: 32 ft. 7 in. (9.9 m.)

ENVIRONMENT: Windowsill to damp, grass-covered soil.

MAJOR INJURIES: No major injuries

SUMMARY: Child was playing with her brother (Case 27) in the bedroom of their fourth floor apartment, probably sitting on windowsill. Apparently one child lost balance and grabbed the other. They both fell backward through the open window nearly 33 ft. to the lawn. Subject landed in sitting position. No injuries of any consequence were received. She was hospitalized 24 hours for observation and is fully recovered.

FALL CHRONOLOGY: Child was sitting on windowsill of fourth floor bedroom window, facing into the room. Witness saw window screen come out followed by the subject, who tumbled in the air several times and landed in a sitting position on damp soil. Subject did not collide in the air with, nor land on top of, her brother.

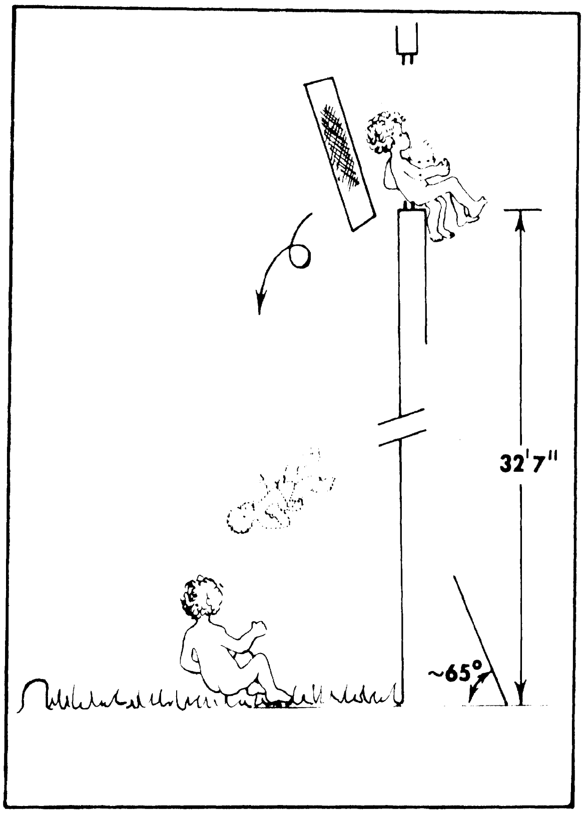
SPECIFIC INJURIES: Only specific injuries noted were vague abdominal pain [MWPM-1] and a slight cut on lip [FILD-1]. No fractures, no loss of consciousness. Final diagnosis was listed as "head injury".

RECOVERY: Complete, no complications since the fall.

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; X HOSPITAL; X WITNESSES;

X OTHER: Apartment manager.

OTHER COMMENTS: Lawn apparently absorbed much of impact. Subject had just had bath and was naked.



CALCULATED DATA:

IMPACT VELOCITY: 45 ft./sec. (13.7 m./sec)

0AIS: 1

ISS: 2

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 27

SUBJECT: Male, 1 yr 5 mos, 2 ft 10 in (.86 m), 25 lbs (11.3 kg)

FALL DISTANCE: 32 ft. 7 in.

ENVIRONMENT: Windowsill to damp, grass-covered soil.

MAJOR INJURIES: No major injuries.

SUMMARY: Child was playing with his sister (see Case 26) in the bedroom of their fourth floor apartment, probably sitting on the windowsill. Apparently, one child lost balance and grabbed at the other. Both fell backward through the open window nearly 33 feet to the lawn. Subject landed on his right side, slightly buttocks-first. Child received no significant injuries. He was hospitalized for observation for two days, and is fully recovered.

FALL CHRONOLOGY: Child was sitting on windowsill of fourth floor bedroom window, facing into room. Witness saw window screen come out, followed by female child, followed immediately by subject. He tumbled once in the air and landed on his right side on the damp, grassy soil. Subject did not collide in the air with, or land on top of, his sister.

SPECIFIC INJURIES: No injuries except two slight abrasions on right hip [PRAI-1]. No loss of consciousness, no fractures. Hospital diagnosis was listed as "head injury".

RECOVERY: Immediate and complete--no complications since fall.

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; X HOSPITAL; X WITNESSES; X OTHER: Apartment manager.

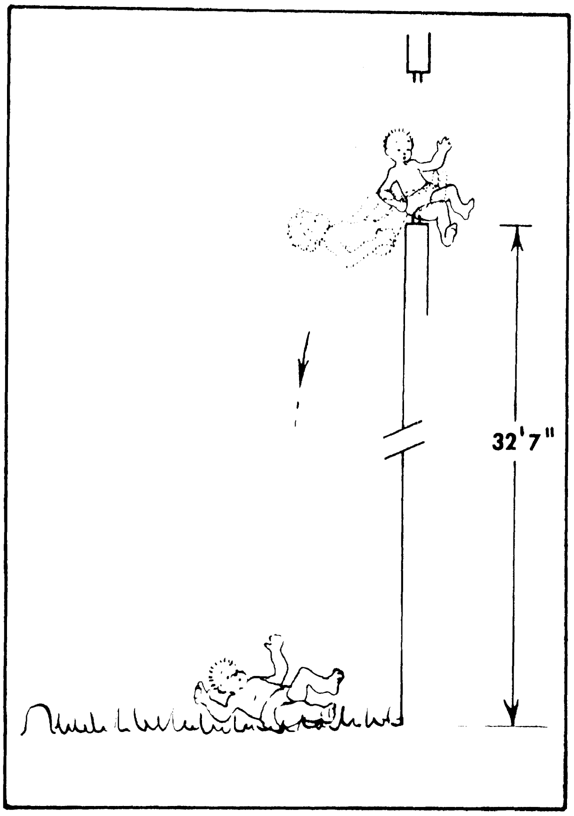
OTHER COMMENTS: Lawn apparently absorbed much of impact. Child was clad only in diapers.

CALCULATED DATA:

IMPACT VELOCITY: 45 ft./sec. (13.7 m./sec.)

0 AIS: 1

ISS: 1



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 28

SUBJECT: Male, 19 yrs. 4 mos., 5 ft. 3 in. (1.60 m.), 125 lbs. (56.7 kg.)

FALL DISTANCE: 75 ft. 4 in. (23.0 m.)

ENVIRONMENT: Flat roof to asphalt

MAJOR INJURIES: Fractures of the right pelvis, left femur, left fibula, left foot and ankle, right tibia, right ankle, and right first rib, sternal separation, hemothorax, and abrasions.

SUMMARY: Window cleaner fell from flat roof to asphalt sidewalk below as he was preparing to move washing cage. Subject fell 75 feet, feet first, sustaining fractures of the pelvis and both lower extremities, rib and sternal fractures, and a left hemothorax. He was hospitalized 34 days, and was confined to a wheelchair when released. Ultimate recovery is unknown.

FALL CHRONOLOGY: Subject pulled on snagged cable. It came loose suddenly and he stumbled backward, spun around and tripped over a six-inch (15.3 cm.) ledge at the edge of the flat roof. He was able to grip the ledge, facing the building, for a few moments with his fingertips, then had to release. He dropped straight down, turning 90 degrees to the right as he fell. He landed, feet-first, about 4 feet (1.2 m.) from the building, on a smooth asphalt sidewalk. As he impacted, he attempted to throw himself forward.

SPECIFIC INJURIES: Fracture of roof of right acetabulum with posterior displacement of head of femur [PRDJ-3]; comminuted fracture with gross displacement of shaft of left femur [TLFS-3]; fracture of upper shaft of left fibula [LLFS-2]; fracture or displacement of 3 left metatarsals and one phalange [QLDJ-2]; fracture of right tibia at the ankle, comminuted and displaced fractures of right calcaneus and navicular [QRFJ-3]; fracture of right first rib on posterior aspect [CRFS-2]; dislocation (8 mm. anteriorly) of body of sternum [CCFS-3]; left hemothorax [CLHP-3]; Laceration of right palm [WRLI-1]; abrasion of left knee [KLAI-1]; pain on left side of face [FLPM-1]. No head injuries.

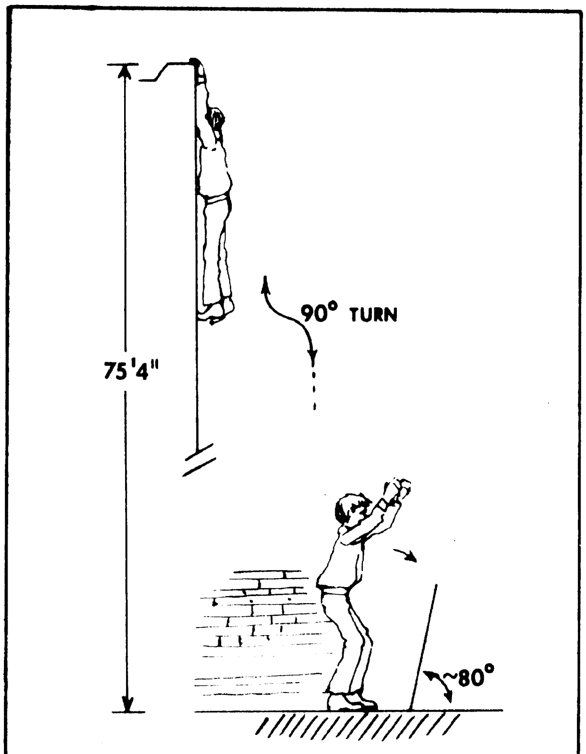
RECOVERY: Subject was still hospitalized at time of investigation (16 days after fall). He expected to recover fully, but thought he would have ankle trouble for a long time.

SOURCES OF DATA: X SUBJECT; __ PARENTS;

X POLICE; X HOSPITAL; __ WITNESSES;

__ OTHER:

OTHER COMMENTS: Subject interview, police and medical records were all in French. A police detective assisted in the interview and translated. Subject had vivid recollection of fall details and claims to have consciously tried to roll at impact. He remembered how to fall from jujitsu training.



CALCULATED DATA:

IMPACT VELOCITY: 66 ft./sec. (20.1 m./sec.)

OAIS: 4

ISS: 19

This case was simulated (see Chap. 3)
Est. peak accel: head 26-35 g; hip 293-312 g
Est. peak axial force(max if no fracture had occurred):
- Foot: 800-9250 lb (36,000-41, 100N)
- Tibia at foot: 12,900-14,100 lb(57,400-62,700N)
- Tibia at knee: 6450-7450 lb (28,700-33,100N)
- Femur proximal; 4200-4800 lb (18,700-21,400N)

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 29

SUBJECT: Female, 1 yr 2 mos, height and weight unknown

FALL DISTANCE: 18 ft. 2 in. (5.5 m)

ENVIRONMENT: Balcony to asphalt driveway

MAJOR INJURIES: Skull fracture

SUMMARY: Baby slipped between slats of balcony of third floor of apartment house, falling 18 ft. to asphalt driveway below. The only apparent injury was a fractured skull.

FALL CHRONOLOGY: Baby slipped through a 6.5 in. (16.5 cm.) gap between decorative slats of apartment house railing, so she probably began falling from a head first position. She landed on a slightly-sloped smooth asphalt driveway, probably head-first.

SPECIFIC INJURIES: No medical records release. Only known injury was a skull fracture [HUFS-2].

RECOVERY: Child appears completely normal. Mother indicates complete recovery.

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; __ HOSPITAL; __ WITNESSES; X OTHER: Newspaper office

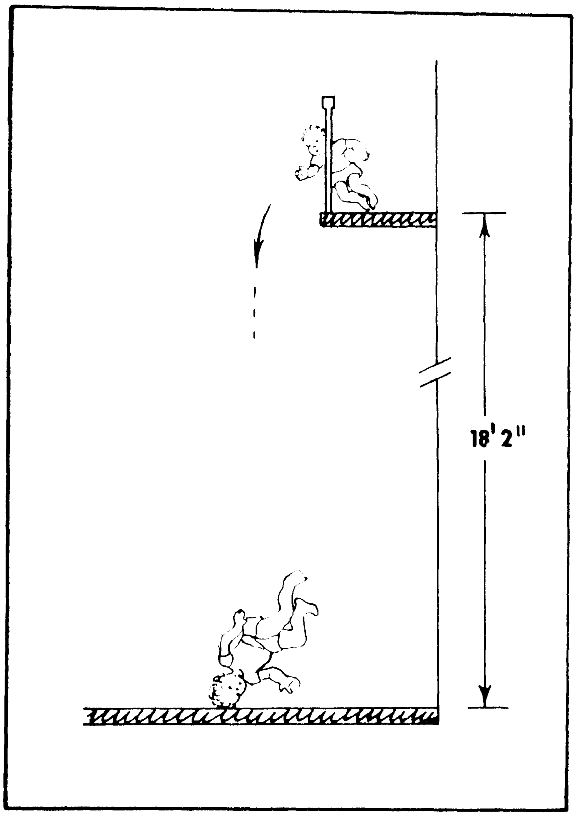
OTHER COMMENTS: Access to information was limited by pending legal action.

CALCULATED DATA:

IMPACT VELOCITY: 34 ft./sec. (10.4 m/sec)

OAIS: 2

ISS: 4



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 30

SUBJECT: Male, 20 yrs., 6 ft. (1.82 m.), 160 lbs. (72.6 kg.)

FALL DISTANCE: 42 ft. 6 in. (13.0 m.)

ENVIRONMENT: Windowsill to bare hard-packed soil.

MAJOR INJURIES: Concussion

SUMMARY: Subject fell from sitting position on windowsill of fourth floor apartment, approximately 42 feet, to bare soil below. Subject was found supine and semi-conscious. As virtually no other injuries were sustained, subject was hospitalized overnight, then released.

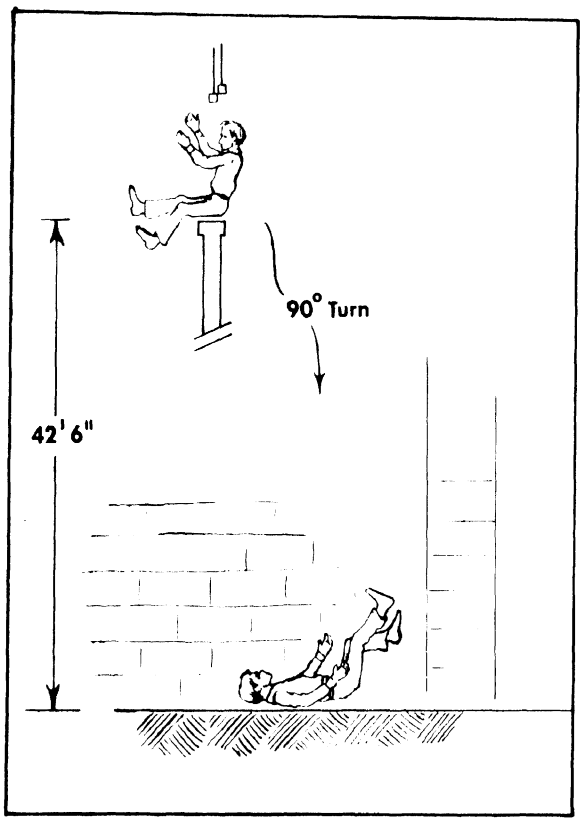
FALL CHRONOLOGY: Subject was sitting on the windowsill of a fourth floor apartment. He fell backward, landing on his back on bare soil below. When police arrived, subject was supine and semi-conscious.

SPECIFIC INJURIES: Concussion [HUKB-2]; slight bleeding at upper margins of upper two incisors [FIOS-1]. No fractures.

RECOVERY: Subject could not be contacted.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
_X_ POLICE; _X_ HOSPITAL; __ WITNESSES;
_X_ OTHER: Apartment manager

OTHER COMMENTS: Alcohol was noted to be on subject's breath, degree of intoxication not known. Subject was transient and could not be located.



CALCULATED DATA:

IMPACT VELOCITY: 51 ft./sec. (15.5 m./sec.)

OAIS: 2

ISS: 5

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 31

SUBJECT: Female, 5 yrs. 1 mo., 4 ft. 1 in. (1.24 m.), 81 lbs. (36.7 kg.)

FALL DISTANCE: 21 ft. 0 in. (6.4 m.)

ENVIRONMENT: Escalator railing to asphalt tile over concrete.

MAJOR INJURIES: Skull fracture, severely bruised right eye, abrasions.

SUMMARY: Girl became separated from babysitter at a two-story shopping mall and apparently fell 21 feet from the moving rail of a down escalator to the tiled, concrete floor below. Primary injuries were a basilar skull fracture, a severely bruised right eye, and abrasions. Subject was hospitalized for one week, and is now fully recovered.

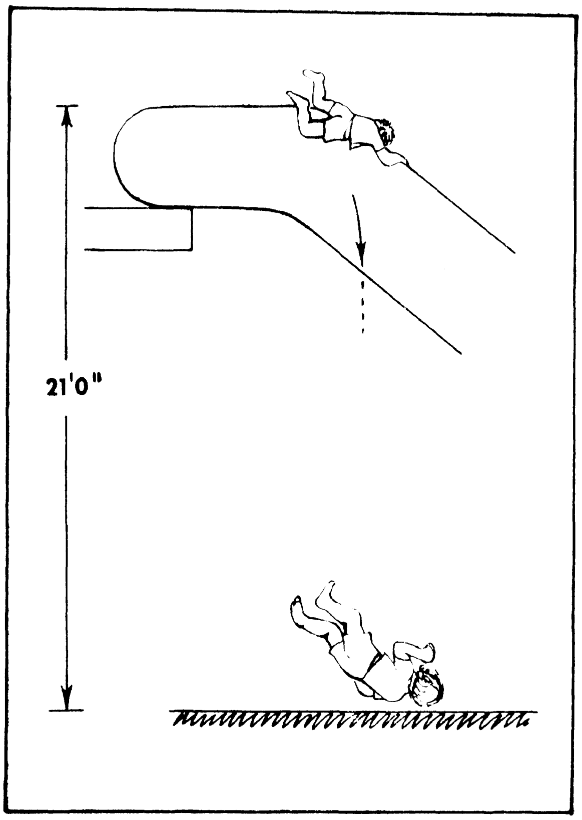
FALL CHRONOLOGY: Subject apparently grabbed the moving rail of the down escalator and was pulled up onto the top of the railing. Witnesses claimed that the subject attempted to throw a leg over the railing, straddled it for a short distance, then lost her balance and fell. She probably landed on the right side of her head on a tiled concrete floor.

SPECIFIC INJURIES: Basilar skull fracture, probably through the right middle fossa (diagnosed from symptoms, but not visible on X-rays), with concussion [HIKB-3]; hematoma in right occipital mastoid area [HROI-1]; slight hematuria [MUCK-3]; severely bruised right eye [FRCE-2]; abrasions of right abdominal wall and right shoulder [MRAI-1, SRAI-1]. No loss of consciousness.

RECOVERY: Recovery is apparently complete, although there appeared to be some residual darkening around right eye.

SOURCES OF DATA: X SUBJECT; X PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES; __ OTHER:

OTHER COMMENTS: Fall was witnessed and their descriptions were related by mother.



CALCULATED DATA:

IMPACT VELOCITY: 36 ft./sec. (11.0 m./sec.)

OAIS: 3

ISS: 22

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 32

SUBJECT: Male, 4 yrs. 6 mos., 3 ft. 5 in. (1.04 m.), 36 lbs. (16.5 kg.)

FALL DISTANCE: 10 ft. 0 in. (3.1 m.)

ENVIRONMENT: Fire escape stairs to wooden platform (and probably on metal stair).

MAJOR INJURIES: Multiple skull fractures, scalp laceration.

SUMMARY: Child fell from near top of fire escape stairs. The subject probably struck his head on metal stair rung before landing on wooden floor of second-floor fire escape balcony, 10 feet below. Recovery is complete except for bad memories.

FALL CHRONOLOGY: Child was playing with companions on third floor fire escape balcony when he started down the fire escape stairs to the second floor. At an unknown point near the top of the stairs, he fell, probably striking his head on a metal stair rung and finally landing on the wooden floor of the second-floor fire escape balcony. His positions at the beginning and end of the fall are unknown.

SPECIFIC INJURIES: Open depressed fracture of right frontal and parietal bones, with extension to right squamosal suture and extension to right mastoid air cells [HRFS-3]; diastasis of coronal suture on right side [HRFS-3]; 5 cm. laceration of scalp in right frontoparietal region (depressed skull fracture was visible under this laceration) [HRLI-2]; minor abrasions on palms and forearms [RBAI-1, WBAI-1].

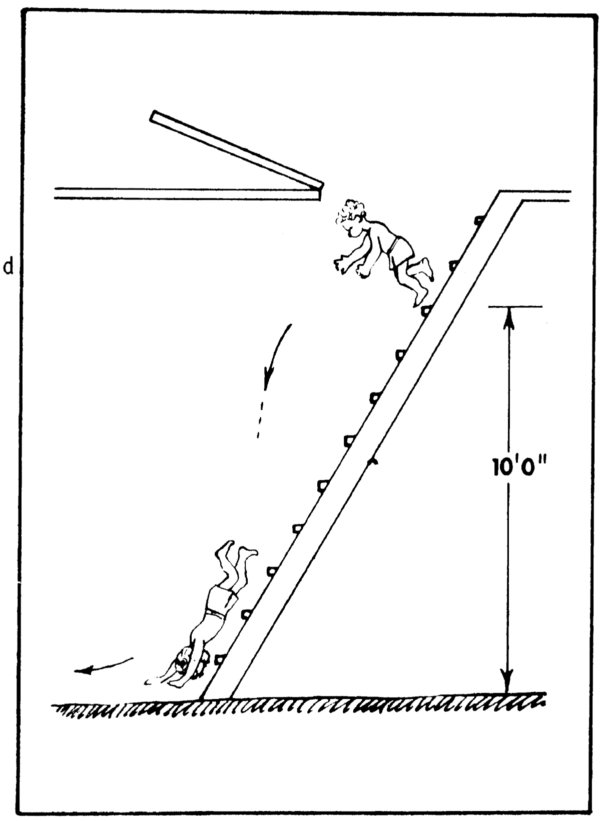
RECOVERY: Recovery is complete. Mother notes child will not go to third floor alone, will not approach fire escapes and is fearful of physicians.

SOURCES OF DATA: _X_ SUBJECT; _X_ PARENTS;

__ POLICE; _X_ HOSPITAL; _X_ WITNESSES;

__ OTHER:

OTHER COMMENTS: Child was talkative until fall was mentioned, then he would no longer speak or cooperate. Only witnesses were other young children. Unknown time (up to 45 minutes) elapsed before mother found child



CALCULATED DATA:

IMPACT VELOCITY: 23 ft./sec. (7.0 m./sec.)

OAIS: 3

ISS: 13

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 33

SUBJECT: Male, 19 yrs. 5 mo., 5 ft. 11 in.(1.80 m), 168 lbs. (76.2 kg)

FALL DISTANCE: 28 ft. 3 in. (8.6 m)

ENVIRONMENT: Windowsill to soil

MAJOR INJURIES: Concussion

SUMMARY: Student fell from building ledge, forward through small tree branches, some 28 feet to the grass covered soil below. Tree branches probably did not break the fall. Subject suffered abrasions and a concussion resulting in three days of hospitalization. He is fully recovered.

FALL CHRONOLOGY: Student was climbing onto building ledge outside of 4th floor dormitory window. While straightening into standing position, he fell forward, through some small, probably brittle tree branches, to the grass covered soil below. The observable broken branches were so small that they probably did not break the fall. The subject probably landed on his right side about 8 feet (2.4 m) from building, then collapsed immediately onto his face and head.

SPECIFIC INJURIES: Concussion [HWKB-2]. Lower back pain on right side [MIPM-1]; abrasions right frontal head and right face [FRAI-1]; swollen nose with epitaxis [FCHR-1]; abrasions of right elbow, right lateral lumbar spine area, and left hand [ERAI-1, MIAI-1, WLAI-1]; sprained muscle right leg [YRSM-1]; physician also noted a temporary amnesia for the event, and an abnormal EEG was recorded. No fractures.

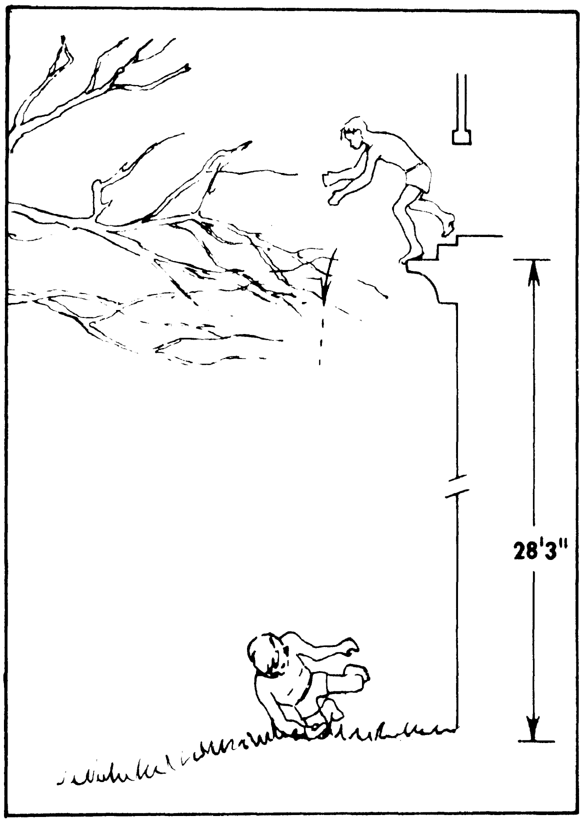
RECOVERY: Recovery is apparently complete.

SOURCES OF DATA: _X_ SUBJECT; __ PARENTS;

__ POLICE; _X_ HOSPITAL; _X_ WITNESSES;

__ OTHER:

OTHER COMMENTS: Subject was severely injured (coma 48 hrs.) in a motorcycle accident 3 1/2 months before the fall. Abnormal EEG could be related to that concussion, also. Subject believed he was unconscious before he landed. He was wearing only gym shorts when he fell.



CALCULATED DATA:

IMPACT VELOCITY: 41 ft./sec. (12.5m/sec.)

OAIS: 2

ISS: 6

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 34

SUBJECT: Male, 29 yrs, height and weight unknown

FALL DISTANCE: 21 ft 2 in (6.5 m)

ENVIRONMENT: House roof to concrete driveway

MAJOR INJURIES: Unknown, possible head injuries and fractured pelvis.

SUMMARY: Subject was shingling roof of a house when he lost balance and fell 21 feet to a concrete driveway. He probably suffered a fractured pelvis and possibly had head injuries. He was hospitalized 25 days and has apparently recovered.

FALL CHRONOLOGY: Subject lost his balance somewhere on pitched roof and slid, probably prone and feet-first, off the roof. He landed, presumably on his side, on a concrete driveway.

SPECIFIC INJURIES: Detailed injuries are unknown. Neighbor thought subject had a fractured pelvis [PUFS-9], ambulance attendant recalled head injuries [HUUU-9], but ambulance log had no space to enter injuries.

RECOVERY: Apparently complete enough to be fully ambulatory.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
X POLICE; __ HOSPITAL; __ WITNESSES;
X OTHER: ambulance service, neighbor

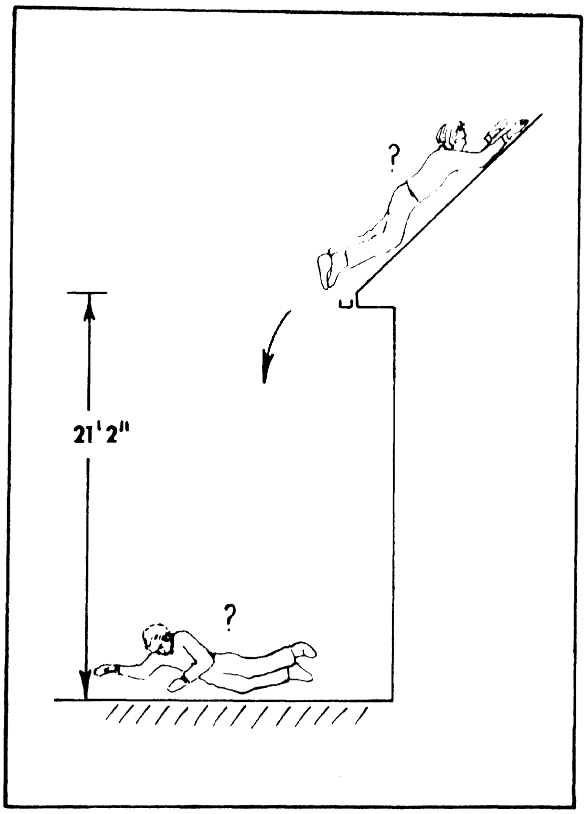
OTHER COMMENTS: This location was visited on three occasions over a period of 7 months. It was not ever possible to locate the subject although he was in the area.

CALCULATED DATA:

IMPACT VELOCITY: 36 ft/sec (11.0 m/sec)

0 AIS: Unknown

ISS: Unknown



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 35

SUBJECT: Female, 15 months, 34 in. (.86 m.), 25 lbs. (11.3 kg.)

FALL DISTANCE: 18 ft. 0 in. (5.5 m.)

ENVIRONMENT: Stairway landing to tiled concrete floor.

MAJOR INJURIES: Cerebral concussion, possible sprain of lower extremities

SUMMARY: Subject crawled or tumbled sideways between railing stanchions at top of stairwell and fell 18 feet to tiled concrete floor. Subject landed on right side and was hospitalized for 4 days. Subject has completely recovered, except for occasional slight limp.

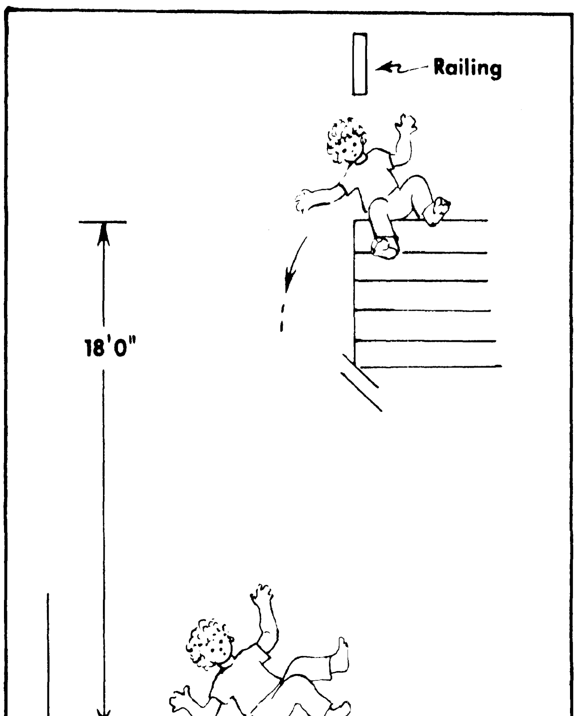
FALL CHRONOLOGY: Child was playing in third floor hallway of an apartment house when she crawled or fell between railing supports into an open stairwell. She free-fell to the first floor level and landed on her right side on a tiled concrete floor.

SPECIFIC INJURIES: Cerebral concussion [HRKB-2]; possible sprain of lower extremitities [YWSM-1]. No evidence of external trauma; no unconsciousness at scene, though was briefly cyanotic; no fractures.

RECOVERY: Complete. Mother reported child could not walk for three days, had very sensitive pelvic area right side. Occasional slight limp. No fear of stairs.

SOURCES OF DATA: X SUBJECT; X PARENTS;
__ POLICE; X HOSPITAL; __ WITNESSES;
__ OTHER:

OTHER COMMENTS: Child was basically uninjured in the fall. Was hospitalized only for observation.



CALCULATED DATA:

IMPACT VELOCITY: 33 ft./sec. (10.1 m./sec.)

OAIS: 2

ISS: 5

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 36

SUBJECT: Male, 18 yrs, height and weight unknown

FALL DISTANCE: 63 ft (19.2 m)

ENVIRONMENT: 7th floor hotel window to asphalt parking lot

MAJOR INJURIES: Fatal after four hours

SUMMARY: Subject apparently jumped from from 7th floor hallway window in hotel. He landed on asphalt parking lot below. He expired four hours later in hospital.

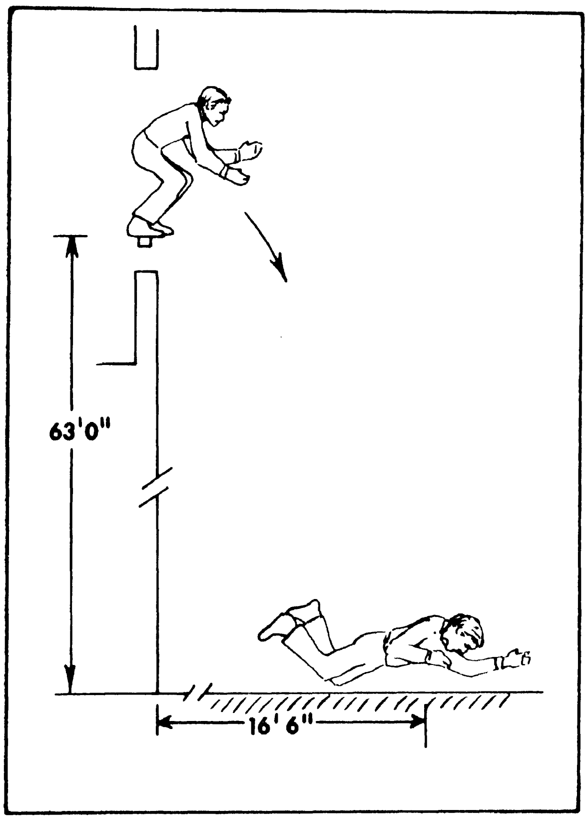
FALL CHRONOLOGY: Several witnesses saw the impact but no one was found that saw the subject leave the window. He probably climbed upon a steel railing in an unglazed window opening and jumped, facing outward. He was described as falling without tumbling, landing on side, feet, legs and hip first, then head. First impact point was 16'6" (5.0 m) from side of building. He bounced and came to rest 23'6" (7.2 m) from building, in a prone position with his left arm turned under his body.

SPECIFIC INJURIES: Four teeth avulsed, major injuries unknown. Newpaper reported head and internal injuries and multiple fractures.

RECOVERY: Fatal after four hours.

SOURCES OF DATA: __ SUBJECT; __ PARENTS; X POLICE; __ HOSPITAL; X WITNESSES; __ OTHER:

OTHER COMMENTS: Fall listed as suicide. Police and medical reports not available.



CALCULATED DATA:

IMPACT VELOCITY: 61 ft/sec (18.6 m/sec)

OAIS: 6

ISS: N/A

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 37

SUBJECT: Male, 4 yrs. 7 mos., height unknown, 43 lbs. (19.5 kg.)

FALL DISTANCE: 21 ft. 0 in. (6.4 m.)

ENVIRONMENT: Windowsill to concrete courtyard

MAJOR INJURIES: No major injuries.

SUMMARY: Boy was playing on bed near open screened window. He fell against the screen, which loosened. Subject then fell through the window, 21 feet to concrete patio below. The boy received minor injuries, no fractures. He was not admitted to a hospital and has fully recovered.

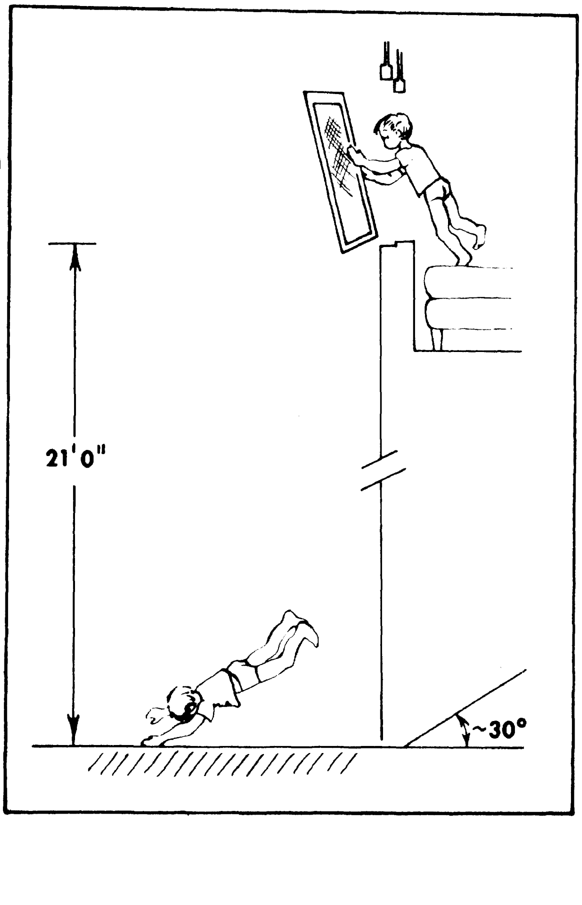
FALL CHRONOLOGY: Child was playing on bed near open screened window of his second floor residence. He jarred the screen loose and fell from the windowsill, through a 35 inch opening, to a concrete play area accessible only from within the building. He probably landed on his left side and rolled.

SPECIFIC INJURIES: Multiple minor abrasions of left hand and forearm [WLAI-1, RLAI-1]. Minor abrasion to left side of head [HLAI-1].

RECOVERY: Fully recovered.

SOURCES OF DATA: X SUBJECT; X PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES; __ OTHER:

OTHER COMMENTS: Parents spoke broken English so some details were difficult to obtain. Child was treated and released from hospital emergency room.



CALCULATED DATA:

IMPACT VELOCITY: 36 ft./sec. (11.0 m./sec.)

OAIS: 1

ISS: 1

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 38

SUBJECT: Male, 43 yrs. 8 mos., 5 ft. 11 in. (1.80 m.), 170 lbs. (77.1 kg.)

FALL DISTANCE: 12 ft. 5 in. (3.8 m.)

ENVIRONMENT: Loft access door to concrete garage floor.

MAJOR INJURIES: Fractures of lumbar vertebrae, elbow and wrist.

SUMMARY: Subject was climbing into attic loft when the extension ladder he was on suddenly closed, causing him to fall 12 1/2 feet to a concrete garage floor. He was hospitalized for one month with fractures of the L-1 vertebra, left elbow and left wrist. He has recovered most of his function and is walking, but still undergoing rehabilitative therapy for his arm and is limited in work capability.

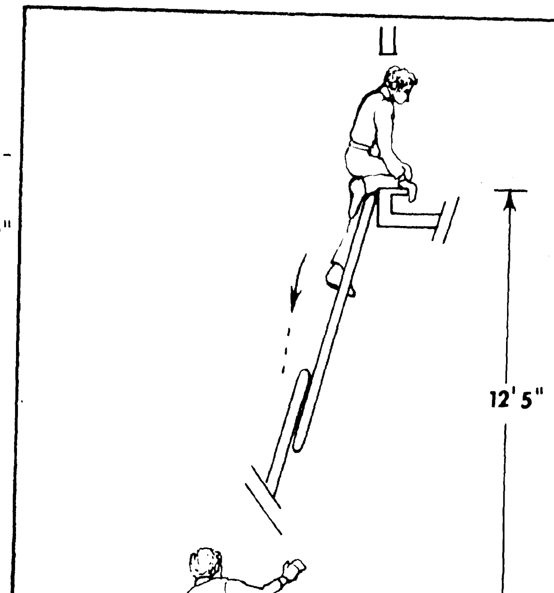
FALL CHRONOLOGY: Subject was climbing from extension ladder through loft access door in his auto repair garage. He had one leg on the door sill and the other on the ladder, when the extension ladder suddenly closed, causing him to lose his balance. Subject fell backwards off ladder to concrete floor below. Subject's wife witnessed the fall, noting that he struck floor feet first, fell onto his back (apparently with his left arm extended), hit his head, then rolled to his left side.

SPECIFIC INJURIES: Severe compression fracture of L1 with displacement of the anterior portion anteriorly [BIFV-3]; undisplaced fracture of left carpal navicular bone [WLFJ-2]; developed adynamic ileus for four days [MIPP-2]; fracture of left elbow [ELFJ-2]; contusions of right ankle [QRCI-1]. No loss of consciousness.

RECOVERY: Nearly recovered by four months after fall, though still had back pain and daily arm therapy. By eight months after fall was working but not lifting, no back pain, but cannot bend over; continuing arm therapy.

SOURCES OF DATA: X SUBJECT; __ PARENTS; __ POLICE; X HOSPITAL; X WITNESSES; __ OTHER:

OTHER COMMENTS: Subject's feet may have contacted ladder, but ladder probably caused only the ankle contusion. Subject's wife reported he had had a "religious experience" consisting of several visions during fall and hospitalization.



CALCULATED DATA:

IMPACT VELOCITY: 28 ft./sec. (8.5 m./sec.)

OAIS: 3

ISS: 14

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 39

SUBJECT: Male, 20 yrs. 7 mos., 5 ft. 11 in. (1.80 m.), 190 lbs. (86.2 kg.)

FALL DISTANCE: 19 ft. (5.8 m.)

ENVIRONMENT: Scaffolding to concrete sidewalk.

MAJOR INJURIES: Fractures of left ulna and radius, multiple fractures of left hemipelvis, jammed left wrist, and right pneumothorax.

SUMMARY: Subject was walking on a moveable scaffolding when a flooring plank snapped suddenly. He pitched forward and fell 19 feet onto a sidewalk. He received a compound fracture of the left ulna, a midshaft fracture of the left radius, three fractures of the left hemipelvis, a jammed left wrist, a right pneumothorax, and minor abrasions. Hospitalized 17 days, still in therapy. Not fully recovered as yet.

FALL CHRONOLOGY: Subject was walking on scaffold when plank suddenly snapped, throwing him forward. He extended his left hand as he fell and landed on a concrete sidewalk. He impacted first with his left hand, then left hip. He rolled and came to rest against a pile of dirt, some of which contaminated the open fracture of his left arm.

SPECIFIC INJURIES: Fracture of left radius at mid-shaft [RLFS-2]; two fractures of left ulna--oblique in distal shaft, badly comminuted in distal articular surface [RLFS-3]; three fractures of left hemipelvis--superior iliac margin with separation of sacroiliac joint, upper left ilium, and left inferior pubic ramus [PLFS-3, PPDJ-3]; right side pneumothorax (30% collapse) [CROP-3]; jammed left wrist [WLSJ-2]; abrasions left lateral thigh [PLAI-1].

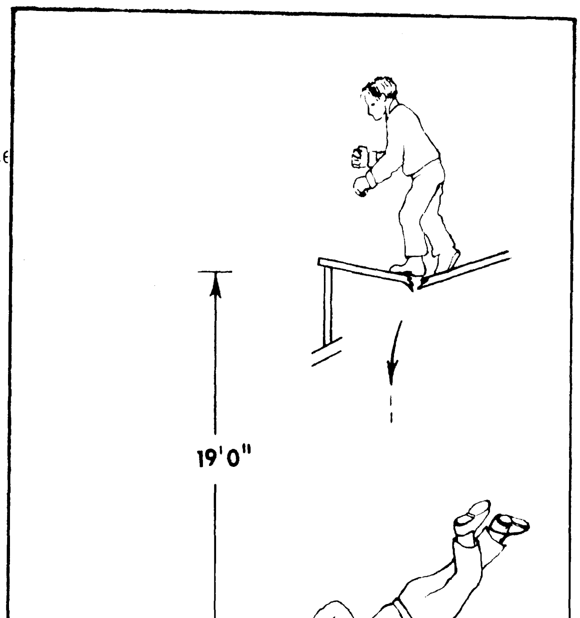
RECOVERY: Partial, as of 11 weeks after fall. Left wrist is still pinned and casted. Still using crutches. Daily therapy for arm and for walking.

SOURCES OF DATA: X SUBJECT; __ PARENTS;

__ POLICE; X HOSPITAL; __ WITNESSES;

__ OTHER:

OTHER COMMENTS: Radiologist found no definite evidence of rib fracture, but subject had a pneumothorax. Didn't expect to return to work for months.



CALCULATED DATA:

IMPACT VELOCITY: 35 ft./sec. (10.7 m./sec.)

OAIS: 3

ISS: 19

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 40

SUBJECT: Male, 8 yrs. 11 mos., 4 ft. 6 in. (1.37 m.), 66 lbs. (29.9 kg.)

FALL DISTANCE: 6 ft. 1 in. (1.9 m.)

ENVIRONMENT: Clothespole to concrete driveway.

MAJOR INJURIES: Cerebral concussion, shock.

SUMMARY: Child was playing and attempted to crawl on top of a horizontal clothesline pole which spans a concrete driveway. He fell off the pole, six feet, to the driveway, sustaining abrasions to the right side of his head, cerebral concussion and shock. Child was hospitalized for three days. Recovery is apparently complete, with no problems at school or play.

FALL CHRONOLOGY: Child attempted to crawl on top of a clothes pole crossbar. The clothespole spans a concrete driveway, high enough to drive under. Child probably fell from an "all-fours" position, landing head first on the right side of his head. He impacted the four inch (10.2 cm.) thick concrete driveway.

SPECIFIC INJURIES: Cerebral concussion [HRKB-2]; facial contusions and abrasions right molar region [FRAI-1, FRCI-1].

RECOVERY: Complete. Had rapid recovery in the hospital, no continuing ill effects.

SOURCES OF DATA: __ SUBJECT; X PARENTS;
__ POLICE; X HOSPITAL; __ WITNESSES;
__ OTHER:

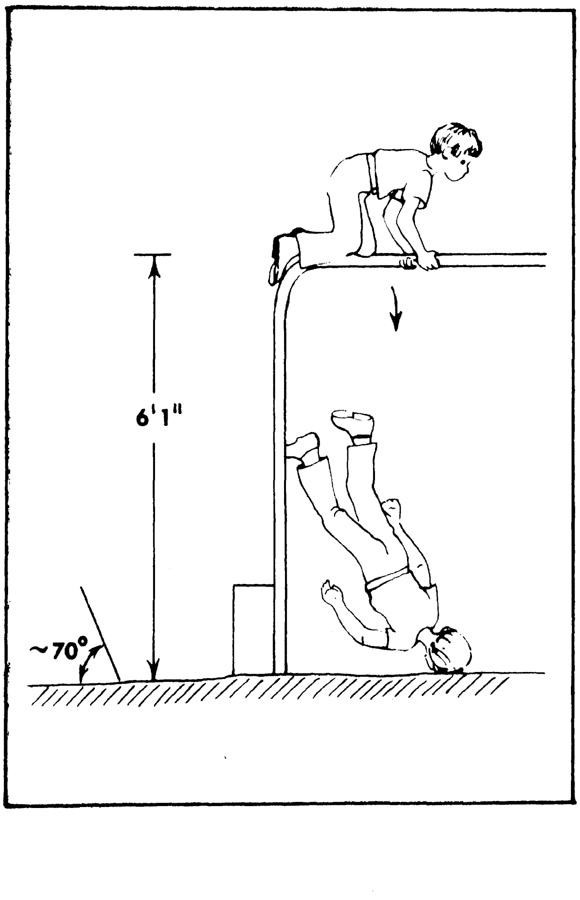
OTHER COMMENTS:

CALCULATED DATA:

IMPACT VELOCITY: 18 ft./sec. (5.5 m./sec)

OAIS: 2

ISS: 5



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 41

SUBJECT: Male, 57 yrs. 11 mos., 5 ft. 10 in. (1.75 m.), 145 lbs. (65.8 kg.)

FALL DISTANCE: 15 ft. 6 in. (4.7 m.).

ENVIRONMENT: Eavestrough and ladder to driveway and ladder.

MAJOR INJURIES: Fractured nasal bones, fractured humerus and knee, lacerations around eyes.

SUMMARY: Subject fell from a ladder while cleaning leaves from the gutters of his residence. Wooden ladder was leaning against a wall when it slipped, causing the subject to fall about 15 feet onto both the ladder and asphalt. Injuries included fractured nasal bones, right humerus and left knee, and lacerations of right eyebrow and eyelid. Most injuries were probably sustained from impact with the ladder. Subject was hospitalized for six days. Recovery is complete except for limited range of motion of right arm.

FALL CHRONOLOGY: Subject was standing partway up the ladder, reaching up to clean leaves from the gutter. The base of the ladder slipped back and the ladder dropped straight down. Subject hung momentarily from gutter, then free-fell, striking both the asphalt and the ladder as he landed. Subject felt that his nose and shoulder hit ladder rungs and that his knee struck ladder rail. Broken safety glasses may have lacerated the eyebrow.

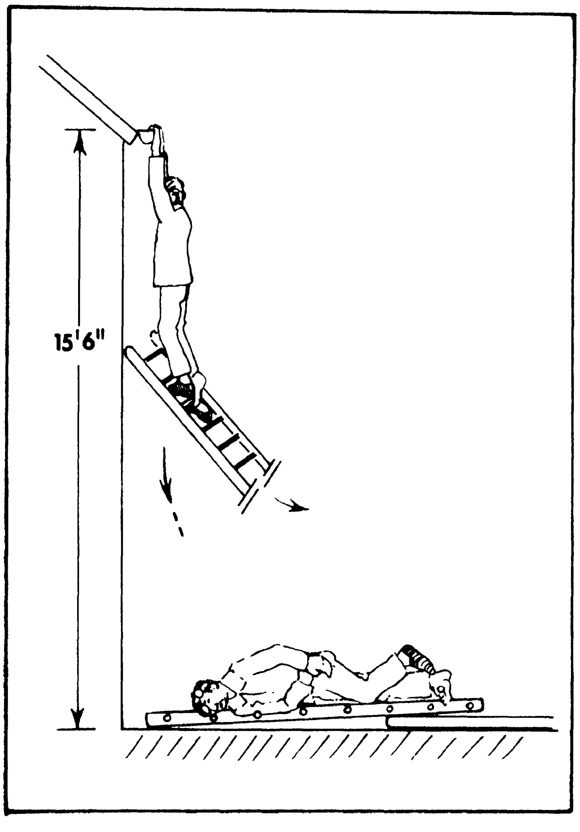
SPECIFIC INJURIES: Fractured nasal bones, depressed [FCFR-2]; comminuted fracture, proximal neck of right humerus [ARFS-3]; stellate fracture of left patella [KLFJ-2]; complex 5 cm. laceration of right eyebrow and eyelid [FRLE-2].

RECOVERY: Complete except for limited range of motion of right arm.

SOURCES OF DATA: X SUBJECT; __ PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: Subject's wife.

OTHER COMMENTS: Difficult to assign fall height since subject's fall was complex. Most injuries apparently caused by contact with ladder. Subject has had two lumbar disk operations--this fall caused no complications.



CALCULATED DATA:

IMPACT VELOCITY: 31 ft./sec. (9.5 m./sec.)

OAIS: 3

ISS: 17

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 42

SUBJECT: Male 11 yrs. 11 mos., 5 ft. (1.52 m.), 85 lbs. (38.6 kg.)

FALL DISTANCE: 17 ft. 6 in. (5.3 m.)

ENVIRONMENT: Stairwell of building under construction from second level to concrete.

MAJOR INJURIES: Fractured skull, concussion, fractured arm.

SUMMARY: Boy was leaving shopping center with friends, passing by a new store under construction. He became separated from the group and fell, unseen, into an unfinished stairwell opening, 17 feet, from second level to first level. He was unconscious for up to several days, and his injuries included concussion, skull fracture and right forearm fracture. He was hospitalized for more than three weeks. His return to school is hampered by speech and memory problems.

FALL CHRONOLOGY: Boy fell unseen into an open, unfinished emergency exit stairwell at a new store under construction at an existing shopping center. He probably stepped forward into the unlighted opening, and probably landed on his head and right arm. The stairs were not yet installed, so he free-fell to the six inch (15 cm.) thick concrete floor.

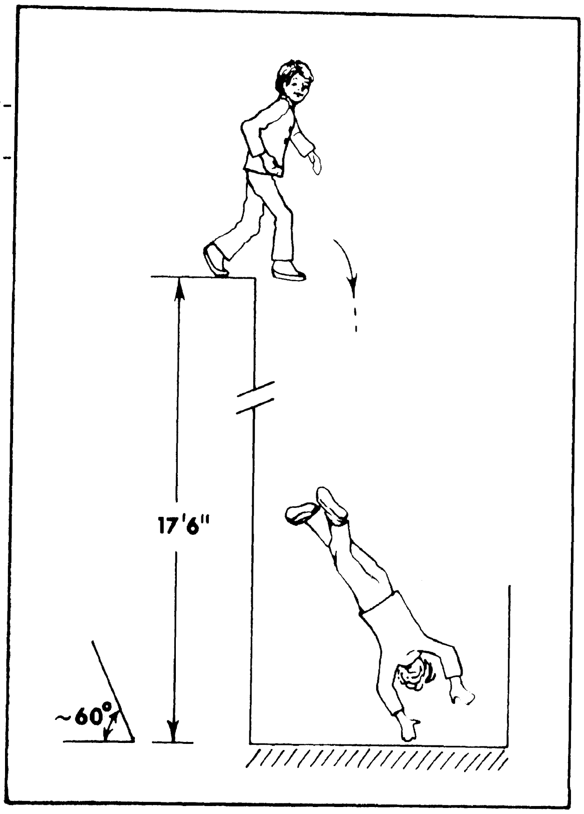
SPECIFIC INJURIES: Injury information was provided by subject's grandparents, with whom he lives. Injuries consist of fractured skull, not depressed, concussion with unconsciousness for up to several days (grandparents said five) [HUKB-5]; fractured right forearm [RRFS-3]; a scalp laceration [HULI-1]; and contusions of the right arm and right ankle [XRCI-2, QRCI-1].

RECOVERY: In coordination and appearance subject is completely normal. Some speech deficiency and memory problems remain. Had not returned to school (eight weeks after fall).

SOURCES OF DATA: X SUBJECT; __ PARENTS; __ POLICE; __ HOSPITAL; __ WITNESSES;

X OTHER: Grandparents, construction supervisor

OTHER COMMENTS: Could not obtain signed medical release due to pending litigation.



CALCULATED DATA:

IMPACT VELOCITY: 33 ft./sec. (10.1 m./sec.)

OAIS: 5

ISS: 38

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 43

SUBJECT: Male, 7 yrs, height and weight unknown.

FALL DISTANCE: 12 ft. 8 in. (3.9 m.).

ENVIRONMENT: Balcony rail to soil or concrete

MAJOR INJURIES: Fractured wrists.

SUMMARY: Boy apparently climbed onto a bicycle which was leaning against the balcony of his apartment building residence. The child fell over the railing approximately 12.5 feet to the surface below, impacting either soil or concrete. Injuries included fractured wrists. The child was hospitalized for two days. Recovery is unknown.

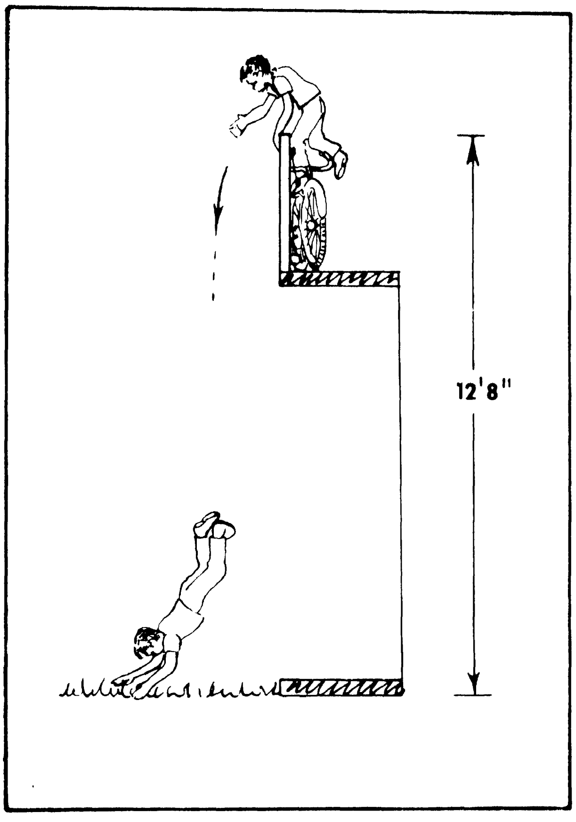
FALL CHRONOLOGY: Child fell from second-floor balcony railing, apparently after climbing on a bicycle. He probably fell forward off the balcony and attempted to break his fall by extending his arms. He could have landed either on concrete paving blocks or on grassy soil. Police reports indicates lying face down when found.

SPECIFIC INJURIES: Fractures of both wrists [WBFJ-2]; any other injuries unknown.

RECOVERY: Unknown.

SOURCES OF DATA: __ SUBJECT; __ PARENTS; _X POLICE; __ HOSPITAL; __ WITNESSES; __ OTHER:

OTHER COMMENTS: Mother was not located at home despite repeated attempts. Apartment neighbors had no useful information.



CALCULATED DATA:

IMPACT VELOCITY: 28 ft./sec. (8.5 m/sec)

OAIS: 2

ISS: 4

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 44

SUBJECT: Female, 8 yrs., height and weight unknown.

FALL DISTANCE: Up to 13 ft. 10 in. (4.2 m.)

ENVIRONMENT: Concrete retaining wall to concrete parking ramp.

MAJOR INJURIES: Skull fracture.

SUMMARY: Child fell from the top of a concrete wall to the parking ramp entrance for an underground garage. Depending upon where she was on the wall when she fell, the child's fall was from six to 14 feet. She sustained a fractured skull and was hospitalized for nine days. She returned to school, but had not fully recovered.

FALL CHRONOLOGY: Details are virtually unknown. The child was apparently playing on the top of an eight inch (20.3 cm.) wide concrete retaining wall which surrounds the entrance to an undergound parking garage. The entrance ramp slopes, and since the precise location of the fall is unknown, it cannot be determined how far she fell. She landed on concrete, or possibly on a metal drain grate at the bottom of the ramp.

SPECIFIC INJURIES: Basilar skull fracture [HIFS-2]. According to newspaper report, she was conscious immediately after the fall.

RECOVERY: She returned to school approximately one month after the fall. While she was progressing satisfactorily, she was not at that time completely normal.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
__ POLICE; __ HOSPITAL; __ WITNESSES;
X OTHER: Newspaper, school principal.

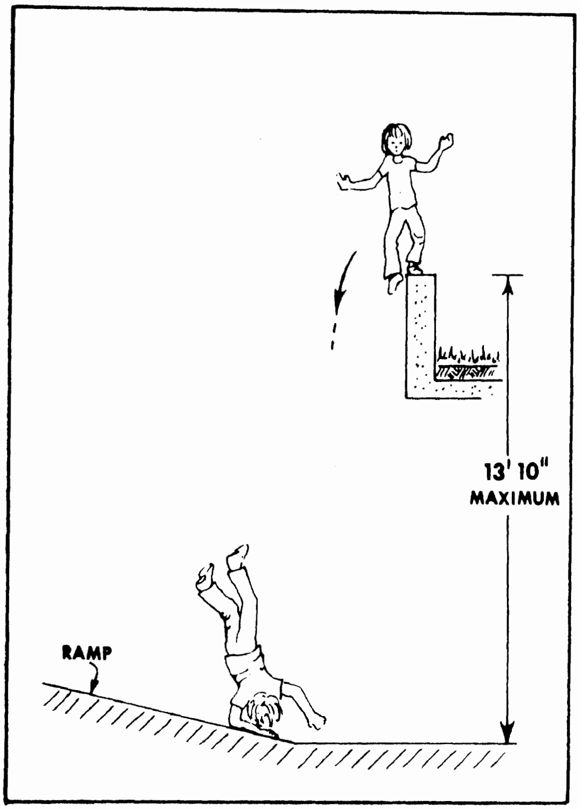
OTHER COMMENTS: The subject's residence changed after the fall and, despite repeated attempts, her parents could not be contacted directly.

CALCULATED DATA:

IMPACT VELOCITY: 29 ft./sec. (8.8 m./sec.)

OAIS: 2

ISS: 4



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 45

SUBJECT: Female, 4 yrs 7 mo, 3 ft 3 in (0.99 m), 35 lbs (15.9 kg)

FALL DISTANCE: 37 ft 5 in (11.4 m)

ENVIRONMENT: Windowsill to steel railing to concrete

MAJOR INJURIES: Fractures of skull, thoracic spine, right humerus and elbow, left radius and ulna, and left tibia and fibula.

SUMMARY: Child climbed from bed onto windowsill, opened window and leaned against screen. Screen came loose and she fell from 5th floor bedroom window some 37 ft into a concrete stairwell, probably first striking a railing beside the stairwell. She sustained fractures of the skull, thoracic spine, right humerus and olecranon, left radius and ulna, and left tibia and fibula at both proximal ends and midshaft, and sustained multiple other scratches and bruises. Child is recovering although there was some possibility of sensory loss in right leg.

FALL CHRONOLOGY: Child apparently climbed onto the windowsill in her 5th floor bedroom and opened the window. She was probably kneeling on the windowsill and leaning against the screen when it dislodged and she fell through the window opening. The nature and location of injuries indicate that she probably struck a steel railing beside the stairwell and came to rest on her right side in the concrete stairwell. The subject probably contacted the top of the railing with the right side of her head and right upper arm then rotated so that she struck the concrete with left leg and arm.

SPECIFIC INJURIES:
Nondepressed long linear fracture of right frontal bone, comatose or semi-comatose for 7 hrs [HRKB-4]; compression fractures of T-3-4-5 vertebrae, with anterior wedging [BSFV-3]; displaced fractures of distal right humerus [ARFS-3] and distal left ulna [RLFS-3], displaced double fractures of left tibia and fibula [LLFS-4]; undisplaced fracture right olecranon and left radius [ERFJ-2, RLFS-2]; abrasions to forehead and back [FSAI-1, BSAI-1], lacerated tongue [FILD-1].

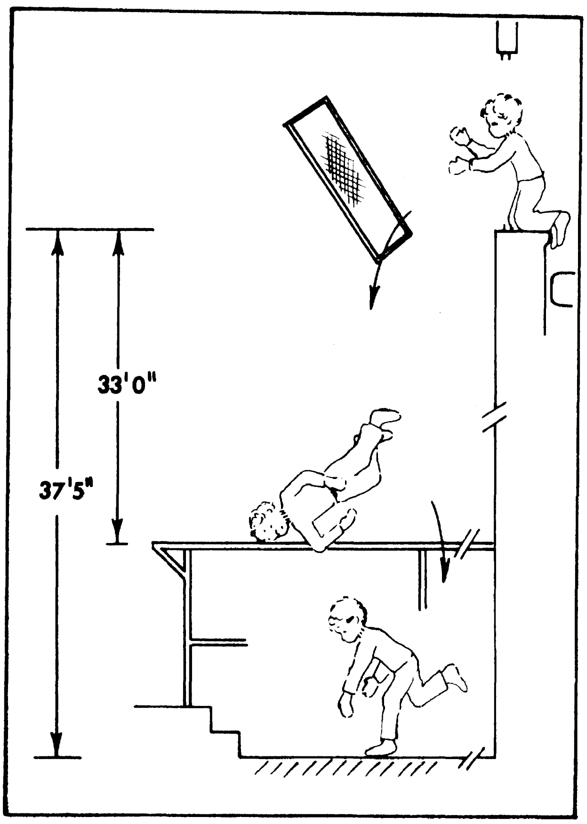
RECOVERY:
As of 5½ weeks after fall, child was still hospitalized with casts on right arm and left leg. Possible paraparesis originating at T-10, extent would not be known for another 2 months.

SOURCES OF DATA: X SUBJECT; X PARENTS;

X POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: Newspaper

OTHER COMMENTS: May have been some snow cover at time of fall, but if so it would not have been thick enough to cushion impact.



CALCULATED DATA:

IMPACT VELOCITY: 48 ft/sec (14.6 m/sec)

OAIS: 4

ISS: 41

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 46

SUBJECT: Male, 14 yrs. 10 mos., 5 ft. 5 in. (1.65 m.), 100 lbs. (45.4 kg.)

FALL DISTANCE: 23 ft. 0 in. (7.0 m.).

ENVIRONMENT: Third floor porch railing to asphalt sidewalk.

MAJOR INJURIES: Contusion of right hip area.

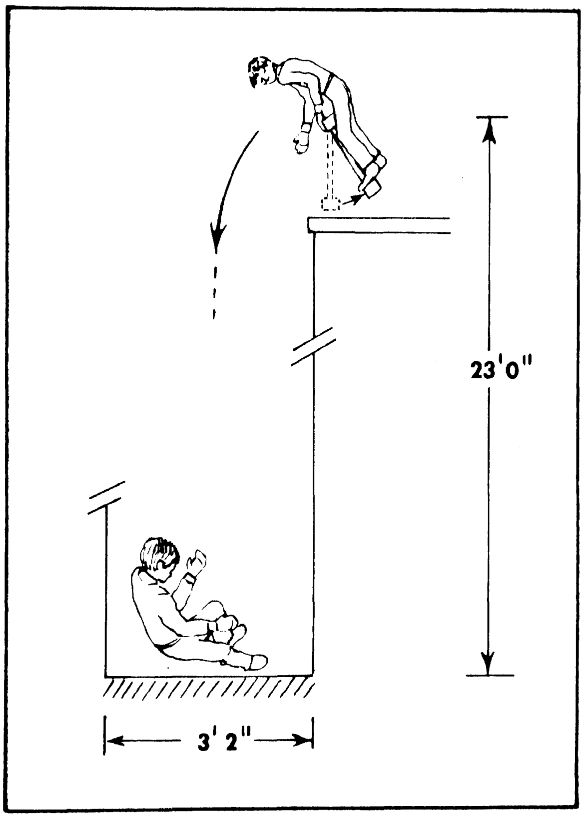
SUMMARY: Subject was standing on lower part of porch rail of his third floor apartment residence, leaning over the side. The lower rail gave way suddenly, flipping him over the top rail, causing him to fall 23 feet to asphalt sidewalk. Subject received a contused right hip and an abrasion on the chin. He was hospitalized for three days and has recovered completely except for occasional soreness in the hip.

FALL CHRONOLOGY: Subject fell from third-story porch, between two buildings that are separated by only 38 inches (97 cm). The subject was standing with his feet on the bottom rail of the porch railing, leaning against the top railing. He was bent over the rail looking toward the back of the building when the rotted lower rail broke loose, causing him to pivot over the top railing and fall. Subject landed on his right hip on the asphalt surface. He apparently did not contact the other nearby building as he fell.
SPECIFIC INJURIES: Contusion of right hip in area of greater trochanter [PRCI-1]; abrasions of the chin and right knee [FIAI-1, KRAI-1]. Subject could not walk for approximately 24 hours after fall.

RECOVERY: Complete except for occasional soreness (as of four weeks after fall).

SOURCES OF DATA: X SUBJECT; X PARENTS;
X POLICE; X HOSPITAL; __ WITNESSES;
__ OTHER:

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 38 ft./sec. (11.6 m./sec.)

0 AIS: 1

ISS: 1

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 47

SUBJECT: Male, 25 yrs. 9 mos., 5 ft. 8 in. (1.74 m.), 195 lbs. (88.5 kg.).

FALL DISTANCE: 23 ft. 4 in. (7.1 m.) total fall.

ENVIRONMENT: House roof to porch roof to concrete sidewalk.

MAJOR INJURIES: Multiple skull fractures, concussion, fracture of vertebral body, hemotympanum.

SUMMARY: Subject was standing on narrow plank scaffold on pitched roof, working on chimney, when scaffolding suddenly collapsed flat against the roof. Subject slid off the roof, falling approximately 10 feet (3.0 m.) striking a porch roof. He then fell an additional 13 1/2 feet (4.1 m.) from porch roof to concrete sidewalk. He sustained multiple skull fractures in the occipital area, concussion, a compression fracture of L-5 vertebral body, a right hemotympanum, and multiple abrasions. He was hospitalized eight days. Recovery appears to be complete.

FALL CHRONOLOGY: Subject was standing on scaffold near peak of roof. Scaffold brace suddenly collapsed and planking fell flat against the roof. Subject pitched forward and slid face down and feet first off the edge. He fell to a porch roof, probably landing feet-first, then falling to a sitting position. He continued off the porch roof and landed on his back, striking the back of his head on a concrete sidewalk.

SPECIFIC INJURIES: Linear left occipital skull fracture extending diagonally across the occipital bone into the right occiput [HPFS-2]; diastasis of right lambdoid suture [HRFS-3]; right basilar skull fracture in the petrous pyramid [HIFS-2]; cerebral concussion [HWKB-2]; hemotympanum of right ear [HRHE-1]; contusion in the right occiput [HPCI-1]; abrasions and contusions of mid- and lower back [BIAI-1]; Compression fracture of L-5 vertebral body [BIFV-3].

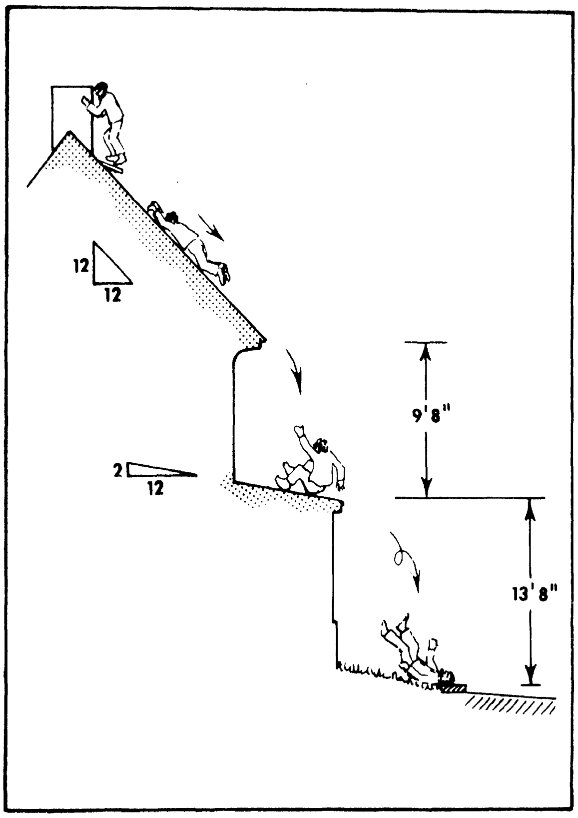
RECOVERY: Completely recovered. Had headaches for a month or so. Currently experiences no residual effects.

SOURCES OF DATA: X SUBJECT; __ PARENTS;

__ POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: Subject's wife

OTHER COMMENTS: This was found to be a broken fall at the time of the investigation; advance information did not indicate broken fall. Subject claimed to have had no loss of consciousness.



CALCULATED DATA:

IMPACT VELOCITY: 39 ft./sec. (11.9 m./sec.)

OAIS: 3

ISS: 19

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 48

SUBJECT: Male, 33 yrs. 7 mos., height and weight unknown

FALL DISTANCE: 15 ft. 1 in. (4.6 m.).

ENVIRONMENT: Second-story porch to concrete sidewalk.

MAJOR INJURIES: Skull fracture with hematoma, cervical fracture, fractured right femur. Fatal.

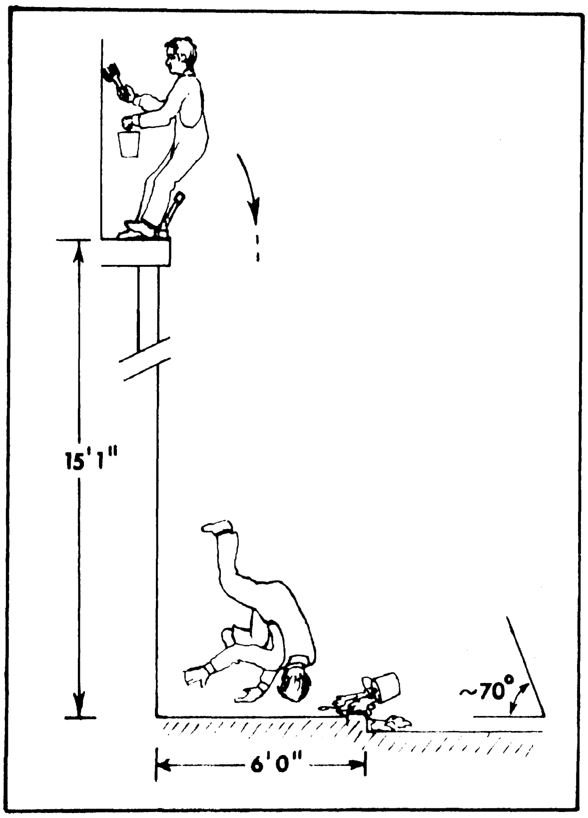
SUMMARY: Subject was standing on small second-floor porch working around a window when he stumbled backwards through the porch railing and fell 15 feet to the concrete sidewalk below. Injuries: cervical fracture at C5, with quadriplegia, a transverse parietal skull fracture with subdural hematoma, fractures of the head and shaft of the right femur, and abrasions of the hands and knees. He was hospitalized for six weeks, but the injuries proved fatal.

FALL CHRONOLOGY: There are no known witnesses. On-site evidence and injury information indicate that the subject was working on a bow window, standing on a narrow portion of the porch. He must have stepped or stumbled backward, breaking the porch rail, and fell to the six-foot (1.8 m.) wide sidewalk below. He probably landed almost exactly on the top of his head, then went heavily onto his right knee.

SPECIFIC INJURIES: Bilateral parietal skull fracture concentric to the coronal suture, unconscious about one hour, large epidural hematoma along midline [HSKB-4]; cervical spine fracture at C5, with anterior displacement of large fragment and with cord transsection and quadriplegia [NPFV-5];comminuted fracture of shaft of right femur, undisplaced fracture of neck of right femur [TRFS-3]; abrasions of both knees, with swelling and ecchymosis [KBAI-2]; abrasions to dorsi of left hand and left foot [WLAI-1, QLAI-1].
RECOVERY: Subject had continuing respiratory difficulty and neurological problems. Respiratory arrest due to pulmonary embolus proved fatal nearly six weeks after fall.

SOURCES OF DATA: __ SUBJECT; _X_ PARENTS;
_X_ POLICE; _X_ HOSPITAL; __ WITNESSES;
_X_ OTHER: Newspaper, medical examiner

OTHER COMMENTS: Impact sequence very difficult to describe since major injuries to both head and femur are those normally seen from initial impact after a long fall. Subject's size is unknown, but physician described him as "large".



CALCULATED DATA:

IMPACT VELOCITY: 30 ft./sec. (9.1 m./sec.)

OAIS: 5

ISS: 50

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 49

SUBJECT: Male, 19 yrs. 3 mos., 5 ft. 8 in. (1.73 m.), 150-160 lbs. (68.0-72.6 kg.).

FALL DISTANCE: 44 ft. 4 in. (13.5 m.).

ENVIRONMENT: Down elevator shaft to concrete and steel elevator pit.

MAJOR INJURIES: Skull fracture, severe edema and contusions of the brain: Fatal.

SUMMARY: Subject was in an unfamiliar building when he apparently mistook an elevator shaft for a rest room door, opened it, and stepped into an empty shaft. He fell 44 feet to the elevator pit, striking either concrete or a steel plate located slightly above the concrete. Subject sustained a fractured skull with severe edema and contusions of the brain and various abrasions and contusions. He was hospitalized for 41 1/2 hours before he expired.

FALL CHRONOLOGY: Subject opened elevator shaft door and stepped into empty elevator shaft. Injury pattern suggests he may have contacted the side of the shaft with his right hip. Subject impacted elevator pit, apparently head first. It is unknown whether subject struck the steel, the concrete, or a combination of both, since a flat spring-loaded steel plate fills much of the floor space in the pit.

SPECIFIC INJURIES: Skull fracture (specific location unknown) with severe edema and contusions of the brain [HUKB-5]; extensive abrasions of right side of head and right hip [HRAI-2, PRAI-2]; laceration of left knee [KLLI-1]; abrasion of right knee and dorsum of right foot [KRAI-1, QRAI-1]; contusion of buttocks [PPCI-1].

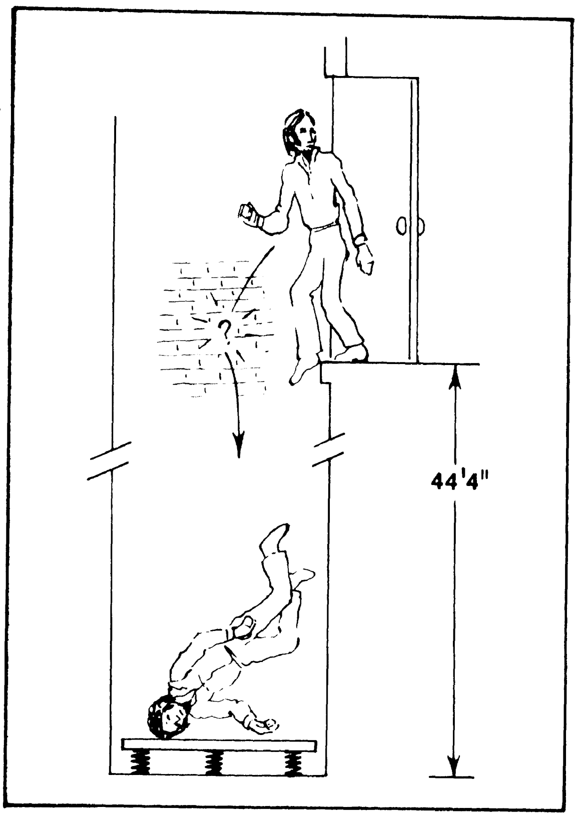
RECOVERY: Fatal after 41.5 hours. Apparently the subject did not regain consciousness.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;

_X POLICE; __ HOSPITAL; __ WITNESSES;

_X OTHER: Medical examiner, building maintenance manager.

OTHER COMMENTS: Measurement was obtained from inside the elevator car. It was not possible to observe the elevator pit.



CALCULATED DATA:

IMPACT VELOCITY: 52 ft./sec. (15.9 m./sec.)

OAIS: 5

ISS: 29

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 50

SUBJECT: Male, 17 yrs. 6 mos., 6 ft. 1 in. (1.85 m.), 158 lbs. (71.7 kg.)

FALL DISTANCE: 16 ft. 3 in. (5.0 m.)

ENVIRONMENT: Flat roof to concrete sidewalk.

MAJOR INJURIES: Bi-malleolar fracture of left ankle.

SUMMARY: During an impromptu race with friends, subject took a "short-cut" across a one-story flat-roofed building. As he was climbing off the front edge of the roof, intending to drop from arm's length to the sidewalk, he slipped and fell 16 feet to the concrete sidewalk below. His only injury was a bi-malleolar fracture of the left ankle. Subject was hospitalized for eight days. Recovery is apparently complete.

FALL CHRONOLOGY: Subject was climbing off the roof and had swung his legs over the side, supporting himself with his arms. The roof edge was at waist level when he slipped. Subject fell straight down facing the building, but without contacting the building with his body. He landed on his left foot on the concrete sidewalk, and came to rest in a standing position on his right foot, leaning against the building.

SPECIFIC INJURIES: Fractures of medial malleolus of left tibia and lateral malleolus of left fibula, with medial displacement of both fragments [LLFS-3]. No other injuries.

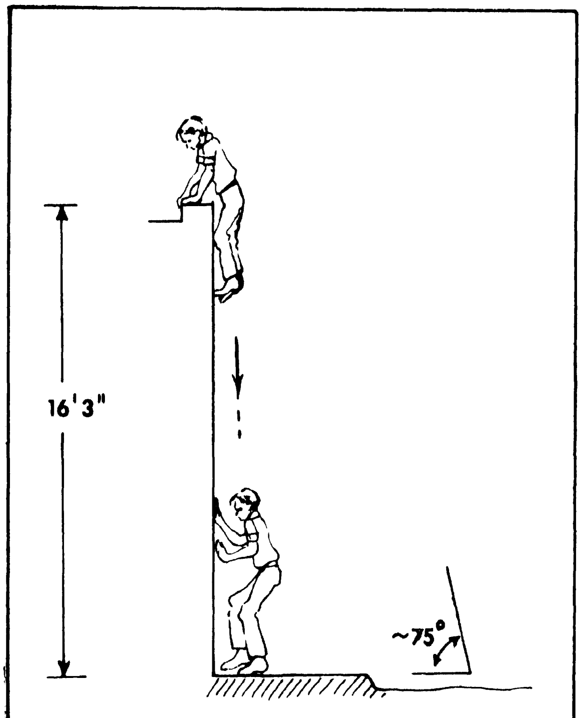
RECOVERY: Complete. No after effects whatever.

SOURCES OF DATA: _X_ SUBJECT; _X_ PARENTS;

__ POLICE; _X_ HOSPITAL; __ WITNESSES;

__ OTHER:

OTHER COMMENTS: Subject is in good physical condition and continued to be active during his convalescence.



CALCULATED DATA:

IMPACT VELOCITY: 32 ft./sec. (9.8 m./sec.)

OAIS: 3

ISS: 9

This case was simulated. Forces do not account for fracture effects. (See Chap. 3)

Est. peak accel: head 14-34 g; hip 96-97 g.

Est. peak axial forces: Foot: 6500-7500 lb (28,900-33,400N);

Tibia at foot: 10,100-10,450 lb (44,900-46,500N);

Tibia at knee: 6150-6900 lb (27,400-30,700N);

Femur (proximal): 4650-5350 lb (20,700-23,800N).

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 51

SUBJECT: Male, 7 yrs. 1 mo., 3 ft. 10 in. (1.17 m.), 42 lbs. (19.1 kg.)

FALL DISTANCE: 18 ft. 0 in. (5.5 m.)

ENVIRONMENT: Second floor windowsill to concrete sidewalk.

MAJOR INJURIES: Displaced fracture of left femur, possible loss of several teeth.

SUMMARY: Child was apparently standing on chair which tipped over, throwing him out of an open window. He fell 18 feet to a sidewalk below the window, landing on left side. Injuries include open fracture of the left femur and possible loss of three teeth. Hospitalized 22 days. Recovery is complete.

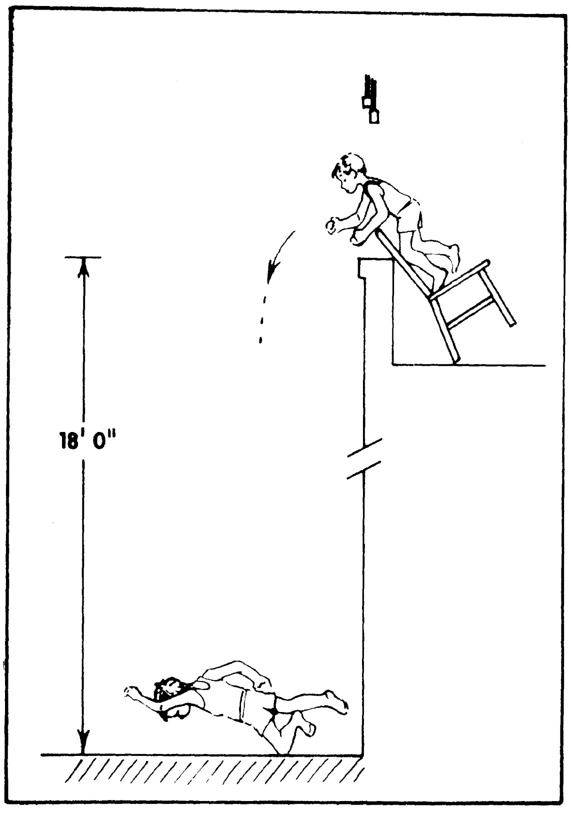
FALL CHRONOLOGY: Child fell off a chair through the second-floor window of apartment building. The window was open and unscreened. Position of subject when he started to fall is unknown. He landed on slightly-sloped concrete sidewalk, probably contacting with left leg and thigh.

SPECIFIC INJURIES: Open transverse fracture of left femur, with displacement full width of bone [TLFS-3]; three teeth missing, maxillary incisors loose and bleeding [FIVS-1, FIOS-1]; small laceration of tongue and lip [FILD-1].

RECOVERY: Subject was in bilateral traction for 20 days, then placed in Spica cast. Appears to be fully recovered now, no limp apparent.

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; X HOSPITAL; __ WITNESSES; X OTHER: Ambulance service.

OTHER COMMENTS: Parents spoke only Spanish, interview conducted through teen-age interpreter.



CALCULATED DATA:

IMPACT VELOCITY: 33 ft./sec. (10.1 m./sec.)

OAIS: 3

ISS: 10

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 52

SUBJECT: Male, 45 yrs. 2 mos., 6 ft. 2 in. (1.88 m.), 190 lbs. (86.1 kg.).

FALL DISTANCE: 12 ft. 0 in. (3.7 m.)

ENVIRONMENT: Flat roof to concrete.

MAJOR INJURIES: Fractures left wrist, left humerus, and left pubic bone.

SUMMARY: Subject was walking on flat roof pushing snow off it. He stepped on a fiberglass skylight which broke instantly, causing him to fall 12 feet to the six inch (15 cm.) reinforced concrete surface below. He sustained fractures of the left wrist, left humerus, and left pubic bone, and contusions of the left extremities. He was hospitalized for five days. Recovery is complete except for restricted range of motion of his arm.

FALL CHRONOLOGY: Subject was constructing flat carport-type roof. He was pushing snow off with a broom and stepped on a fiberglass skylight panel with his left foot, near the edge of the panel. The panel collapsed instantly, throwing the subject to his left side and off the roof, through a four-foot (1.2 m.) open space. He landed on bare, smooth concrete, left side down, probably in the sequence wrist-elbow-hip-full left side.

SPECIFIC INJURIES: Displaced fracture of surgical neck of left humerus [ALFS-3]; displaced fracture of left radius at wrist [WLFS-3]; undisplaced fracture of base of left elbow at styloid process [ELFJ-2]; simple fracture of left pubic area of pelvis [PLFS-2]; bruises and contusions on left extremities [XLCI-1, YLCI-1].

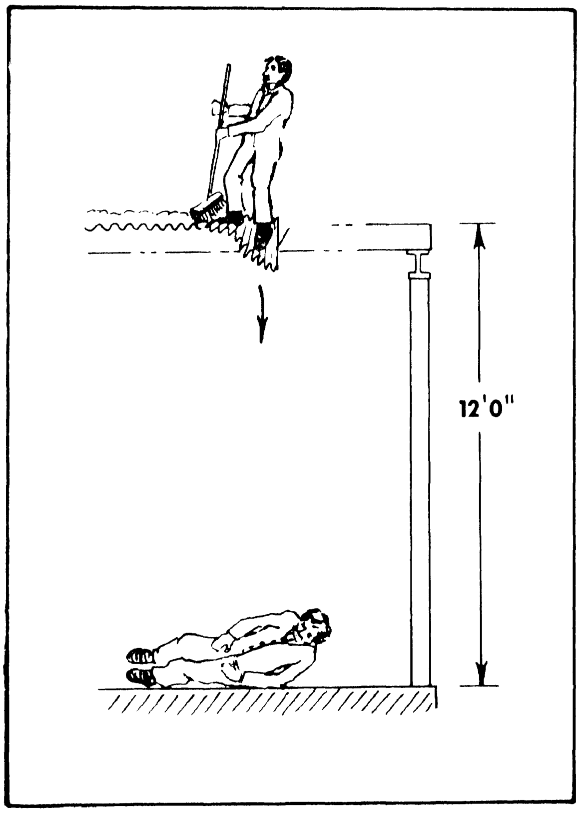
RECOVERY: Complete for normal movements; has about 15 degrees range of motion loss in left arm.

SOURCES OF DATA: X SUBJECT; __ PARENTS;

__ POLICE; X HOSPITAL; __ WITNESSES;

__ OTHER:

OTHER COMMENTS: Skylight, roof panels, and snow were all the same color. It was difficult to see the skylight. Subject appeared to remember the fall sequence quite well. He free-fell and did not contact roof structure.



CALCULATED DATA:

IMPACT VELOCITY: 27 ft./sec. (8.2 m./sec)

OAIS: 3

ISS: 10

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 53

SUBJECT: Male, 50 yrs. 6 mos., 5 ft. 9 in. (1.75 m.), 190 lbs. (86.2 kg).

FALL DISTANCE: 17 ft. 0 in. (5.2 m.)

ENVIRONMENT: Ladder to concrete floor.

MAJOR INJURIES: Fractures L-1 and L-2, left wrist, left knee, right foot.

SUMMARY: Subject was repairing an overhead heater at his place of employment. He was standing on a ladder which had been placed on a five foot high scaffold. The ladder slipped and the subject free-fell to the concrete floor. His injuries include fractures of L1, L2, the left wrist, right foot and left knee. Subject was hospitalized 66 days. Recovery is progressing satisfactorily, but is not complete.

FALL CHRONOLOGY: Subject was standing near the top of the ladder, facing the heater. The ladder slipped and subject fell onto a six inch (15 cm.) thick concrete floor, landing feet-first. His knees buckled and he landed heavily on his buttocks, then fell to his back, contacting the floor momentarily with his head. He came to rest on his right side and did not lose consciousness.

SPECIFIC INJURIES: Compression fracture to left side of L-2 vertebra [BIFV-3]; fracture of L-1 left transverse process [BIFV-2]; left wrist--undisplaced fracture of carpal navicular [WLFJ-2]; right foot-fractures of third and fourth metatarsals, navicular and cuboid with slight displacement [QLFS-3, QLFJ-2]; left knee--slight undisplaced fracture of tibia [LLFS-2]; severe abdominal pain [MWPW-1]; contusion, right occipital skull area [HPCI-1].

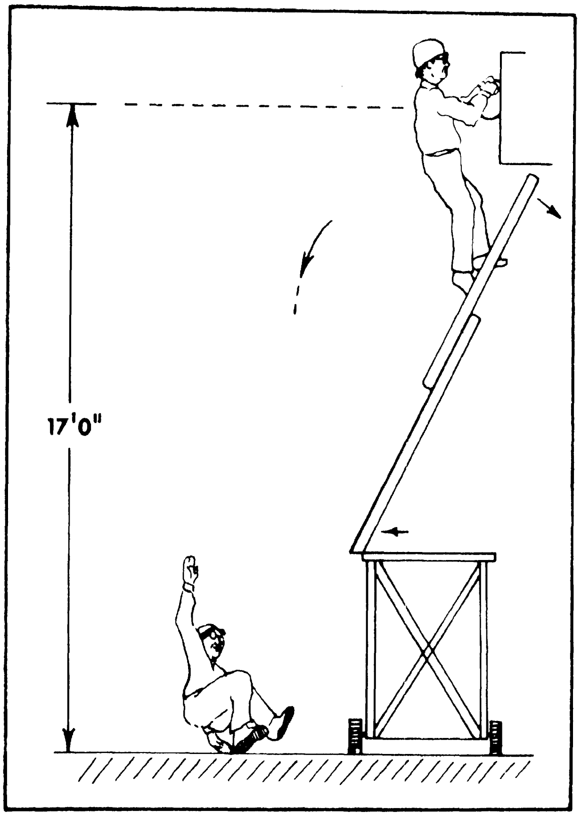
RECOVERY: Still hospitalized eight weeks after fall. Did not expect to return to work for several months. Therapy was planned.

SOURCES OF DATA: X SUBJECT; __ PARENTS;

__ POLICE; X HOSPITAL; X WITNESSES;

__ OTHER:

OTHER COMMENTS: Witness provided seemingly reliable information about fall sequence. Subject had open-heart surgery three years prior to fall, but had no known ill effects due to the fall.



CALCULATED DATA:

IMPACT VELOCITY: 32 ft./sec. (9.8 m./sec.)

OAIS: 4

ISS: 19

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 54

SUBJECT: Male, 18 yrs. 4 mos., 6 ft. 3 in. (1.91 m.), 190 lbs. (86.2 kg.)

FALL DISTANCE: 21 ft. 4 in. (6.5 m.)

ENVIRONMENT: Pitched roof to concrete porch.

MAJOR INJURIES: Fractured nose, multiple facial contusions.

SUMMARY: Student was moving between dormers on steeply-pitched roof. A slate shingle broke, throwing him backward off roof in a partially-upright position. He then free-fell some 21 feet, landing feet-first on a concrete porch. His injuries included a fractured nose, multiple contusions of the face and lips, and bruises and abrasions of extremities. He was hospitalized 2 1/2 days; recovery is complete.

FALL CHRONOLOGY: As he stepped between the dormers, a slate roof shingle broke and caused the subject to slide backward four feet six inches (1.4 m.) down the roof and over the edge, feet first in a semi-crouched position. His left wrist may have contacted a partial porch roof as he fell. He landed feet-first on the concrete porch, then toppled forward onto his face and right side.

SPECIFIC INJURIES: Hairline (but somewhat depressed) fracture of the nose along the septum [FCFR-2]; contusions and edema of the nose [FCCR-1]; lacerations of upper and lower lips [FICD-1]; contusions and abrasions of elbows, right buttock, and left anterior tibial regions [EBCI-1, PRAI-1, LLAI-1].

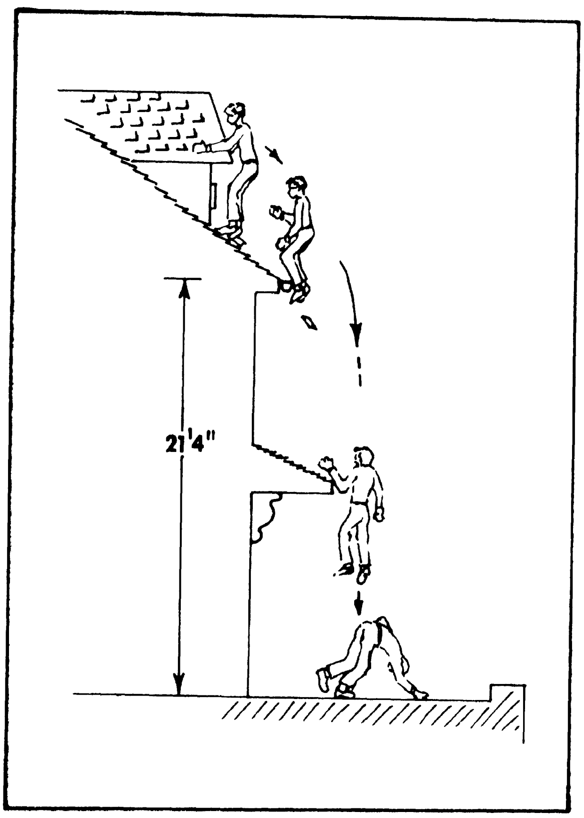
RECOVERY: Apparently complete. Has normal appearance and movement. Occasional slight wrist pains.

SOURCES OF DATA: X SUBJECT; __ PARENTS;

__ POLICE; X HOSPITAL; X WITNESSES;

__ OTHER:

OTHER COMMENTS: Two witnesses--one saw him begin to fall, the other saw the impact. Probably received bruised tibia from roof gutter and sore wrist from hitting partial porch roof.



CALCULATED DATA:

IMPACT VELOCITY: 36 ft./sec. (11.0 m./sec.)

OAIS: 2

ISS: 5

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 55

SUBJECT: Male, 40 yrs. 10 mos., 5 ft. 11 in. (1.80 m.), 162 lbs. (73.5 kg.).

FALL DISTANCE: 22 ft. 4 in. (6.8 m.).

ENVIRONMENT: Highway overpass railing to asphalt roadway.

MAJOR INJURIES: Fractured left pelvis and internal injuries.

SUMMARY: Subject left nursing home he lives at, hitchhiked to nearby bridge overpass, and jumped off railing, landing on an asphalt roadway 22 feet below. His injuries are not completely known, but include a fractured left pelvis and internal injuries. He was hospitalized 5 1/2 weeks and was still confined to a wheelchair 6 1/2 weeks after fall.

FALL CHRONOLOGY: Subject jumped from railing of an overpass bridge, with his forearms covering his face. A witness saw him land feet first, but leaning to left side, then collapse in a heap. He came to rest on his left side, and did not move after the impact, although there are no indications of unconsciousness.

SPECIFIC INJURIES: Injury data are incomplete since medical records could not be reviewed. Subject's brother summarized injuries as a bump on the left side of the head [HLKB-1], a fractured left hip [PLFS-3], and abrasions to the left leg [YLAI-1].

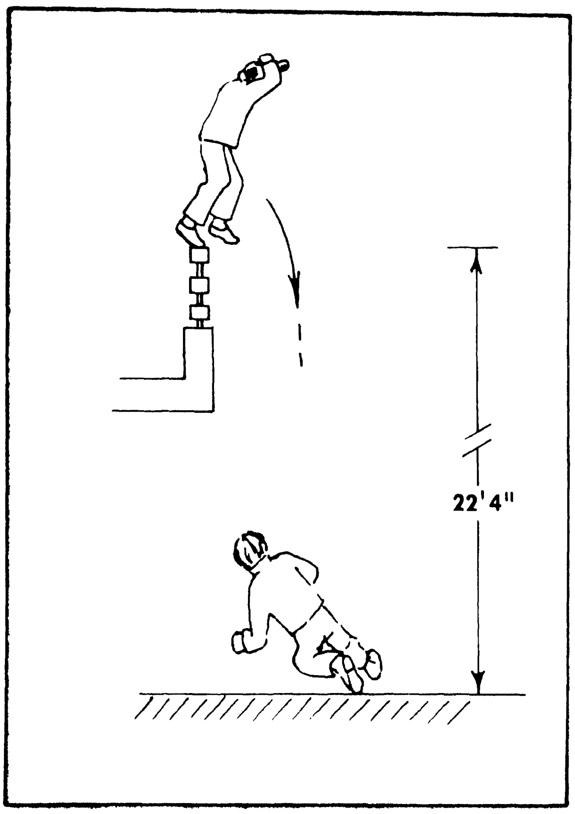
RECOVERY: Does not yet have full use of hip--still confined to wheelchair.

SOURCES OF DATA: _X_ SUBJECT; __ PARENTS;

_X_ POLICE; __ HOSPITAL; _X_ WITNESSES;

_X_ OTHER: Subject's brother.

OTHER COMMENTS: Subject suffers from progressive mental disorder and provided no injury information. Subject could not sign release, guardian (brother) refused to sign it.



CALCULATED DATA:

IMPACT VELOCITY: 37 ft./sec. (11.3 m./sec)

OAIS: 3

ISS: 11

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 56

SUBJECT: Male, 10 yrs, 4 ft 3 in (1.30 m), approx. 50 lbs (22.7 kg)

FALL DISTANCE: 18 ft 1 in (5.5 m)

ENVIRONMENT: Second floor railing to tiled concrete floor

MAJOR INJURIES: Fractured right arm, possible skull fracture

SUMMARY: Subject was in school, and for unknown reason fell over the second floor stairwell railing through the stairwell opening, 18 feet, to the tiled concrete floor below. Paramedics at the scene described his injuries as a fractured right arm, possible skull fracture, contusions, lacerations, and a concussion. No data available for length of hospitalization or degree of recovery.

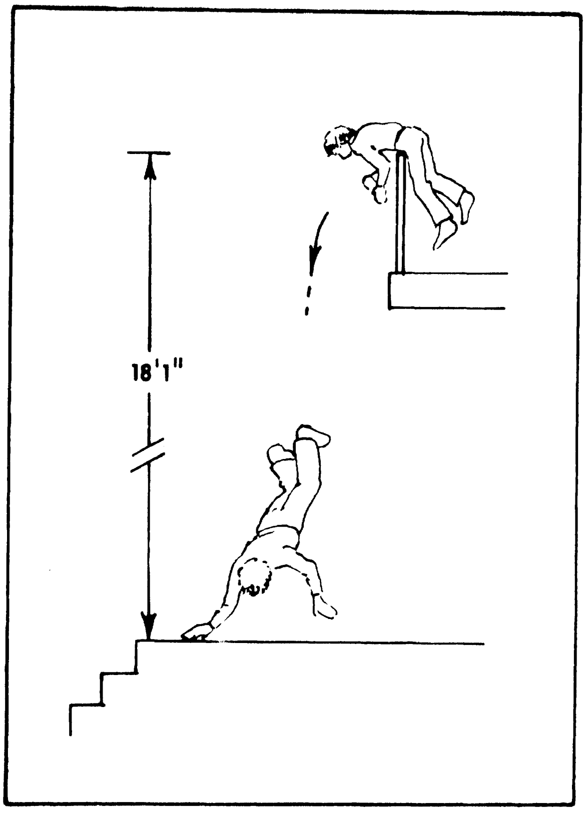
FALL CHRONOLOGY: Child fell over the top of the railing in the second floor stairwell. It is unknown whether he fell forward or backward over the railing, and he may have struck an adjacent stairway bannister as he fell. Impact sequence is undefined, though injuries indicate he landed on his left arm and head. He impacted a tiled concrete floor and may have rolled down a short staircase after impact.

SPECIFIC INJURIES: Injury information provided by paramedic who attended child on site. Displaced fracture of right forearm [RRFS-3], concussion with possible skull fracture [HUKB-2], contusions of forehead [FSCI-1], lacerations of upper lip [FILD-1], and bloody nose [FCHR-1]. He was conscious at the scene, and both eyes rapidly swelled shut.

RECOVERY: Unknown, but there was no indication from school officials that he had suffered any permanent damage.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
__ POLICE; __ HOSPITAL; __ WITNESSES;
X OTHER: paramedic; ambulance report; school officials

OTHER COMMENTS: Parents were not at home, did not respond to written request for information and release.



CALCULATED DATA:

IMPACT VELOCITY: 33 ft/sec (10.1 m/sec)

OAIS: 3

ISS: 14

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 57

SUBJECT: Male, 2 yrs. 5 mos., height unknown, 27 lbs. (12.3 kg.).

FALL DISTANCE: 12 ft. 0 in. (3.7 m.).

ENVIRONMENT: Second floor porch to concrete sidewalk and hard-packed soil.

MAJOR INJURIES: Three skull fractures, lacerations and hematoma of face and head.

SUMMARY: Child was standing on small porch trying to open screen door. It opened suddenly, and he fell backwards through a space in the porch railing. He fell 12 feet, his head impacting a concrete sidewalk. Injuries included skull fractures of right and left frontal, right temporal, and left orbital regions, lacerations and hematomas of the face, and two "black eyes". He was hospitalized four days. Recovery is complete.

FALL CHRONOLOGY: Child was pulling on shut screen door while standing on small porch outside second-story apartment. The door opened suddenly and the child lost his grip, stumbling backward. He hit a crossbar railing, dropped to a sitting position and fell off the porch backward, under the railing. He landed head-first, on the frontal area of his skull, with his head on the concrete sidewalk and body on packed dirt.

SPECIFIC INJURIES: No immediate loss of consciousness, but got progressively drowsy over 1/2 hour period [HWKB-2]; three skull fractures: diastatic, from right frontal to right temporal region [HRFS-3]; undisplaced, from roof of left orbit into left frontal region [FSFS-2]; undisplaced, in right frontal area above the diastatic fracture [FSFS-2]; short deep laceration of forehead [FSLI-1]; ecchymosis of both eyes [FBCI-2]; hematoma of right temple [HRCI-1]; bloody nose [FCHR-1]; other facial lacerations [FWLI-1].

RECOVERY: Apparently complete; child has acted normally since release from hospital.

SOURCES OF DATA: __ SUBJECT; X PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES; X OTHER: Neighbor.

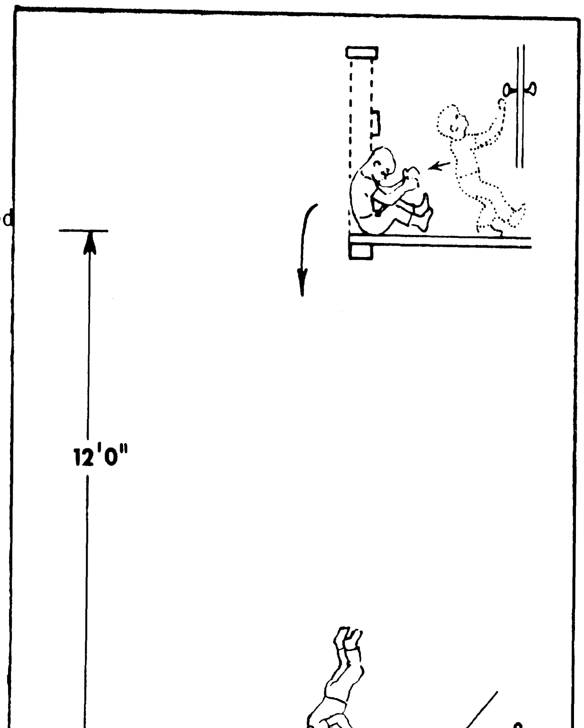
OTHER COMMENTS: Subject was not taken to local hospital until 45 minutes after fall, since he seemed OK initially. Was transported to large hospital 70 miles from home for hospitalization.

CALCULATED DATA:

IMPACT VELOCITY: 27 ft./sec. (8.2 m./sec.)

OAIS: 3

ISS: 14



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 58

SUBJECT: Male, 20 yrs., 5 ft. 4 in. (1.63 m.), 140 lbs. (63.5 kg.).

FALL DISTANCE: 28 ft. 3 in. (8.6 m.), plus roof slide.

ENVIRONMENT: Wet slate roof to flat composition gravel roof.

MAJOR INJURIES: Fractured pelvis, chest and lung contusions, facial lacerations.

SUMMARY: Subject attempted to drop from one level of a peaked roof to a lower level. He lost footing and slid off the wet roof, falling 28 feet to a flat gravel roof. His injuries included a fractured pelvis, contusions of the left chest and lung, and lacerations and abrasions of the face. He was hospitalized 8 1/2 days. Recovery is almost complete, but he still limps slightly and has some facial scarring.

FALL CHRONOLOGY: Subject swung down from peaked roof to lower peak of slate roof. Weather was rainy and subject lost footing. He slid seven feet (2.1 m.) down the 8/12 pitch roof, and off the edge--feet first and face up. He landed on a flat tar-and-gravel roof, probably striking with his right hip, then face. He was found lying supine.

SPECIFIC INJURIES: Semi-conscious but lucid at the scene [HWKB-1]; pelvic fracture of right iliac wing, with slight separation and subluxation of pubic symphysis [PRFS-2, PAOS-3]; slight leftward deviation of mediastinum and heart; contusion of left chest and left lung, with left hemothorax [CLCP-3, CLHP-3]; laceration of right eyebrow, and small facial abrasions [FRLI-1, FWAI-1].

RECOVERY: Complete except for slight scarring above right eye, slight stiffness of the legs, and slight limp.

SOURCES OF DATA: X SUBJECT; __ PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES; __ OTHER:

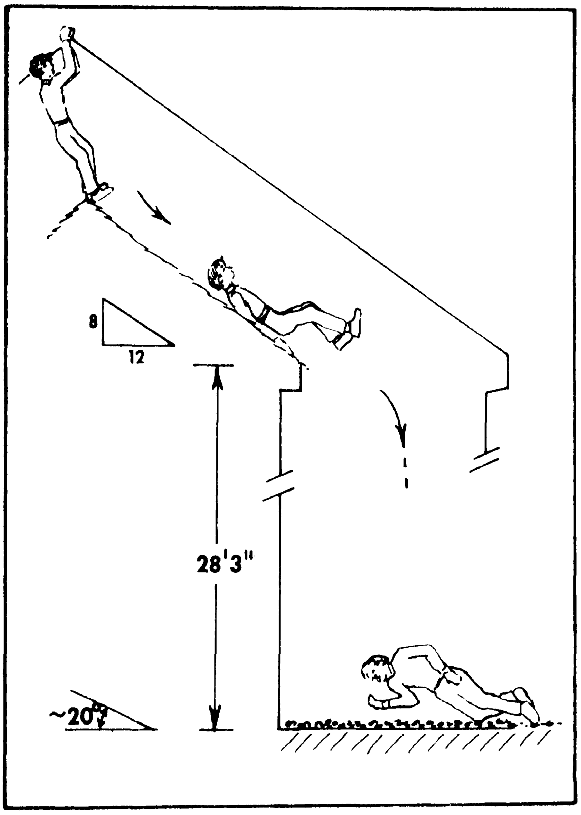
OTHER COMMENTS: Subject thought he lost consciousness while falling, does not remember impact.

CALCULATED DATA:

IMPACT VELOCITY: 41 ft./sec. (12.5 m./sec.)

OAIS: 3

ISS: 19



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 59

SUBJECT: Male, 21 yrs, 5 ft 10 in (1.78 m), 159 lbs (72.1 kg)

FALL DISTANCE: 11 ft 0 in (3.4 m)

ENVIRONMENT: Flat roof to concrete

MAJOR INJURIES: Basilar skull fracture, right hemiparesis, Wernicke's aphasia

SUMMARY: Subject was working on flat roof at construction site, cutting a hole for a vent. He tripped and fell through the hole, 11 ft., striking concrete. His injuries included a fractured skull, right hemiparesis, and speech and receptive aphasia. Subject was hospitalized approximately 8 weeks then discharged for continued therapy on an outpatient basis.

FALL CHRONOLOGY: Worker lost his balance and fell head first through a 3.5 ft. square opening in roof. He landed on his head on either the concrete floor or a small panel of plywood that covered a hole in the floor directly below the hole in the roof. Subject probably struck the concrete first with his head, then he came to rest face down with his feet on the plywood and his head on the concrete.

SPECIFIC INJURIES: Left basilar skull fracture, with mild right hemiparesis and severe Wernicke's aphasia [HLKB-4]; ecchymosis of left forehead [FSCI-1].

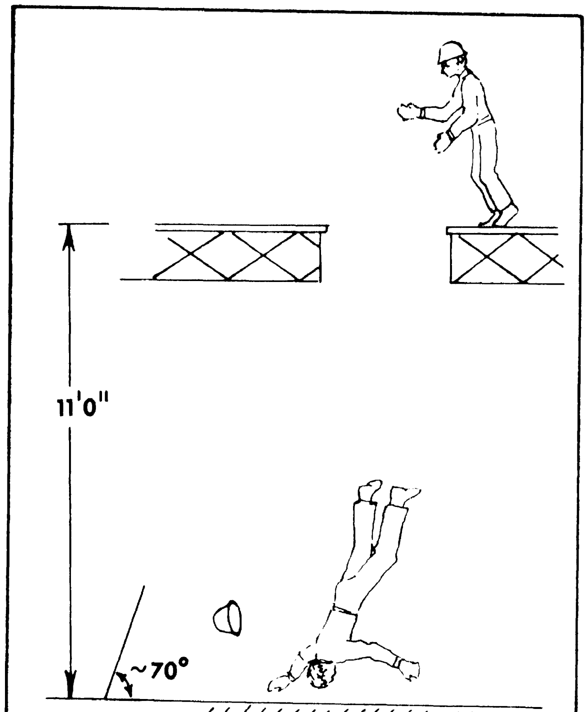
RECOVERY: Receives outpatient, rehabilitative therapies.

SOURCES OF DATA: X SUBJECT; __ PARENTS;

__ POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: Supervisor at construction site, physician, therapist

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 26 ft/sec (7.9 m/sec)

OAIS: 4

ISS: 17

This case was simulated. Responses do not account for fracture effects (See Chap 3).
Est. peak head accel: 495-551 g's
Est. peak normal force-head: 7700-10200 lb (34,200-45,300 N)
Est. peak head deflection: .60-.80 in (1.52-2.03 cm)

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 60

SUBJECT: Female, 18 yrs., approx. 5 ft 3 in (1.60 m), approx. 115 lbs (52.3 kg)

FALL DISTANCE: 72 ft. 6 in. (22.1 m.)

ENVIRONMENT: Bridge railing to smooth thick ice.

MAJOR INJURIES: Fractures of cervical spine and clavicle; multiple fractures of pelvis, both legs, both ankles and left heel; some nerve damage.

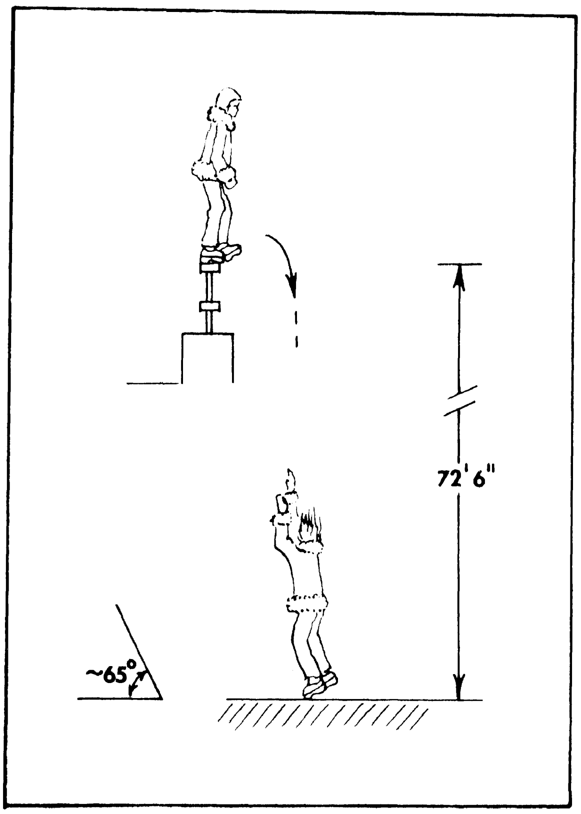
SUMMARY: Subject fell from top of railing of highway bridge, 72 1/2 feet to the frozen river below. She was semi-conscious at the scene and suffered many fractures. Injuries include fractured cervical spine, left clavicle, pelvis, right femur, tibia and fibula, left fibula and tibia, both ankles, and left heel, and nerve damage to right side. She was hospitalized 10 weeks and is now at a rehabilitation center, walking in casts.

FALL CHRONOLOGY: Subject was in unknown position at start of fall, probably standing on top rail facing off the bridge. She landed feet-first, facing bridge, on smooth, rigid ice that was at least one foot (30 cm.) thick. She came to rest in a prone position. There were no cracks in the ice at the impact point.

SPECIFIC INJURIES: No medical release obtained, information was provided by subject's father. Fractured cervical spine [NPFV-3]; fractured left clavicle [SLFS-2]; fractured pelvis (two places, exact location unknown) [PUFS-3]; fractured right femur [TRFS-3]; compound fractures right tibia and fibula, with gross dislocation [LRFS-3]; shattered right ankle [QRFJ-3]; multiple compound fractures left tibia (three-inch section at ankle is missing) and fibula [LLFS-4]; shattered left ankle and heel [QLFJ-3]; nerve damage to right leg (80% sensory loss) [YRCN-3]; probable concussion [HWKB-2]. No skull fractures.
RECOVERY: Incomplete after 10 weeks. Will be in casts for up to one year. Nerve damage clearing. In rehabilitation center temporarily.

SOURCES OF DATA: __ SUBJECT; _X_ PARENTS;
_X_ POLICE; __ HOSPITAL; __ WITNESSES;
_X_ OTHER: Ambulance company, newspaper.

OTHER COMMENTS: Parents were reluctant to discuss the case and would not sign release. Height measurement is close approximation, since wind under bridge was bowing measuring tape.



CALCULATED DATA:

IMPACT VELOCITY: 65 ft./sec. (19.8 m./sec.)

OAIS: 5

ISS: 29

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 61

SUBJECT: Male, 13 mo, ht unknown, 22 lbs (9.7 kg)

FALL DISTANCE: 32 ft 4 in (9.9 m)

ENVIRONMENT: Windowsill to concrete sidewalk

MAJOR INJURIES: Multiple skull fractures, fracture left femur, ruptured spleen, multiple facial lacerations.

SUMMARY: Infant was standing on windowsill, tripped and tumbled through a small, open, tilt-in window on the third floor of a hotel. He fell to the concrete sidewalk 32 feet below. Injuries included parietal and basilar skull fractures, fractures of the left femur, right humerus and right fibula, a ruptured spleen, bruises and abrasions. He was hospitalized 13 days. As of one week after the fall, he was in fair condition and was still medicated, but was recovering.

FALL CHRONOLOGY: There were no direct witnesses to the start of the fall. The child was just learning to walk. It is likely he was standing on a wide windowsill and lost his balance. He fell onto a 15 x 40 in (38 x 102 cm) tilt-in window and rolled out of the window opening. He landed nearly 6 feet (1.8 m) from the building on a concrete sidewalk. He probably landed initially on his head and face, with his left arm under him, then struck his left knee.

SPECIFIC INJURIES: Linear right parietal skull fracture with extension into slightly depressed fracture of left frontal area [HSFS-3]; probable right basilar skull fracture [HIFS-2]; comminuted supracondylar fracture of left femur [TLFS-3]; "very minor" torus fractures of left humerus and fibula [ALFS-2, LLFS-2]; ruptured spleen [MLRQ-4]; periduodenal hematoma [MILD-3]; severely contused left eye [FLCE-2]; right hemotympanum [HRHE-1]; bloody nose [FCHR-1].

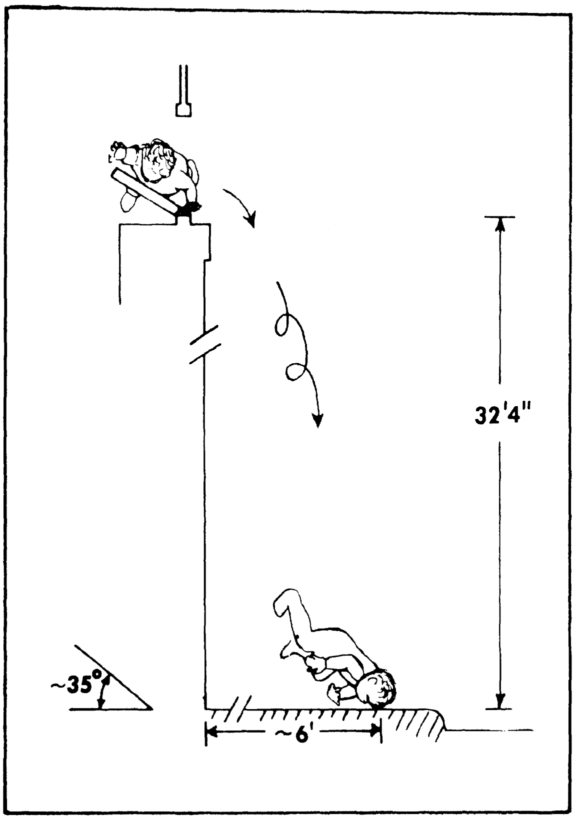
RECOVERY: Still hospitalized one week after fall. At discharge from hospital, physician noted that he was alert and in his mother's opinion essentially normal.

SOURCES OF DATA: __ SUBJECT; X PARENTS;

__ POLICE; X HOSPITAL; __ WITNESSES;

__ OTHER:

OTHER COMMENTS: It was not possible to observe the child in the hospital.



CALCULATED DATA:

IMPACT VELOCITY: 46 ft/sec (14.0 m/sec)

OAIS: 4

ISS: 34

This case was simulated. Responses do not account for fracture effects. (See Chap. 3).

Est. peak head accel: 696-751 g's

Est. peak normal force--head: 4100-4200 lb (18,200-18,700 N)

Est. peak head deflection: 1.01-1.02 in (2.56-2.59 cm)

Est. peak resultant force--femur at knee: 1200-1400 lb (5350-6250 N)

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 62

SUBJECT: Female, 2 yrs 1 mo, 2 ft 8 in (0.81 m), 23 lb (10.4 kg)

FALL DISTANCE: 13 ft 3 in (4.0 m)

ENVIRONMENT: Main floor landing to terrazo floor in lower lobby of auditorium.

MAJOR INJURIES: Frontal and parietal skull fractures, cerebral concussion, dural tear.

SUMMARY: Child was with parents who were setting up exhibit in auditorium foyer. She wandered to railing and slipped between uprights, falling 13 feet to concrete terrazo floor of lower lobby area. She suffered head injuries consisting of linear fractures of the right frontal and left parietal bones, cerebral concussion and edema, a dural tear and subgaleal hematomas. She was hospitalized 56 days, then again overnight two months later. Her recovery is not complete, but her condition continues to improve.

FALL CHRONOLOGY: According to witness, child slid feet-first between uprights of railing on main floor landing. The railing uprights are spaced 10 3/4 in (27.3 cm) apart. She landed "flat on her back". She came to rest immediately and was unconscious.

SPECIFIC INJURIES: Diastatic fracture of right frontal bone, linear fracture in left frontal parietal region, severe cerebral concussion with coma and seizures for more than a week, generalized cerebral edema, focal intracerebral hemorrhage, and a right frontal dural tear [HRKB-5]; and massive bilateral subgaleal hematomas [HSCI-2].

RECOVERY: One year after fall, child was exhibiting epileptic symptoms (controlled through medication). She was mentally alert and doing well in her day-care center.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
X POLICE; X HOSPITAL; X WITNESSES;
X OTHER: Auditorium personnel, attorney

OTHER COMMENTS: Witness noted child was no wearing shoes but was in stocking feet. Witness felt child might have slipped on polished floor.

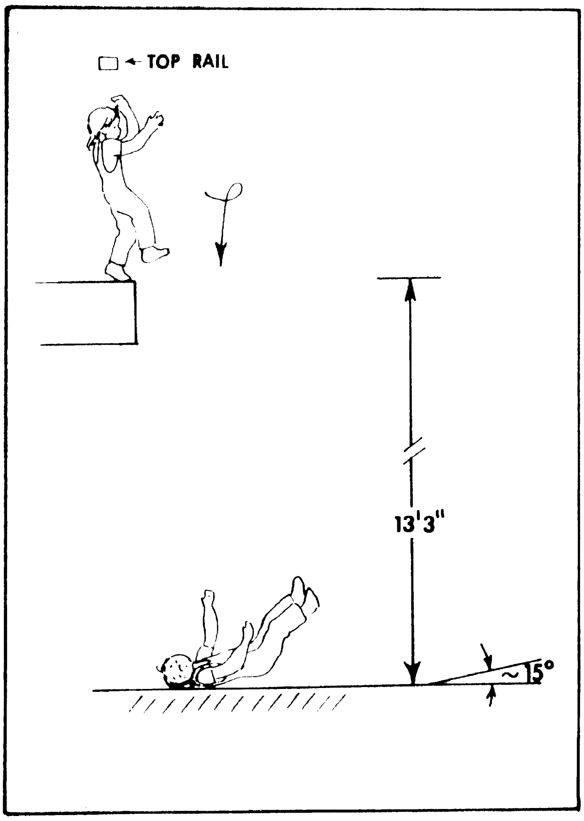
CALCULATED DATA:

IMPACT VELOCITY: 29 ft/sec (8.8 m/sec)

O AIS: 5

ISS: 29

This fall was simulated. Responses do not account for fracture (See Chapt. 3).
Est. peak head accel: 640-652 g's
Est. peak normal force (head): 3330-3450 lb (14,800-15,400N)
Est. peak head deflection: .55 in (1.4 cm)



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 63

SUBJECT: Female, 27 yrs, 5 ft 2 in (1.56 m). 110 lbs (49.9 kg)

FALL DISTANCE: 20 ft 7 in (6.3 m)

ENVIRONMENT: Balcony railing to concrete patio

MAJOR INJURIES: Fractures of both heels, right wrist, and pelvis.

SUMMARY: Subject was sitting on railing of second-floor balcony when she slipped and fell some 20 ft. to concrete patio below. Injuries included comminuted bilateral fractures of the calcaneus bones, fracture of right carpal scaphoid, fracture of left ischium and contusion of left lower costochondral junction. Subject had not completely recovered at time of investigation.

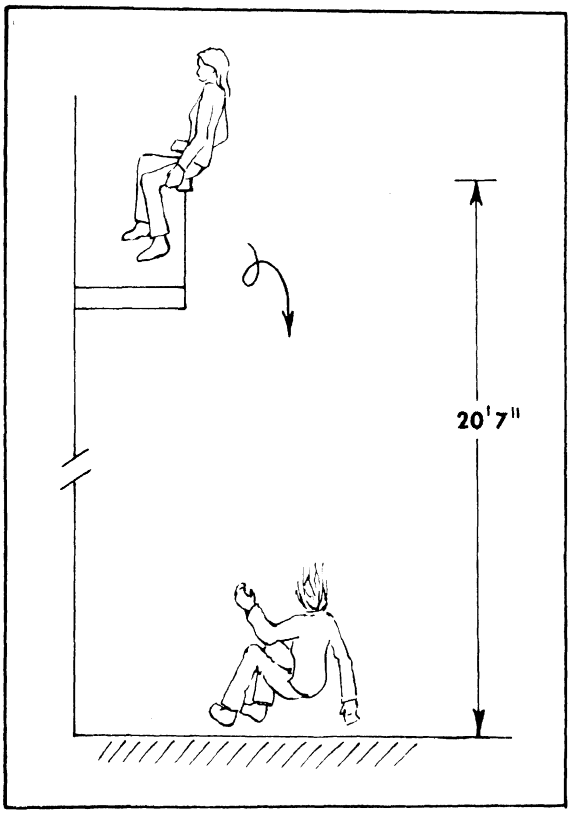
FALL CHRONOLOGY: Subject fell from seated position on balcony railing to concrete patio below. She impacted on both feet, then buttocks and right wrist.

SPECIFIC INJURIES: Comminuted bilateral fractures of calcaneus, with flattening of the articular surface [QBFJ-3]; fracture of right carpal scaphoid [WRFJ-2]; fracture of left ischium in pelvis [PLFS-2]; chest contusion at left lower costochondral junction [CLCI-2].

RECOVERY: Placed in bilateral walking casts. Still in casts 2½ months after fall.

SOURCES OF DATA: X SUBJECT; __ PARENTS;
X POLICE; X HOSPITAL; X WITNESSES;
X OTHER: Physician billings

OTHER COMMENTS: Subject had been drinking and may have been pushed. Case in litigation.



CALCULATED DATA:

IMPACT VELOCITY: 36 ft/sec (11.0 m/sec)

OAIS: 3

ISS: 13

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 64

SUBJECT: Male, 7 yr 4 mo, ht unknown, 65 lb (29.5 kg)

FALL DISTANCE: 7 ft 10 in (2.4 m)

ENVIRONMENT: Main floor of barn to cement floor below

MAJOR INJURIES: Concussion, undisplaced skull fracture, facial abrasions

SUMMARY: Subject was probably trying to descend ladder from main barn floor to dairy section. He lost balance and fell nearly 8 feet to a clean cement floor. He was unconscious for about one hour. Injuries include concussion, undisplaced frontal bone fracture and facial abrasions. He was hospitalized six days and is now fully recovered.

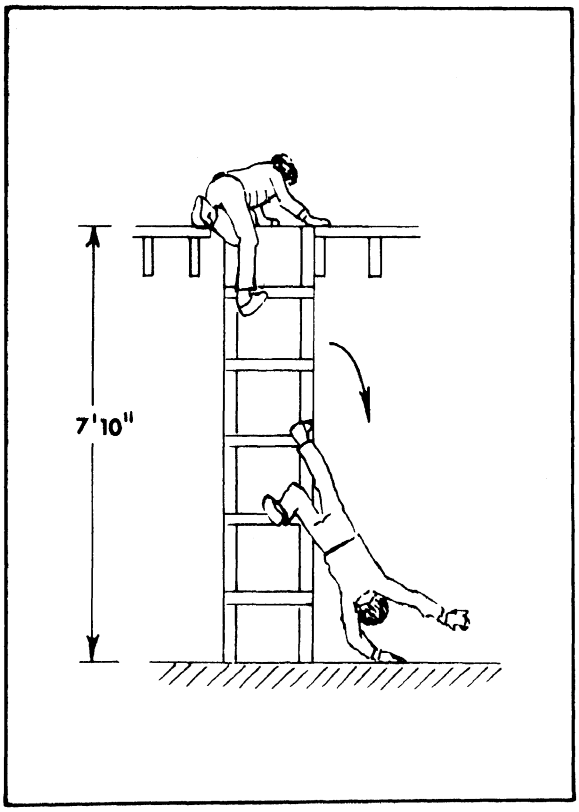
FALL CHRONOLOGY: Child was probably stepping from main barn floor to a ladder which is built into barn wall. Apparently his foot slipped off the first rung and he rotated as he fell, landing on the right frontal portion of his head. He came to rest on his back, spread-eagle, but with his right leg tucked under the left. The cement floor was clean.

SPECIFIC INJURIES: Non-depressed linear fracture of skull frontal bone, concussion with unconsciousness for about 1 hr and stuperous for about 24 hrs [HRKB-4]; bleeding in right middle ear behind typamic membrane [HROE-1]; large abrasion in right fronto-temporal region ("boggy") [HRAI-2].

RECOVERY: Complete, according to mother. He has no continuing ill effects or unusual behavior.

SOURCES OF DATA: __ SUBJECT; X PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES; X OTHER: ambulance service

OTHER COMMENTS: Mother recalled at-rest position since she reached subject while still unconscious and before he had been moved. Was treated briefly at local hospital then transferred to a larger one.



CALCULATED DATA:

IMPACT VELOCITY: 21 ft/sec (6.4 m/sec)

OAIS: 4

ISS: 21

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 65

SUBJECT: Male, 70 yr 10 mo, 6 ft 0 in (1.83 m), 210 lbs (95.3 kg)

FALL DISTANCE: 15 ft 9 in (4.8 m)

ENVIRONMENT: Ladder to floor joist and floor

MAJOR INJURIES: Multiple rib fractures, fractured left fibula, partial lung collapse

SUMMARY: Subject was climbing a wooden ladder attached to wall of church belfry. A ladder rung near the top pulled loose, causing him to swing around and fall off the ladder. He fell nearly 16 feet to an unfinished belfry floor, landing on the edge of a floor joist. Injuries included fractures of four ribs on the left side, a fracture of the left fibula, a partial lung collapse, and large contusions on the left side.

FALL CHRONOLOGY: Subject was standing on vertical ladder which was attached to belfry wall. He was near the top, reaching up to a trap door with one hand, when one end of the rung he was holding onto pulled loose and pivoted out. This swung the subject around and he fell facing away from the ladder. He landed on his left side with his chest striking a 2 x 10 floor joist which supports the bell-rope pulley. The joist was on edge and probably caused the rib fractures.

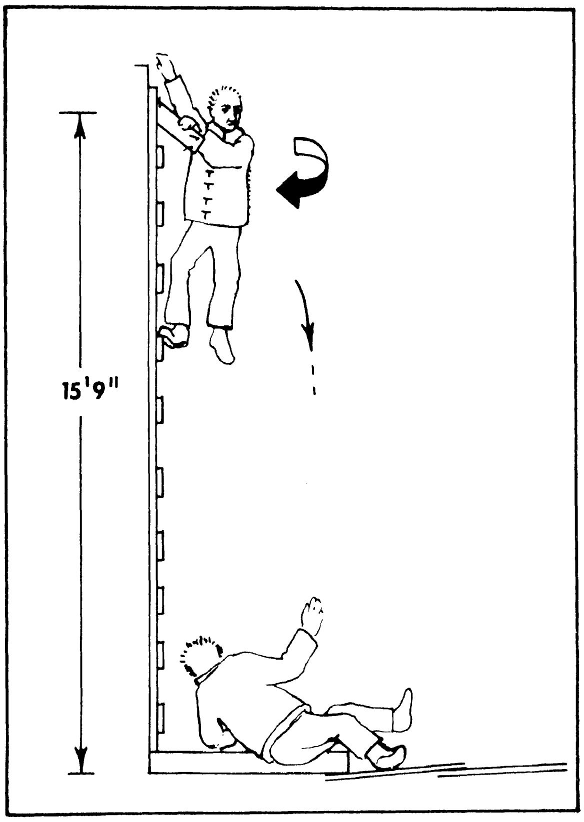
SPECIFIC INJURIES: Fractures of 4th - 8th ribs (left),with fractures near both posterior and anterior axillary lines and some displacement [CLFS-4]; slightly comminuted fracture of proximal left fibula [LLFS-3]; partial collapse of right lung (without puncture or pneumothorax)[CROP-3]; abrasions of left hand and left lateral lower leg [WLAI-1, LLAI-1]; contusion of left side from armpit to knee [CLCI-2]; dazed, no loss of consciousness [HUKB-1].

RECOVERY: Complete except for some stiffness and decreased range of motion in left arm. No limp.

SOURCES OF DATA: X SUBJECT; __ PARENTS; __ POLICE; X HOSPITAL; X WITNESSES;

X OTHER: subject's wife, ambulance service

OTHER COMMENTS: Injuries probably caused primarily by contact with irregular surfaces.



CALCULATED DATA:

IMPACT VELOCITY: 31 ft/sec (9.4 m/sec)

OAIS: 4

ISS: 29

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 66

SUBJECT: Male, 8 yr 11 mo, 4 ft 3 in (1.30 m), 60 lbs (27.2 kg)

FALL DISTANCE: 17 ft 3 in (5.3 m)

ENVIRONMENT: Catwalk to asphalt highway

MAJOR INJURIES: Fractures of the left forearm

SUMMARY: Child was walking backwards on railroad trestle catwalk, talking with a friend. He stepped backwards into a hole where a plank was missing and fell 17 ft to the asphalt pavement of a street. His injuries include fractures of the left radius and ulna and minor abrasions of the face. He was hospitalized 36 hrs for observation. Recovery is complete except for left arm which is still casted.

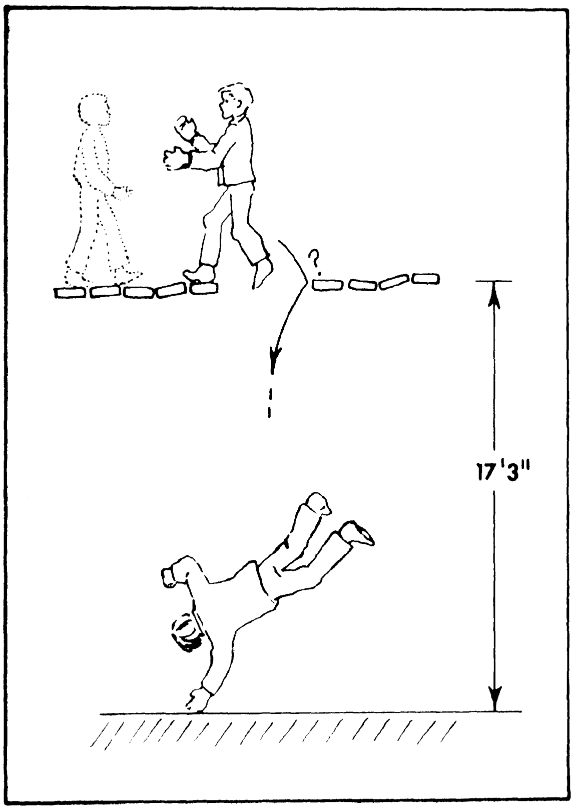
FALL CHRONOLOGY: Subject stepped backward through a hole in the catwalk on which he was walking. He apparently dropped straight through the hole without significant contact, although his back may have rubbed against a plank. He landed on his outstretched left arm, then fell to his left side. He landed in front of a car which narrowly avoided hitting him.

SPECIFIC INJURIES: Fractures of distal shafts of left radius and ulna, with displacement [RLFS-3] slight laceration pinna of left ear [HLLE-1]; abrasion of right face and lower back [FRAI-1, BIAI-1]. No loss of consciousness.

RECOVERY: Subject's left forearm still in cast four weeks after fall, expected to be completely healed by six weeks. No other complications.

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; X HOSPITAL; X WITNESSES; __ OTHER:

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 33 ft/sec (10.1 m/sec)

OAIS: 3

ISS: 11

This case was simulated as a simplified fall onto the hip from 10 and 20 feet (3.0 and 6.1 m).
Est. peak accel of head: 560 g's (10 ft), 793 g's (20 ft);
Est. peak accel of hip: 157 g's (10 ft), 214 g's (20 ft)

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 67

SUBJECT: Male, 22 yrs 8 mo, 6 ft 1 in (1.85 m), 195 lbs (88.5 kg)

FALL DISTANCE: 26 ft 8 in (8.1 m)

ENVIRONMENT: Window to concrete sidewalk

MAJOR INJURIES: None

SUMMARY: Subject was waiting for friend in adjacent empty apartment. Subject was attempting to crawl from window of empty apartment to window of friend's apartment when he lost his balance. Subject fell from third story,about 27 feet, to concrete sidewalk below. He received no fractures nor serious injuries and refused medical treatment.

FALL CHRONOLOGY: Subject was probably in standing position on windowsill, leaning toward the other window. He lost his balance and fell to concrete sidewalk below. He probably landed feet-first and rolled to his side, although impact position is uncertain. He may also have struck a fabric awning as he fell, although it was in a tattered condition and probably would not have broken the fall.

SPECIFIC INJURIES: Generalized contusions (he told friend he had sore muscles "all over") [OWCI-1]; apparently no fractures.

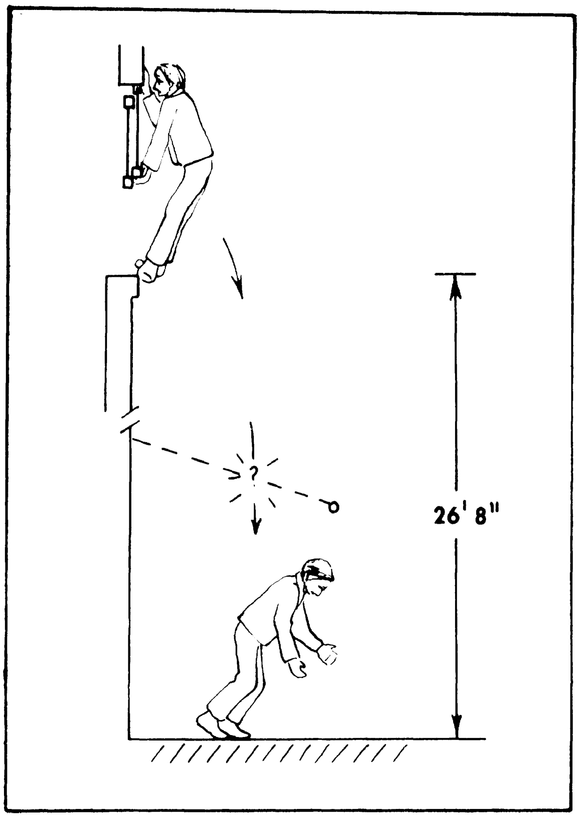
RECOVERY: Refused medical aid, rested on sidewalk bench after fall.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;

X POLICE; __ HOSPITAL; X WITNESSES;

X OTHER: friend (owner of apartment)

OTHER COMMENTS: There was no damage to the framework of the awning. One witness thought he fell through the awning, the other did not.



CALCULATED DATA:

IMPACT VELOCITY: 41 ft/sec (12.5 m/sec)

OAIS: 1

ISS: 1

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 68

SUBJECT: Male, 1 yr 8 mo, 2 ft 8 in (0.81 m), 23 lb (10.4 kg)

FALL DISTANCE: 21 ft (6.4 m)

ENVIRONMENT: 3rd floor window to wooden porch

MAJOR INJURIES: Frontal skull fracture, concussion

SUMMARY: The child climbed out open third floor window, onto flat roof area and walked or crawled about 6 ft (1.8 m) to where he fell from the roof 21 feet to first floor rear porch. He landed head-first. The child was hospitalized 5 days with a skull fracture.

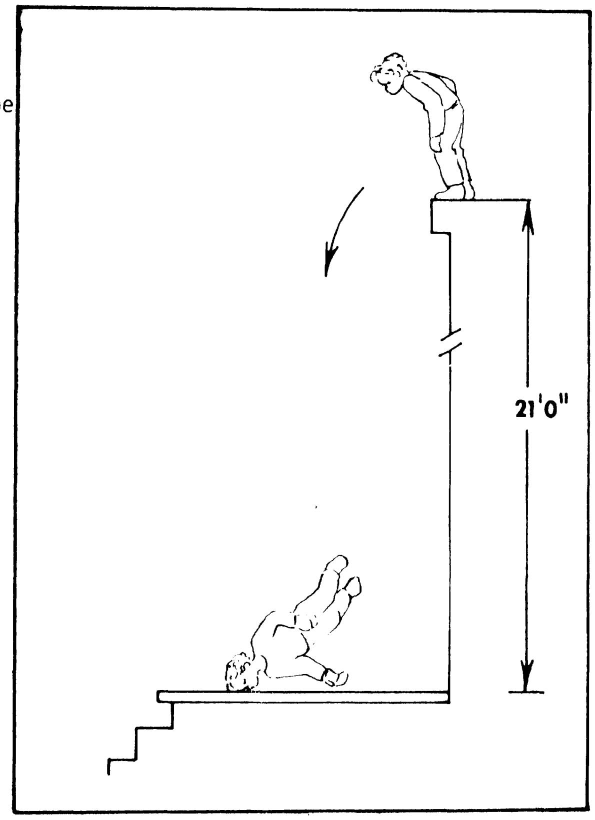
FALL CHRONOLOGY: Child climbed onto an end table, then out an open 3rd floor window onto a flat roof. He continued walking or crawling to the edge of the roof, then fell 21 ft to first floor rear porch composed of 1½ inch (3.8 cm) boards 3½ to 5½ inches (8.9 - 14.0 cm) wide. The child impacted head-first, on the right forehead area.

SPECIFIC INJURIES: Contusions of right forehead [FSCI-1]; abrasion of nose, [FCAI-1]; undisplaced right linear frontal skull fracture and concussion, with no loss of consciousness [HRKB-2].

RECOVERY: Complete, no reported sequelae.

SOURCES OF DATA: X SUBJECT; X PARENTS;
X POLICE; X HOSPITAL; X WITNESSES;
X OTHER: newspaper, fire department rescue squad.

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 36 ft/sec (11.0 m/sec)

OAIS: 2

ISS: 5

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 09

SUBJECT: Male, 3 yrs 11 mo, 3 ft 7 in (1.09 m), 50 lbs (22.7 kg)

FALL DISTANCE: 11 ft 11 in (3.6 m)

ENVIRONMENT: Windowsill to pitched roof to frozen soil

MAJOR INJURIES: Fracture of left femur

SUMMARY: Child was playing in bedroom, apparently throwing toys out the window to watch them slide down the roof. He climbed onto windowsill and fell to pitched roof, then slid off the roof and landed on frozen soil. He had a fractured left femur and a mild abdominable contusion. He was hospitalized in traction for 43 days and has almost completely recovered.

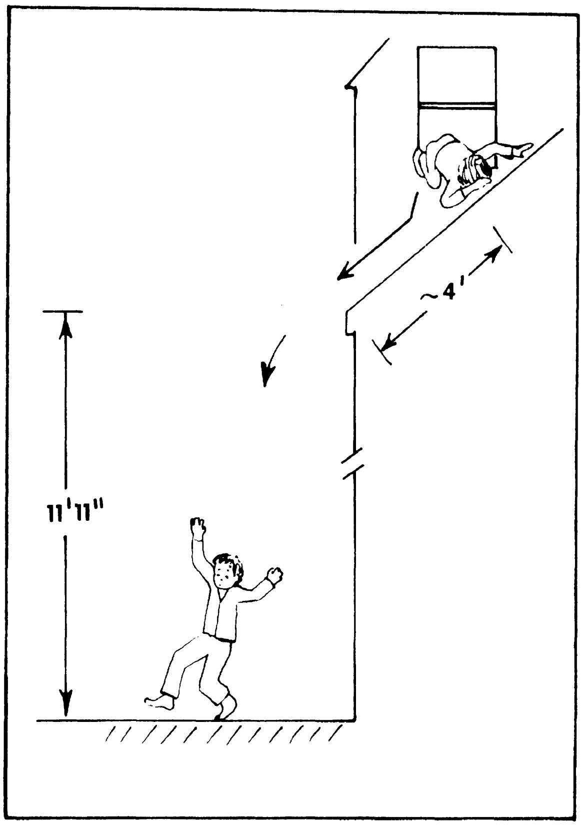
FALL CHRONOLOGY: Child climbed onto windowsill, facing out. He tumbled onto a pitched roof just below his window and slid about 3 ft (.9 m) down the roof and off the edge. He landed, probably on his left knee, on frozen soil, then fell to sitting position with his lower left leg under his body.

SPECIFIC INJURIES: Displaced fracture in midshaft of left femur [TLFS-3]; contusion of abdomen [MCCI-1].

RECOVERY: Nearly complete at time of interview (just after release from hospital). Full recovery expected.

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; X HOSPITAL; __ WITNESSES; __ OTHER:

OTHER COMMENTS: There was approximately one inch (2-3 cm) of snow on the ground but it would not have significantly cushioned the fall.



CALCULATED DATA:

IMPACT VELOCITY: 27 ft/sec (8.2 m/sec)

OAIS: 3

ISS: 10

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 70

SUBJECT: Male, 6 yr 9 mo, ht unknown, 55 lb (24.9 kg)

FALL DISTANCE: 10 ft 0 in (3.0 m)

ENVIRONMENT: Main floor of barn to concrete floor

MAJOR INJURIES: Concussion, cerebral hemorrhage: Fatal

SUMMARY: Child was attempting to help uncle feed the dairy herd. He pushed a hay bale through a partially-opened access hole in the main floor of a barn, then apparently lost his balance and fell through the hole after the hay bale. He landed on the concrete floor 10 ft below. He was unconscious immediately and remained comatose. Injuries proved fatal 7½ hours after the fall.

FALL CHRONOLOGY: The boy apparently created a triangular opening in the barn floor by moving a cover part way off the hay hole. He then shoved a hay bale through the hole. The bale was probably a tight fit and when pushed hard, he lost his balance and followed the bale through the hole. He apparently did not land on the bale, but instead impacted the upper right part of his head on a smooth concrete floor. He came to rest in a prone position.

SPECIFIC INJURIES: Unconscious or semi-comatose until he expired. Concussion, probably with cerebral hemorrhage [HUKB-5]; ecchymosis and swelling of right eye [FRCE-1]; abrasions of right temple [HRAI-1]. No fractures were found.

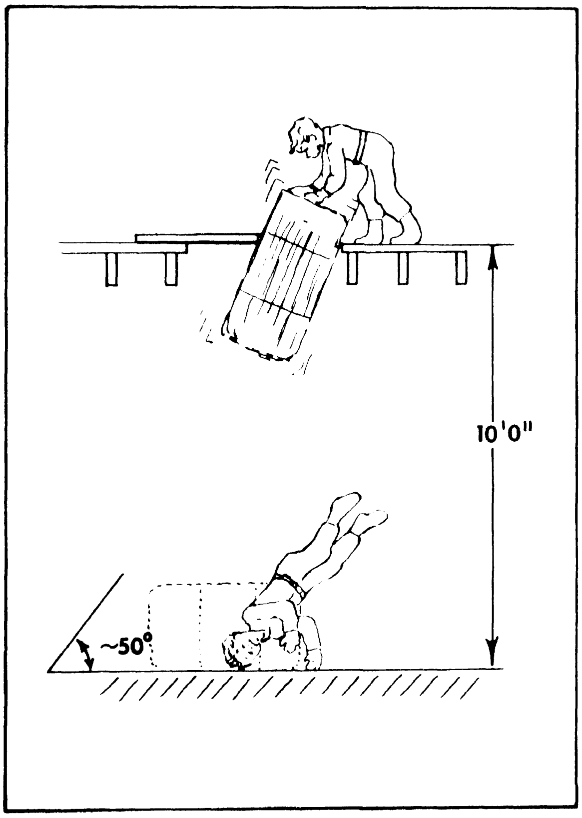
RECOVERY: Did not recover: fatal after 7½ hours. Developed violent tremors, then had respiratory arrest.

SOURCES OF DATA: __ SUBJECT; X PARENTS;

__ POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: uncle, farm handyman

OTHER COMMENTS: An autopsy was requested by physician, but parents refused. Distance from accident site to nearest hospital was 21 miles (33.8 km).



CALCULATED DATA:

IMPACT VELOCITY: 23 ft/sec (7.0 m/sec)

OAIS: 5

ISS: 27

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 71

SUBJECT: Female, 5 yrs 1 mo, 3 ft 6 in (1.07 m), 42 lbs (19.1 kg)

FALL DISTANCE: 8 ft 4 in (2.5 m)

ENVIRONMENT: Main floor of barn to concrete floor

MAJOR INJURIES: Basilar skull fracture. Fatal after 5 days.

SUMMARY: Child was playing in barn while her brothers were doing chores. She backed into an open hay hole on the first floor and fell 8 feet, landing head-first on the concrete aisle of the dairy section. Her injuries included fracture of the right orbit, a basilar skull fracture, severe brain damage, and multiple abrasions. She was hospitalized with her condition deteriorating steadily until she died 5 days after the fall.

FALL CHRONOLOGY: The child probably backed into the open hole. It is likely she struck the far side of the hole with her shoulder causing her to rotate into a face-down, head-first position. She landed on the left part of her forehead and came to rest face down.

SPECIFIC INJURIES: Stellate fracture in the anterior floor of the cranial vault, with severe concussion and progressive edema in the left cerebrum [HLKB-5]; abrasions to left forehead, left shoulder, and both knees [FSAI-1, SLAI-1, KBAI-1]; bloody nose [FCHR-1].

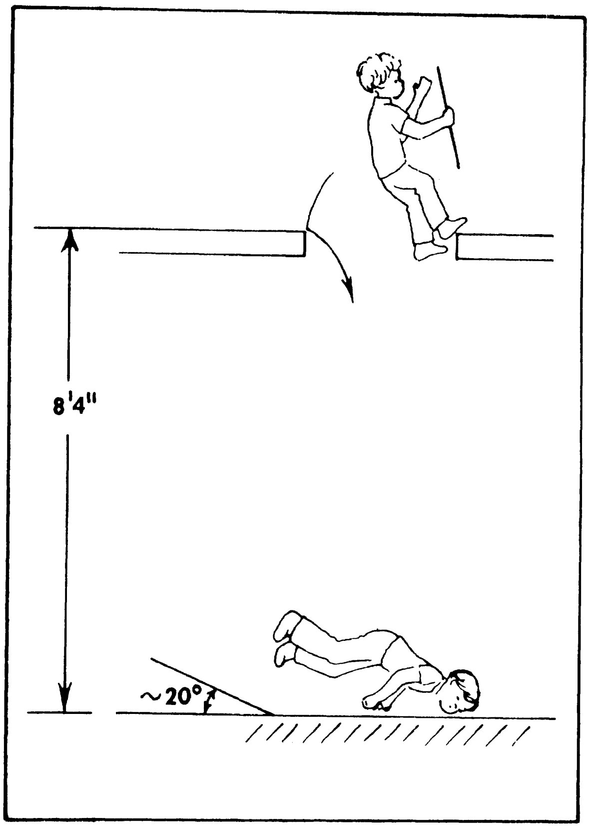
RECOVERY: She was revived briefly at the scene, but became increasingly comatose. Placed on mechanical respirator 36 hours after fall. No spontaneous activity thereafter, expired 5 days after fall.

SOURCES OF DATA: __ SUBJECT; X PARENTS;

__ POLICE; X HOSPITAL; __ WITNESSES;

__ OTHER:

OTHER COMMENTS: Subject lived some distance from hospital and there were delays in getting treatment.



CALCULATED DATA:

IMPACT VELOCITY: 21 ft/sec (6.4 m/sec)

OAIS: 5

ISS: 26

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 72

SUBJECT: Male, 33 yrs 6 mo, 5 ft 10 in (1.78 m), 160 lbs (72.6 kg)

FALL DISTANCE: 17 ft 0 in (5.2 m)

ENVIRONMENT: Flat metal canopy to concrete

MAJOR INJURIES: Fractures of mandible, femur, wrist, hand

SUMMARY: Subject stepped onto unsupported panels of a flat canopy over a truck loading dock. The panels collapsed suddenly and he fell 17 feet to ice-covered concrete, landing between two trucks. He received fractures of facial bones, the left hand, right wrist, left femur and left patella. He was hospitalized 57 days, still walks with crutches, and is not expected to be able to work for one year.

FALL CHRONOLOGY: Subject stepped off steel beam frame of canopy onto flat aluminum panels. Several panels collapsed and subject dropped through resulting 3 x 4 ft (.9-1.2 m) hole. He landed on his hands and knees on a concrete driveway that was slightly coated with ice. He came to rest face up behind his truck and beside a semi-trailer parked at the dock. There is some question whether his face contacted the edge of the semi-trailer.

SPECIFIC INJURIES: Comminuted fracture of the mandible and the cheek bones on left side of face [FLFS-3]; fractured and dislocated fingers of right hand [WRFJ-1]; fractured, "jammed" left wrist [WLFJ-3]; Comminuted fracture of left patella [KLFJ-3]; distal shaft fracture of left femur [TLFS-2].

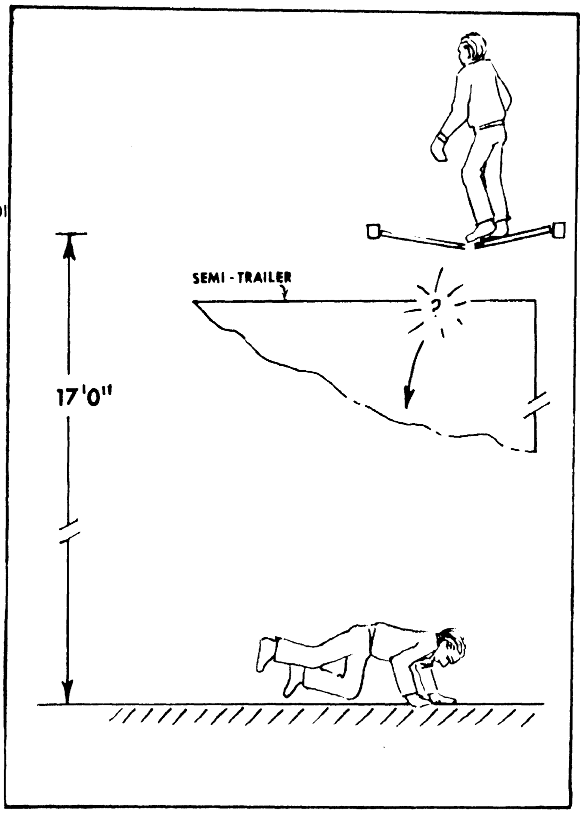
RECOVERY: Apparently very slow. As of three months after fall, he had no feeling on left side of face, did not have full use of left wrist and was on crutches. He was expected to be on crutches and off work for one year.

SOURCES OF DATA: X SUBJECT; __ PARENTS;

__ POLICE; __ HOSPITAL; __ WITNESSES;

X OTHER: Subject's daughter, industrial safety director and other employees at fall site.

OTHER COMMENTS: Injury information obtained from safety report and from daughter. In later conversation with subject, he refused to give information or sign medical release because of pending litigation.



CALCULATED DATA:

IMPACT VELOCITY: 32 ft/sec (9.8 m/sec)

OAIS: 3

ISS: 18

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 73

SUBJECT: Male, 47 yrs 2 mo, 6 ft 2 in (1.88 m), 210 lbs (95.1 kg)

FALL DISTANCE: 10 ft 7 in (3.2 m)

ENVIRONMENT: Roof peak to asphalt driveway

MAJOR INJURIES: Multiple vertebral body fractures, wrist fracture.

SUMMARY: Fireman was on roof fighting a fire. He was moving sideways with hands on one side of roof peak and feet on the other. He slipped on ice and slid off roof, landing in sitting position on asphalt driveway. Injuries included a blow to the jaw which knocked him out, fractures of one thoracic and two lumbar vertebrae, fractured and buckled sacrum, and fractured left wrist. He was hospitalized 5 days and was expected to be off-duty for 3-4 months.

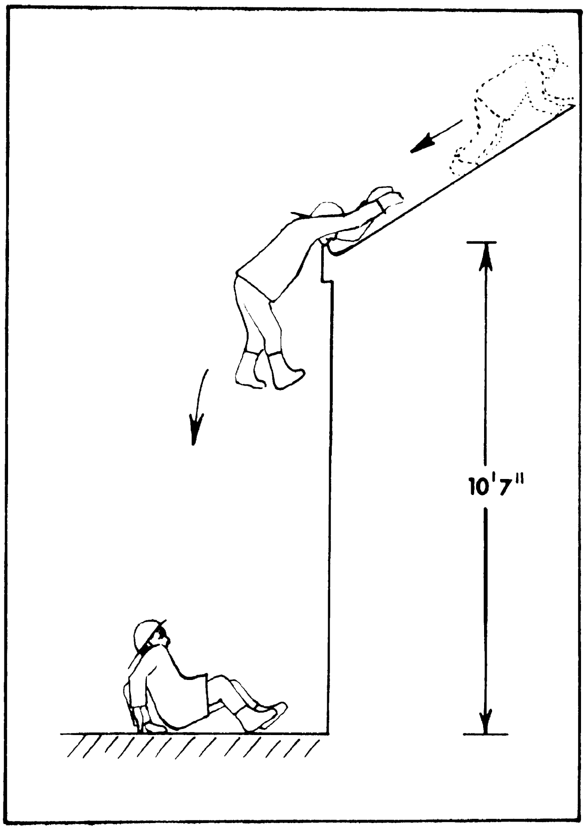
FALL CHRONOLOGY: He moved sideways along the roof with his gloved hands gripping the peak. He lost grip at an icy area of the roof and slid down the tar-paper-covered roof on his hands and feet. His chin hit a gutter as he fell off the roof. He landed in a sitting position with his arms behind him.

SPECIFIC INJURIES: He was knocked unconscious briefly by a blow to the chin [FIKB-2]; slight compression fracture of T-7 [BSFV-3]; Compression fractures of anterior portions of L-1 and L-2 [BIFV-3]; Fractures and buckling of S-3, S-4, and S-5 [PPFS-3]; Perilunate dislocation of left carpal bones, with fracture of left navicular [WLDJ-3]; fracture of 5th right metacarpal, with dislocation of metacarpal-phalangeal joint [WRFJ-1].

RECOVERY: His left wrist was casted for two months and is stiff, back was apparently recovered. He expected to be off-duty for up to four months.

SOURCES OF DATA: X SUBJECT; __ PARENTS;
__ POLICE; X HOSPITAL; __ WITNESSES;
X OTHER: Fire Department

OTHER COMMENTS: Subject was heavily clothed with winter firefighting gear.



CALCULATED DATA:

IMPACT VELOCITY: 25 ft/sec (7.6 m/sec)

OAIS: 3

ISS: 27

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 74

SUBJECT: Male, 13 yrs 3 mo, 5 ft 8 in (1.73 m), 120 lbs (54.4 kg)

FALL DISTANCE: 22 ft 0 in (6.7 m)

ENVIRONMENT: Concrete wall to smooth, solid ice

MAJOR INJURIES: Displaced fractures of both lower legs and of the right foot

SUMMARY: Subject was attempting to cross a frozen canal raceway along the top of a concrete viaduct. The boy lost his foothold when approximately 3/4 across and fell onto the frozen surface of the raceway, some 22 ft below. Subject was hospitalized for 18 days with displaced fractures of the left tibia and fibula, the right tibia and right talus. He is now partly recovered, with full recovery expected.

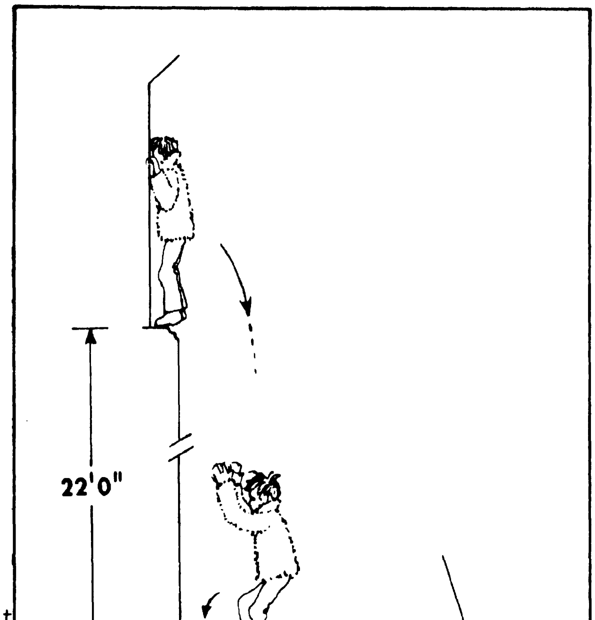
FALL CHRONOLOGY: Subject was crossing frozen raceway watercourse by holding onto a chain link fence and working his way sideways across the viaduct on his toes. He slipped off the viaduct when he reached a crumbled concrete section. He was in a standing position facing the fence when he started to fall. He dropped almost straight down, landing on thick, rigid, smooth ice which was dusted with snow. The landing position is estimated to be feet first, body crouched slightly forward, left leg somewhat straighter than right. He probably then fell forward onto his hands, coming to rest on all fours. He crawled several feet to a different location before rescuers arrived.

SPECIFIC INJURIES: Displaced fractures across distal third of left tibia and fibula [LLFS-3]; undisplaced fracture of the right tibia at medial malleolus [LRFS-2]; displaced fracture of dome of the right talus [QRFJ-3].

RECOVERY: Right leg completely recovered. Left leg still in half-leg walking cast as of 12 weeks after fall.

SOURCES OF DATA: X SUBJECT; X PARENTS;
__ POLICE; X HOSPITAL; __ WITNESSES;
X OTHER: rescuing fireman, newspaper, canal lock operator

OTHER COMMENTS: Subject was very heavily clothed when he fell--probably provided much padding. Water level in canal raceway had been raised by time of investigation. Canal officials provided information about water level at time of fall.



CALCULATED DATA:

IMPACT VELOCITY: 37 ft/sec (10.7 m/sec)

OAIS: 3

ISS: 9

This case was simulated. Forces do not account for fracture effects (see Chapter 3).

Est. peak accel: head 111-191 g; hip 84-131 g

Est. peak axial forces: foot: 4750-6650 lb (21,100-29,600 N)
Tibia at foot: 4450-6750 lb (19,800-29,900 N)
Tibia at knee: 2450-3900 lb (10,900-17,300 N)
Femur (proximal): 1750-2800 lb (7,800-12,500 N)

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 75

SUBJECT: Female, 20 yrs, 5 ft 2 m (1.57 m), 95 lbs (43.0 kg)

FALL DISTANCE: 67 ft 0 in (20.4 m)

ENVIRONMENT: Eighth floor window to lawn

MAJOR INJURIES: Concussion, multiple rib fractures with pneumothorax, ruptured spleen, fractures of L5, sacrum, pelvis, both ankles.

SUMMARY: Subject was intoxicated, for unknown reasons climbed onto windowsill. She fell from sitting position some 67 feet and landed feet first on lawn. She received multiple injures including cerebral contusion and concussion, fractures of 5 left and 2 right ribs, a right pneumothorax, a ruptured spleen, retroperitoneal hemorrhage, and fractures of L-5, the sacrum, the pelvis (ischum, ilium, pubic bone and acetabulum), and both ankles. She was hospitalized 20 days and is recovering satisfactorily.

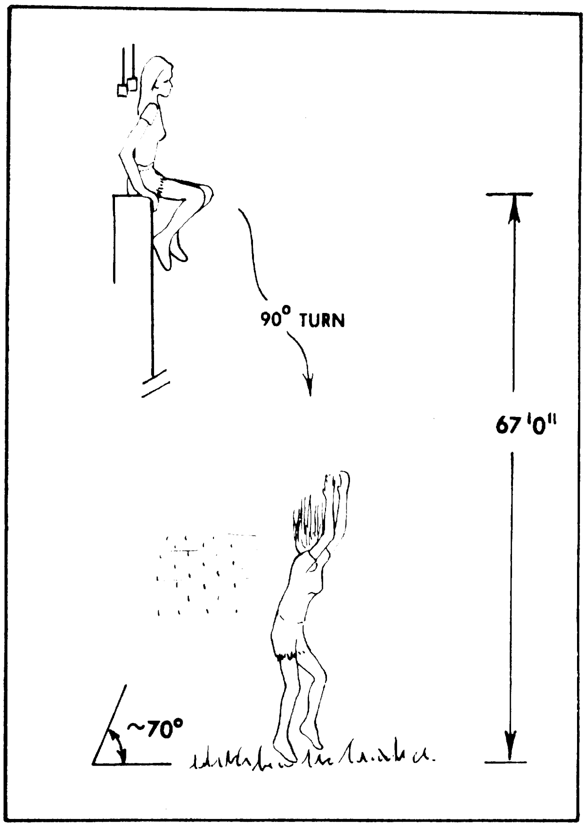
FALL CHRONOLOGY: Subject was apparently sitting on eighth-floor windowsill of her dormitory room, facing out. She apparently fell forward and down, landing on her feet on the grassy soil below. Impressions of her feet, about 2 in (5 cm) deep, were found about 8 ft (2.5 m) from building. She probably pitched forward when she landed.

SPECIFIC INJURIES: Cerebral concussion and contusion, semi-comatose for several hours [HUKB-4]; fractures of right ribs nos 2,3,4,5,7 and left ribs 1,2 [CBFS-4]; 30% right pneumothorax [CROP-3]; ruptured spleen, [MLRQ-4]; retroperitoneal hematoma & slight hematuria [MULD-4]; fracture of transverse process and lamina of L-5 [BIFV-3]; comminuted, displaced fracture of sacrum [PPFS-3]; nondisplaced fractures of right hemipelvis in ischum, ilium, pubic ramus, & acetabulum [PRFS-2]; displaced fractures of right medial malleolus & talus, & nondisplaced fracture of left talus [QBFJ-2].

RECOVERY: Partial at time of investigation. She was home and mostly ambulatory, mental status good.

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; X HOSPITAL; X WITNESSES; X OTHER: dormitory residents

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 62 ft/sec (18.9 m/sec)

OAIS: 5

ISS: 48

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 76

SUBJECT: Male, 7 yrs, 4 ft 0 in (1.22m), 62 lbs (28.1 kg)

FALL DISTANCE: 17 ft 6 in (5.3 m)

ENVIRONMENT: Tree limb to dry hard-packed ground

MAJOR INJURIES: Fractures of left femur and left wrist

SUMMARY: Child was climbing in pecan tree at home. He was standing on a branch when the limb broke causing the child to fall 17.5 ft to hard, dry ground below. His injuries included a fractured mid-shaft of the left femur, a fractured left wrist, and bruises on the right side of his head. Child was hospitalized 23 days. Recovery is apparently complete.

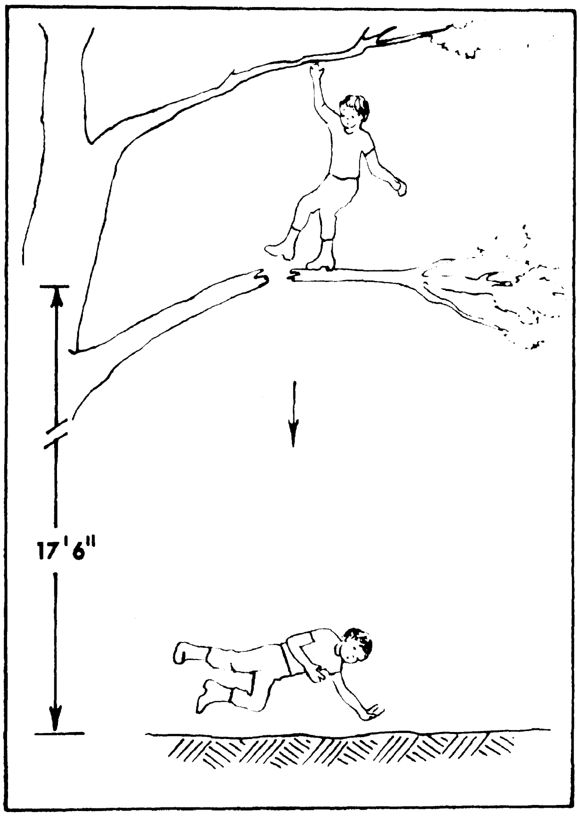
FALL CHRONOLOGY: Child fell when tree branch he was standing on broke. He did not contact other branches as he fell. Impact was on hard dry ground, used as a roadway for farm vehicles. He probably landed on his left arm and knee. He was lying on his right side when found.

SPECIFIC INJURIES: Comminuted fracture of midshaft of left femur [TLFS-3]; displaced fracture of distal left radius at the epiphyseal joint [WLFJ-3]; contusions to right side of head [HRCI-1].

RECOVERY: Complete. Fractures were completely united within 6 months. No after-effects.

SOURCES OF DATA: __ SUBJECT; X PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES; __ OTHER:

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 33 ft/sec (10.1 m/sec)

OAIS: 3

ISS: 10

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 77

SUBJECT: Male, 13 yrs 6 mo, approx 5 ft (1.5 m), approx 100 lbs (45.4 kg)

FALL DISTANCE: 39 ft 6 in (12.0 m)

ENVIRONMENT: Concrete deck to smooth asphalt

MAJOR INJURIES: Skull fractures, cerebral concussion and contusion, fractures of both forearms, right femur and right patella, contused kidney

SUMMARY: Boy was attempting to fly kite on concrete deck at a restored historical site. He fell backwards into a large pit, landing on his outstretched arms on a smooth asphalt surface after falling nearly 40 feet. Injuries included frontal and basilar skull fractures with concussion and probable contusion, multiple fractures of the left forearm and fractures of the right forearm, right femur and right patella. He was hospitalized 107 days, in three hospitals. He has recovered completely except for permanent loss of sight.

FALL CHRONOLOGY: Subject was backing up atop concrete deck. Kite string snapped and he stumbled backward over 7 in (18 cm) lip around circular pit and fell into the pit. He landed on smooth asphalt on his outstretched arms, collapsed onto his head and right knee and came to rest on his back.

SPECIFIC INJURIES: Linear frontal and right basilar skull fractures, with cerebral concussion and contusion and loss of vision [FSFS-2, HIKB-5]; probable blunt trauma to heart, with partial right bundle branch block [CCCH-3]; contused kidney [MUCK-3]; displaced fractures of distal right radius and ulna [RRFS-3]; severe comminuted fractures of midshaft and metaphyses of left radius and ulna [RLFS-4]; comminuted fractures of right femur at midshaft and right patella [TRFS-3, KRFJ-3]; contusions both eyes [FBCE-2].

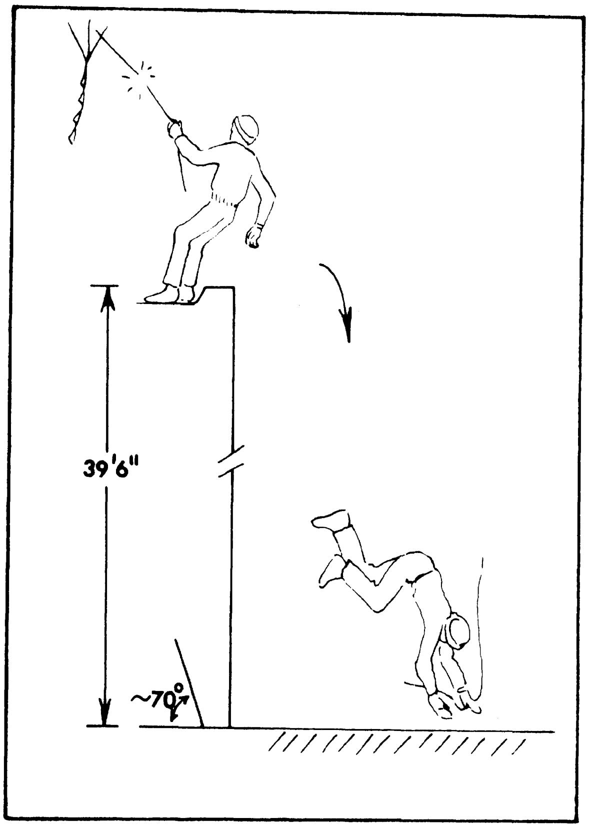
RECOVERY: As of ten weeks after fall, his right arm was still braced and he needed a walker. Six months after fall, apparently fully recovered except for permanent total blindness in both eyes.

SOURCES OF DATA: __ SUBJECT; X PARENTS;

X POLICE; X HOSPITAL; X WITNESSES;

X OTHER: Ambulance Service

OTHER COMMENTS: Subject adapting well and rapidly to blindness. Physicians initially gave him only 5 % chance of survival.



CALCULATED DATA:

IMPACT VELOCITY: 49 ft/sec (14.9 m/sec)

0 AIS: 5+

ISS: 50

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 78

SUBJECT: Male, 5 yrs, height unknown, 45 lbs (20.4 kg)

FALL DISTANCE: 17 ft 6 in (5.3 m)

ENVIRONMENT: Porch railing to concrete pavement

MAJOR INJURIES: Right linear parietal skull fracture, concussion

SUMMARY: Child was waiting with his sister on the third floor landing of his apartment residence. He apparently climbed over or between the vertical metal bars of the landing railing and was hanging onto the outside of railing when he lost his grip. Child fell 17 ft. to the concrete patio. He sustained a right linear parietal skull fracture and was hospitalized 17 days.

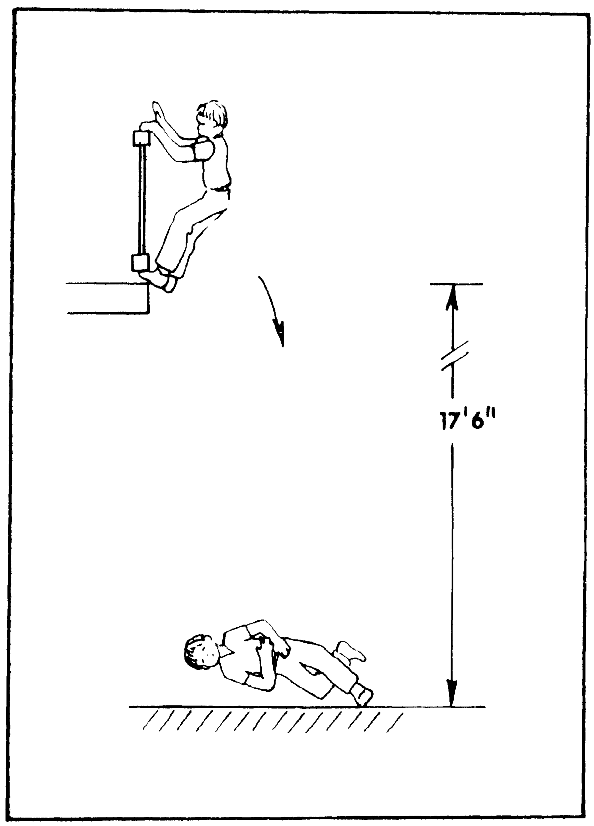
FALL CHRONOLOGY: He climbed over 3 ft (.9 m) rail, or between the vertical metal bars, and was hanging on the outside of the railing facing the porch. He lost his grip and fell to the concrete patio. Child probably landed feet first, then toppled onto right side, striking right side of head on pavement.

SPECIFIC INJURIES: Long linear fracture through the postero-inferior aspect of the right parietal bone with the fracture line extending into the lambdoidal suture and squamosal suture; concussion but no loss of consciousness [HRKB-2].

RECOVERY: Apparently complete.

SOURCES OF DATA: X SUBJECT; X PARENTS;
X __ POLICE; X HOSPITAL; __ WITNESSES;
__ OTHER:

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 33 ft/sec (10.1 m/sec)

OAIS: 2

ISS: 4

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 79

SUBJECT: Male, 1 yr 10 mo, 2 ft 9 in (.84 m), 36 lbs (16.3 kg)

FALL DISTANCE: 12 ft 3 in (3.7 m)

ENVIRONMENT: Window to bare soil

MAJOR INJURIES: Cerebral concussion, orbital fracture

SUMMARY: Child was standing at slightly open window watching some activity outside. Apparently, he pushed window open further and leaned out to get a better view. Screen came loose and child fell 12 feet to the bare soil beneath the window. He was hospitalized 4 days with a concussion and right orbital fracture. Recovery is complete except for some residual blackening under right eye.

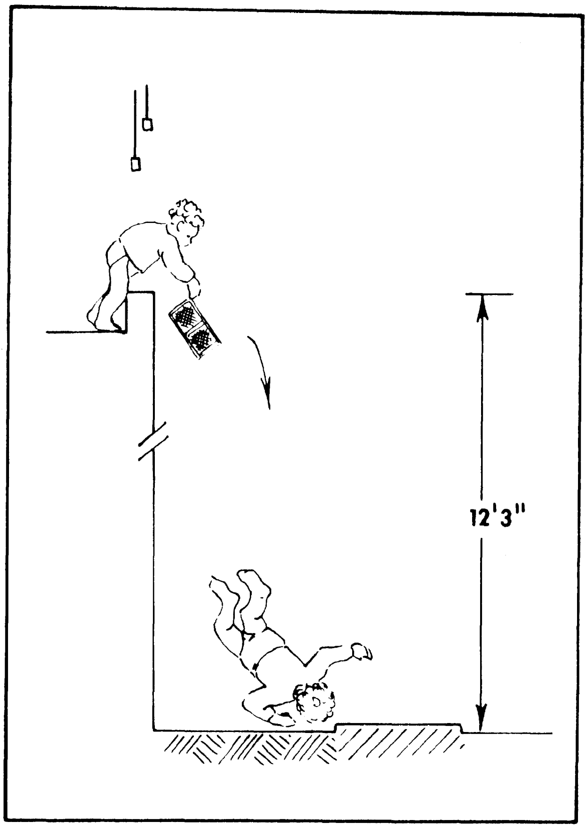
FALL CHRONOLOGY: Window was open only a few inches, with an expandable screen in outer window channel. Child pushed window open further and leaned out, dislodging screen and tumbling over windowsill. He landed head-first on bare soil next to slate sidewalk. He was found lying face down with his head on the slate, but he was conscious and moving by that time.

SPECIFIC INJURIES: Cerebral concussion, with undisplaced hairline orbital fracture right side [HRKB-2]; major contusion of right eye [FRCE-2]; abrasion over right anterior iliac bone [PRAI-1].

RECOVERY: Complete except for some residual blackening under right eye.

SOURCES OF DATA: __ SUBJECT; X PARENTS; X POLICE; X HOSPITAL; __ WITNESSES; __ OTHER:

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 28 ft/sec (8.5 m/sec)

OAIS: 2

ISS: 8

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 80

SUBJECT: Female, 4 yrs, 3 ft 4 in (1.02 m), 32 lbs (14.5 kg)

FALL DISTANCE: 17 ft 6 in (5.3 m)

ENVIRONMENT: Porch to concrete walk

MAJOR INJURIES: Linear skull fracture, brain contusion, bruises on right side of face.

SUMMARY: Child was chasing a ball on back porch of second floor residence of her baby-sitter. She ran under the porch railing and fell about 17 ft. to the concrete walk in the rear yard. She sustained a linear skull fracture, brain contusion, and bruises and was hospitalized 10 days. Recovery is complete.

FALL CHRONOLOGY: She apparently lunged for her ball near the edge of the porch. The middle rail was missing and the child passed under the 25 in (64 cm) high top rail. Probably, her momentum carried her off the porch. She landed head first on a concrete pavement.

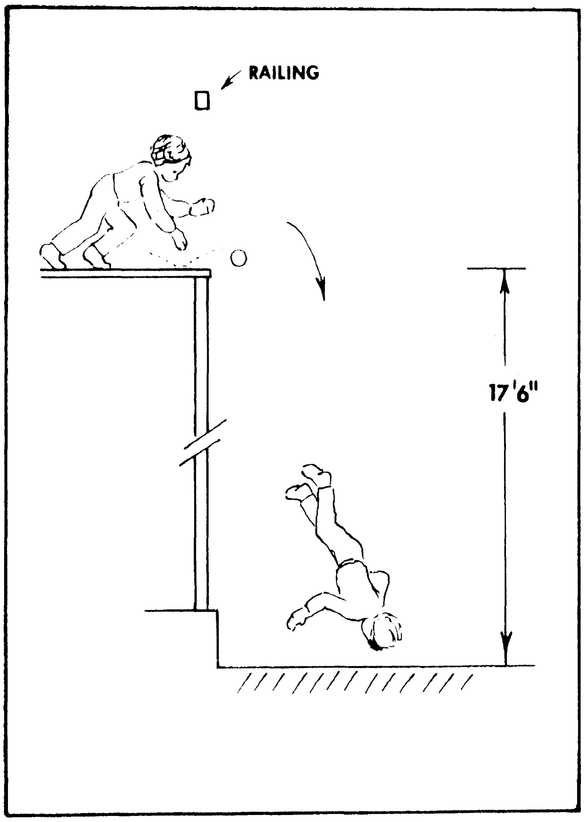
SPECIFIC INJURIES: Linear skull fracture right side, with concussion and slight brain contusion (no loss of consciousness) [HRKB-3]; bruises right side of face [FRCI-1]; abrasion right thigh. [TRAI-1].

RECOVERY: Complete according to physician. Mother noted no changes in personality or temperament.

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; __ HOSPITAL; __ WITNESSES;

X OTHER: Ambulance Service

OTHER COMMENTS: Parents declined to approve medical release as they were planning litigation.



CALCULATED DATA:

IMPACT VELOCITY: 33 ft/sec (10.1 m/sec)

OAIS: 3

ISS: 10

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 81

SUBJECT: Male, 3 yrs 8 mo, 3 ft 0 in (0.91 m), weight unknown

FALL DISTANCE: 25 ft 4 in (7.7 m)

ENVIRONMENT: Third floor windowsill to hard packed gravel driveway.

MAJOR INJURIES: Fractures of right femur and left orbit.

SUMMARY: Child was leaning out of window, probably looking at squirrel in nearby tree. He fell from third story bedroom window, about 25 ft., to gravel driveway below. He was hospitalized 44 days for treatment of his injuries which included a transverse fracture of midshaft of right femur, left orbital fracture, and facial lacerations. Complete recovery was expected.

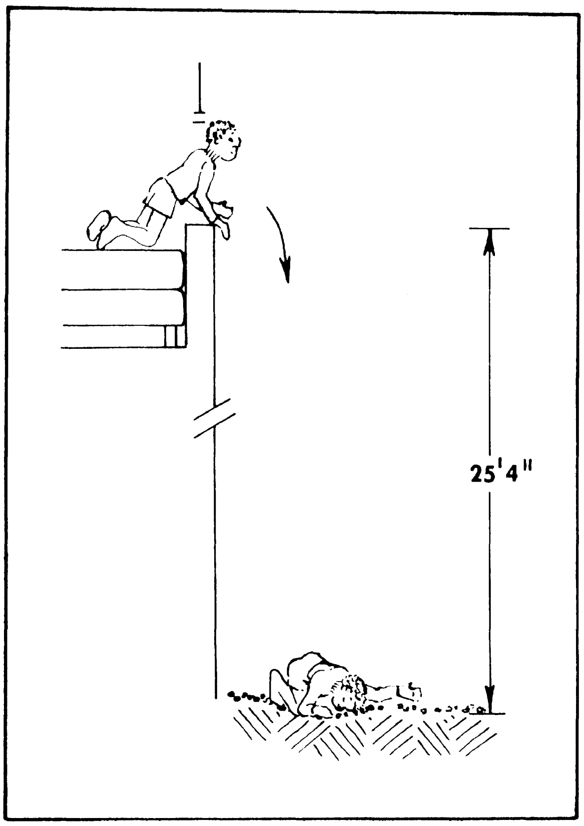
FALL CHRONOLOGY: Child was probably leaning forward out of window. He leaned too far and fell out of window. He probably landed in a prone position but with his right leg drawn up under him. He was found on his knees with face on ground.

SPECIFIC INJURIES: Dazed and slightly stuporous for 24 hours [HLKB-1]; displaced transverse fracture of midshaft of right femur [TRFS-3]; fracture of floor of left orbit [FLFS-3]; superficial lacerations over left eye, on left cheek and left lower lip [FSLI-1, FLLD-1].

RECOVERY: Progressing. Subject was still in hospital at time of investigation. Full recovery was expected.

SOURCES OF DATA: __ SUBJECT; X PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES; __ OTHER:

OTHER COMMENTS: Subject had history of two other falls which were not free-falls.



CALCULATED DATA:

IMPACT VELOCITY: 40 ft/sec (12.2 m/sec)

OAIS: 3

ISS: 19

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 82

SUBJECT: Male, 16 yrs, 5 ft 6 in (1.68 m), 121 lbs (54.9 kg)

FALL DISTANCE: 11 ft 10 in (3.6 m)

ENVIRONMENT: Broken tree branch to asphalt street

MAJOR INJURIES: Concussion, bruises

SUMMARY: Youth was attempting to retrieve a horse's halter which had become caught in tree limbs. He climbed the tree and went out on a branch to reach the halter. The limb broke suddenly and the youth fell about 12 feet to the asphalt pavement, landing on his back. Injuries included a cerebral concussion and abrasions and contusions of right shoulder and right forearm. The youth was hospitalized for observation over night and discharged the next day.

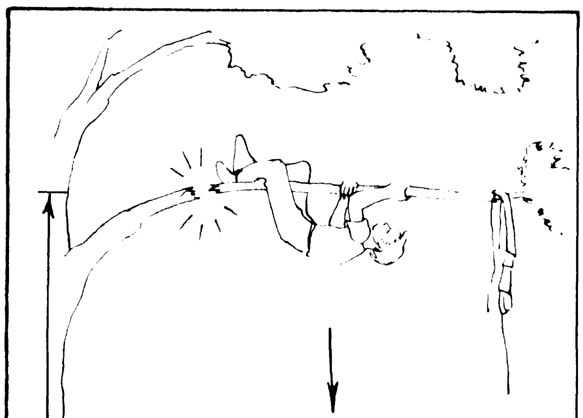
FALL CHRONOLOGY: Youth climbed along branch, with his hands and legs wrapped around the branch (sloth-like). The branch was brittle; it did not bend much but broke suddenly. He landed on asphalt paving near the edge of the street with his head in a round-bottom 3 in (8 cm) deep water runoff channel which is continuous with the street paving. According to witness, youth impacted head-first, then on his right shoulder and back. He came to rest in a supine position with his legs on the street and head and shoulders in the storm drain channel.

SPECIFIC INJURIES: Cerebral concussion, with a short period of nausea but no loss of consciousness [HPKB-2]; abrasions of the upper right shoulder, right forearm and right occipital area [SRAI-1, RRAI-1, HPAI-1]; contusion on back parallel to spine [BCCI-1].

RECOVERY: Nearly complete two weeks after fall. Had slight vision problem when looking down (his eyes cross, he said).

SOURCES OF DATA: X SUBJECT; X PARENTS; __ POLICE; X HOSPITAL; X WITNESSES; __ OTHER:

OTHER COMMENTS: Broken branch was about 2 in (5 cm) diameter at the break point.



CALCULATED DATA:

IMPACT VELOCITY: 27 ft/sec (8.2 m/sec)

OAIS: 2

ISS: 5

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 83

SUBJECT: Male, 3 yrs, 3 ft 3 in (0.99m) approx 30 lbs (13.6 kg)

FALL DISTANCE: 16 ft 3 in (5.0 m)

ENVIRONMENT: Second story window to unpaved alley

MAJOR INJURIES: No significant injuries

SUMMARY: Child fell about 16 ft from second story window to unpaved alleyway. His injuries included a bruise over left eye, scratches on left side of face, and bruise on back of leg. He was hospitalized for 5 days for observation.

FALL CHRONOLOGY: Child was probably standing on his bed. He fell through an open second-floor window and landed, probably head-first, on hard-packed gravel.

SPECIFIC INJURIES: Bruise over left eye [FLCE-1]; scratches on left side of face [FLAI-1]; bruise on leg [LUCI-1]. No other known injuries (x-rays all negative).

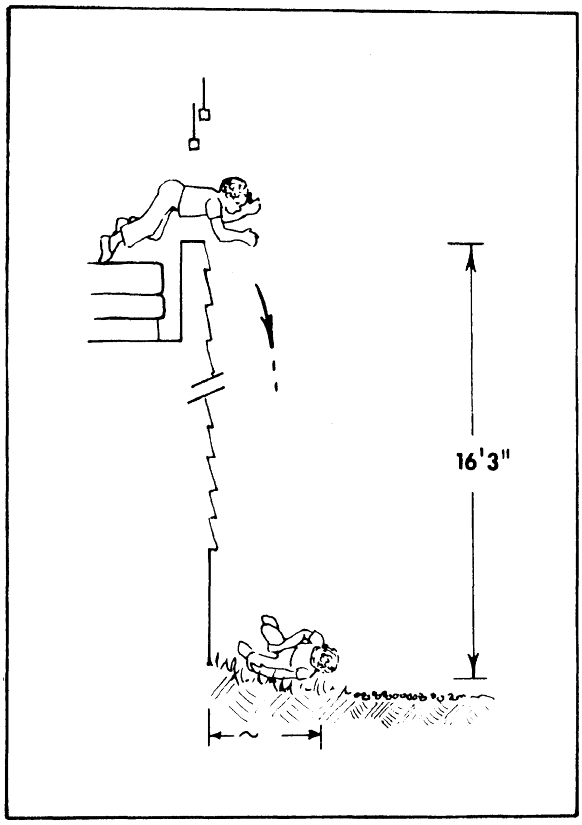
RECOVERY: Complete, no apparent after effects.

SOURCES OF DATA: X SUBJECT; X PARENTS;

__ POLICE; __ HOSPITAL; __ WITNESSES;

__ OTHER:

OTHER COMMENTS: Parents declined to release records.



CALCULATED DATA:

IMPACT VELOCITY: 31 ft/sec (9.4 m/sec)

0 AIS: 1

ISS: 1

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 84

SUBJECT: Male, 1 yr 4 mo, height unknown, 23 lb (10.4 kg)

FALL DISTANCE: 10 ft 6 in (3.2 m)

ENVIRONMENT: 2nd story window to lawn

MAJOR INJURIES: Possible concussion, possible internal injuries.

SUMMARY: Child fell from a 2nd story window, rolling as he lost his balance, and landed back-first on a lawn of thick grass. Injuries included contusions to lower back, concussion with a short period of unconsciousness. Subject may also have had slight internal injuries since he was described as "coughing up blood all night." Treated and released at hospital. Recovery apparently complete.

FALL CHRONOLOGY: Toddler apparently lost balance and fell to sitting position beside unscreened tilt-out lower section of apartment window. Since the windowsill was only a few inches above the floor, the child rolled sideways out of window. He landed on his back on deep turf lawn.

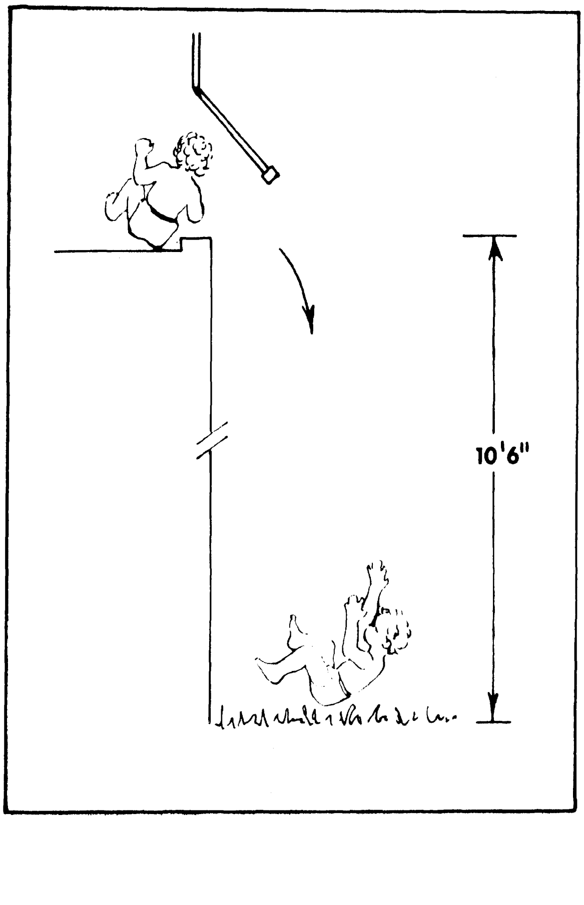
SPECIFIC INJURIES: Concussion, short period of unconsciousness [HPKB-2]; contusions on lower back above buttocks [BLCI-1].

RECOVERY: Complete. Initially had trouble sleeping; was irritable for a month.

SOURCES OF DATA: __ SUBJECT; X PARENTS; X POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: Apartment manager

OTHER COMMENTS: Father, a paramedic, gave mouth to mouth resuscitation for about 30 sec to revive the child.



CALCULATED DATA:

IMPACT VELOCITY: 25 ft/sec (7.6 m/sec)

OAIS: 2

ISS: 5

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 85

SUBJECT: Male, 3 yrs 11 mo, 2 ft 10 in (0.86 m), weight unknown

FALL DISTANCE: 12 ft 7 in (3.8 m)

ENVIRONMENT: Second-floor window to lawn

MAJOR INJURIES: None

SUMMARY: Child climbed onto windowsill in bedroom. He fell against the screen, which came loose. He fell almost 13 feet, landing on a grassy lawn. He sustained no injuries and was not treated or examined by a physician.

FALL CHRONOLOGY: Child leaned against or fell against window screen while playing next to open window. The screen dislodged and the child fell to a soft grassy lawn. His position at landing is unknown, but presumably was not head-first.

SPECIFIC INJURIES: He had no injuries at all. He was not seen by a physician.

RECOVERY: No injuries, no indication of after effects.

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; __ HOSPITAL; __ WITNESSES; __ OTHER:

OTHER COMMENTS:

UNKNOWN

CALCULATED DATA:

IMPACT VELOCITY: 28 ft/sec (8.5 m/sec)

OAIS: 0

ISS: 0

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 86

SUBJECT: Male, 61 yrs, 6 ft (1.83 m), weight unknown

FALL DISTANCE: 9 ft 6 in (2.9 m)

ENVIRONMENT: Top of step ladder to smooth asphalt

MAJOR INJURIES: Fractures of feet and ankles of both legs

SUMMARY: Subject was on a platform inspecting welds. Apparently believing that someone was holding the ladder, the subject stepped from beam onto top of ladder. When the stepladder started to tip over, the subject pushed himself away from beams and fell, about 10 ft, to asphalt. He suffered fractures to both ankles and both feet. He was hospitalized about two weeks and has not yet recovered full use of his legs.

FALL CHRONOLOGY: Subject, assuming that the ladder was being steadied from below, probably dropped to the top rung from a beam which was 4 ft (1.2 m) higher than the ladder. The ladder slipped, the subject felt himself falling and pushed away from the beam and the ladder. He fell backward in an upright position, landing heels first on a smooth asphalt surface. He came to rest on his back with his legs partly drawn up.

SPECIFIC INJURIES: Fractures of both lower legs [LBFS-2]; fractures of both "feet" (probably heels) [QBFS-2]. No unconsciousness, no indication of other injuries.

RECOVERY: Not yet fully recovered. Crutches or wheelchair are periodically necessary (as of 7½ months after fall). Returned to work 3 months after fall.

SOURCES OF DATA: __ SUBJECT; __ PARENTS; __ POLICE; __ HOSPITAL; __ WITNESSES; _X_ OTHER: supervisor, fellow employees

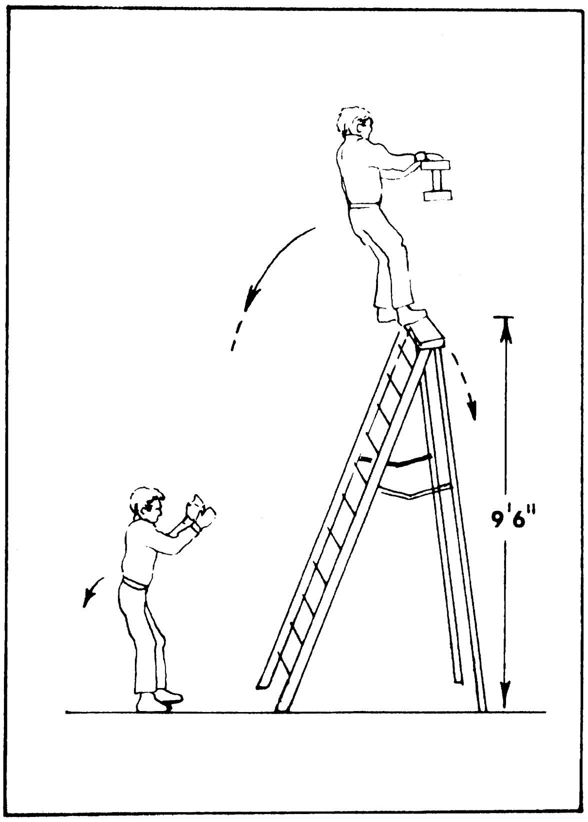
OTHER COMMENTS: Subject was out of town at time of investigation and could not be contacted. He had described fall sequence to fellow employees.

CALCULATED DATA:

IMPACT VELOCITY: 23 ft/sec (7.0 m/sec)

OAIS: 2

ISS: 4



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 87

SUBJECT: Male, 6 yr 6 mo, ht unknown, wt 55 lbs (24.9 kg)

FALL DISTANCE: 10 ft 2 in (3.1 m)

ENVIRONMENT: First floor level to concrete basement floor

MAJOR INJURIES: Cerebral contusion, right hemiparesis

SUMMARY: Child fell through basement stairway opening of house under construction. He fell to smooth concrete basement floor, landing on head, and was knocked unconscious. Injuries included severe brain contusion and right hemiparesis--no fractures. Hospitalized eight days, in therapy since. Recovery is partial.

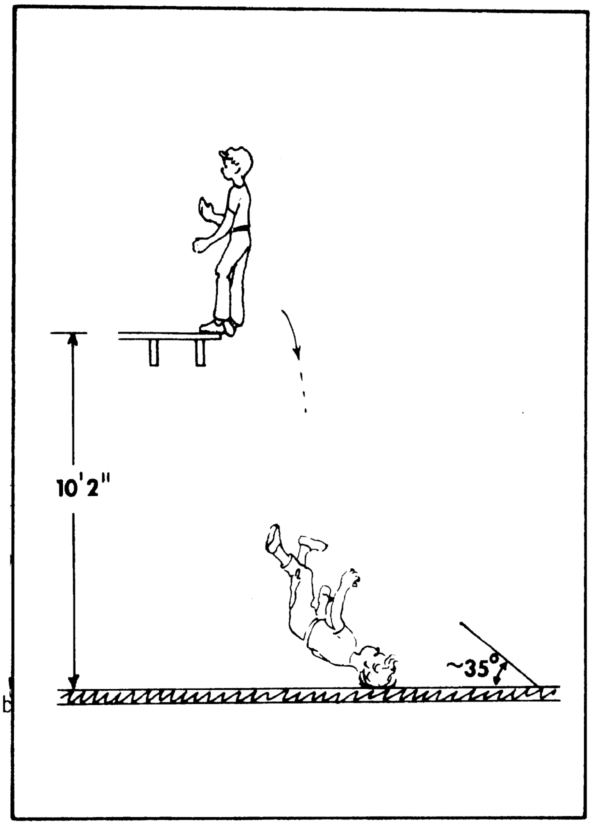
FALL CHRONOLOGY: Subject was in house under construction. Basement stairwell was framed in, but stairs were not installed. Position at start of fall unknown, presumably backed into open stairwell from standing position, fell 10 ft 2 in, and landed on the right side of his head, behind the ear.

SPECIFIC INJURIES: Slight contusion, right temporal and mastoid areas [HRCI-1]; severe cerebral contusion, with right hemiparesis, was comatose or stuporous for several days [HLKB-5]. No fractures were sustained.

RECOVERY: Partial recovery. Speech, ambulation and hearing restored. Right-side limp persists; has no use of right arm.

SOURCES OF DATA: X SUBJECT; X PARENTS;
__ POLICE; X HOSPITAL; __ WITNESSES;
__ OTHER:

OTHER COMMENTS: Site was not visited, since construction complete. Fall height was accurately measured by father of subject.



CALCULATED DATA:

IMPACT VELOCITY: 24 ft/sec (7.3 m/sec)

OAIS: 5

ISS: 26

This case was simulated (see Chapter 3).
Est. peak head accel: 582-660 g's
Est. peak normal force to head: 4,700-4,800 lb (20,900-21,350 N)
Est. peak head deflection: .48-.49 in (1.22-1.24 cm)

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 88

SUBJECT: Male, 10 yrs, 8 mo, 4 ft 8 in (1.42 m), 72 lbs (32.7 kg)

FALL DISTANCE: 15 ft 0 in (4.6 m)

ENVIRONMENT: Roof to frozen grass-covered soil

MAJOR INJURIES: Fractures of both forearms, extensive laceration inside lower portion of mouth

SUMMARY: Child was attempting to fly a kite on nearly-flat roof of family home. His brother saw him slip backward off the edge of the roof, falling 15 ft to the frozen ground. Injuries included an open fracture of the right forearm, a closed fracture of the left forearm and an extensive laceration of the lower gingival area. He was hospitalized for 2 days and is now fully recovered.

FALL CHRONOLOGY: Child was running backward on nearly flat roof of residence trying to get his kite airborne. He slipped on an icy area somewhere near the edge of the composition stone-and-tar roof and fell backward over the edge in a standing or nearly standing position. He probably rotated in mid-air, landing on his outstretched arms immediately beside a brick-edged flower bed, then impacting his chin on a brick. He apparently rolled after landing, since traces of blood were found on the lawn several feet from his final position.

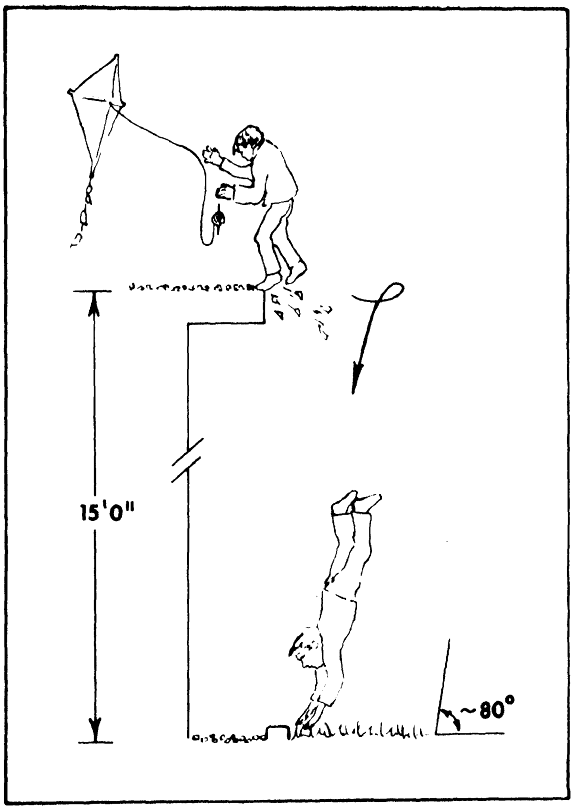
SPECIFIC INJURIES: Fractures of both right and left radius and ulna, in distal shafts, with marked overriding (open on right side) [RBFS-3]; 3-4 in (7.6-10.2 cm) laceration of lower gingival margin, with soft tissue avulsed from lower teeth almost to inferior border of mandible [FILD-2]; abrasion and swelling of right cheek [FRAI-1], bloody nose [FCHR-1].

RECOVERY: Complete. Subject regained confidence in use of arms by swimming often.

SOURCES OF DATA: __ SUBJECT; X PARENTS; X POLICE; X HOSPITAL; X WITNESSES;

X OTHER: Ambulance service

OTHER COMMENTS: Mother indicates that subject no longer goes onto the roof. Grass was found deeply imbedded inside the gingival laceration.



CALCULATED DATA:

IMPACT VELOCITY: 30 ft/sec (9.1 m/sec)

AIS: 3

ISS: 14

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 89

SUBJECT: Male, 1 yr 6 mo, 2 ft 11 in (0.89 m), 30 lbs (13.6 kg)

FALL DISTANCE: 13 ft 6 in (4.1 m)

ENVIRONMENT: Window to asphalt sidewalk

MAJOR INJURIES: Contusion right buttock, swollen right foot

SUMMARY: Infant apparently climbed up on a chest beneath the window in his bedroom and fell out the window. He fell about 13 ft to asphalt walkway. Infant was treated and released from hospital with no injuries other than a contusion of the right buttock. The following day his mother noticed considerable swelling of his right foot which was subsequently put in a walking cast for three weeks.

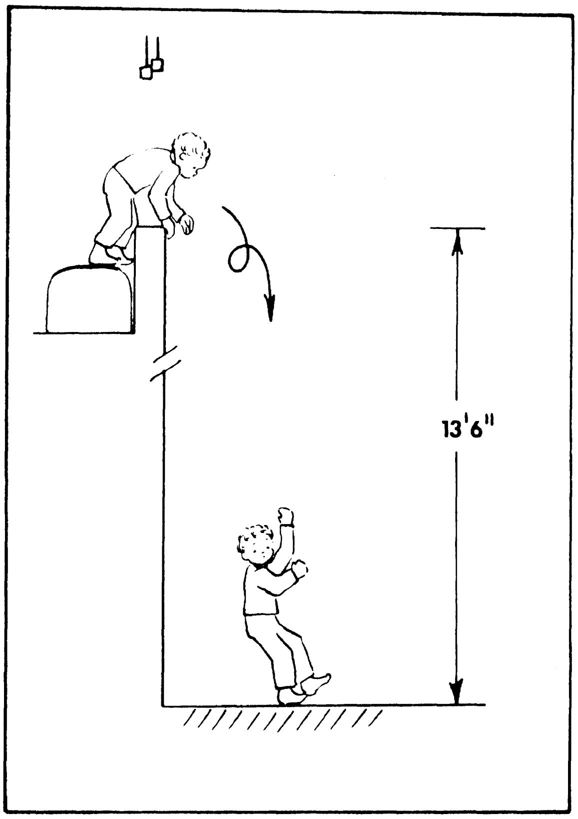
FALL CHRONOLOGY: Infant fell from second story window to asphalt walkway. He landed on his feet, then fell to a sitting position. He came to rest on his belly.

SPECIFIC INJURIES: Contusion right buttock [PPCI-1]; swelling of right foot and ankle [QRCI-1].

RECOVERY: Apparently complete.

SOURCES OF DATA: X SUBJECT; X PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES; X OTHER: brother (8 yr)

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 29 ft/sec (8.8 m/sec)

OAIS: 1

ISS: 1

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 90

SUBJECT: Male, 19 yrs 1 mo, 5 ft 10 in (1.78 m), 160 lbs (72.6 kg)

FALL DISTANCE: 14 ft 2 in (4.3 m)

ENVIRONMENT: Broken skylight through false ceiling to concrete floor

MAJOR INJURIES: Severe concussion, fracture of T-7 vertebra with paraplegia

SUMMARY: Subject and his girlfriend (see Case 91) sat on large skylight dome on a roof. The dome broke and the two persons fell back-first through a thin false ceiling and landed on a tiled concrete floor. This subject's injuries included severe concussion, a fracture of T-7 with cord transsection and subsequent paraplegia, and lacerations. He was expected to be permanently paraplegic and was still hospitalized for therapy.

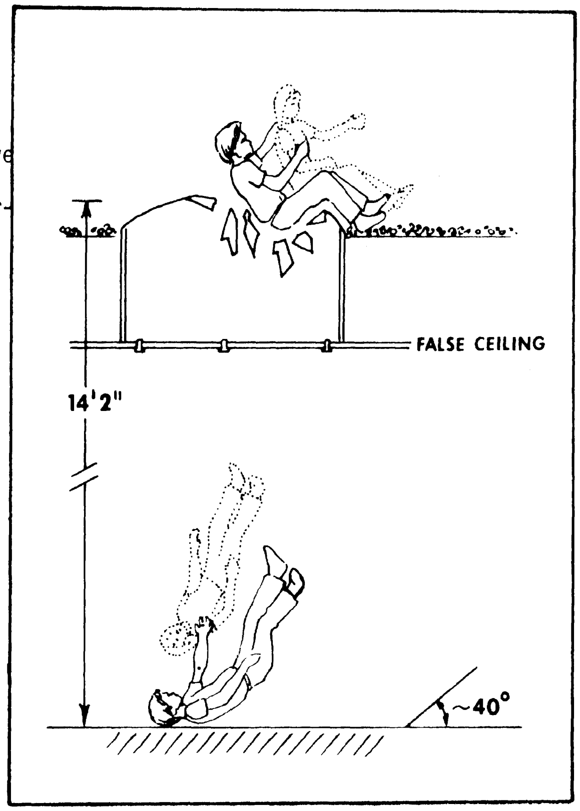
FALL CHRONOLOGY: Subject was presumably sitting on skylight, with his girlfriend beside him. When the skylight broke, they both tipped backward into the opening. He fell through a lightly-supported false ceiling and landed on his head and back on a tiled concrete floor. The two subjects landed side-by-side.

SPECIFIC INJURIES: Severe concussion and cerebral edema, subject semi-comatose for nearly three weeks [HUKB-5]; fracture of T-7, with cord transsection [BSFV-5]; lacerations of back of head and right elbow [HPLI-1, ERLI-1].

RECOVERY: Subject still hospitalized in long-term care facility as of two months after fall. He will be permanently paraplegic.

SOURCES OF DATA: __ SUBJECT; X PARENTS; X POLICE; __ HOSPITAL; X WITNESSES; X OTHER: Friend of subjects 90 & 91

OTHER COMMENTS: Friend thought fall might have occurred as subject tried to catch subject 91 as she fainted from epileptic seizure. According to parents, subject is quite depressed over lack of activity and prospects of paraplegia.



CALCULATED DATA:

IMPACT VELOCITY: 29 ft/sec (8.8 m/sec)

OAIS: 5

ISS: 51

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 91

SUBJECT: Female, 21 yr 2 mo, approx. 5 ft 5 in (1.65 m), approx 105 lbs (47.6 kg)

FALL DISTANCE: 14 ft 2 in (4.3 m)

ENVIRONMENT: Broken skylight through false ceiling to concrete floor

MAJOR INJURIES: Severe occipital skull fracture, severe brain trauma; fatal

SUMMARY: Subject and her boyfriend (see case 90) sat on large skylight dome on roof. The dome broke and the two persons fell back-first through a thin false ceiling to a tiled concrete floor. Subject was knocked unconscious immediately and remained in a coma until her death four days later. Injuries included at least a severe skull fracture and concussion and lacerations.

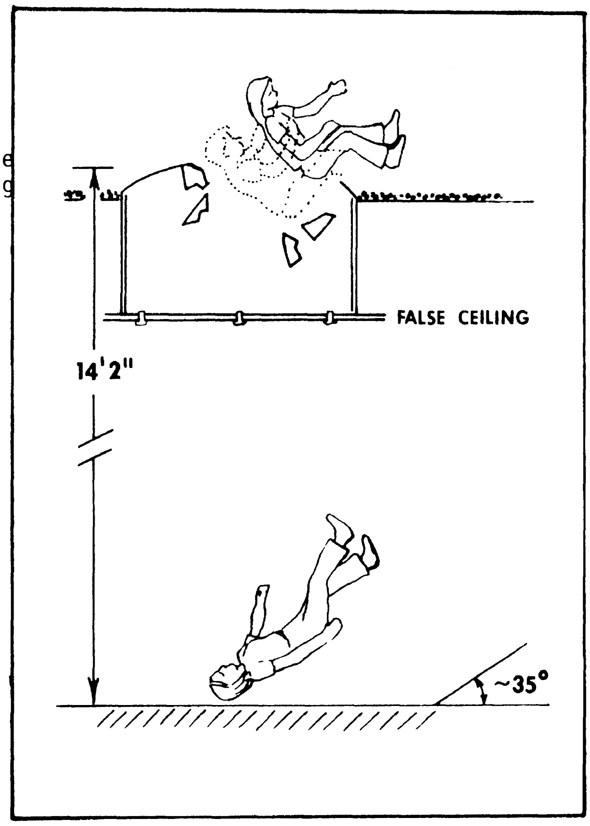
FALL CHRONOLOGY: Subject was presumably sitting on the skylight with her boyfriend beside her. When the skylight broke, they both fell through the opening, back-first. She probably fell slightly after he did. They passed through a lightly-supported false ceiling. The subject probably landed on the back of her head, then fell onto her back immediately beside her boyfriend. One witness thought she came to rest somewhat on top of him; another witness disagreed.

SPECIFIC INJURIES: Severe fracture of occipital skull (it was described as "soft"), with severe concussion: Subject was in coma for four days [HPKB-5]; laceration occipital region [HPLI-1].

RECOVERY: Subject did not recover. She remained in a coma till her death four days post-impact.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
X POLICE; __ HOSPITAL; X WITNESSES;
X OTHER: Friend of subjects 91 and 90

OTHER COMMENTS: Medical records not available so other possible injuries unknown. According to friend, subject might have been fainting from epileptic seizure and fall may have occurred as boy friend tried to catch her.



CALCULATED DATA:

IMPACT VELOCITY: 29 ft/sec (8.8 m/sec)

0 AIS: 5

ISS: 26

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 92

SUBJECT: Male, 11 yrs, 4 ft 8 in (1.42 m), 65 lbs (29.5 kg)

FALL DISTANCE: 12 ft 4 in (3.8 m)

ENVIRONMENT: Haymow to concrete floor

MAJOR INJURIES: Concussion, intracerebral hematoma, contusion of left temporal area.

SUMMARY: Subject was helping at uncle's farm by dropping bales of straw through a haymow trapdoor to the dairy area below. His glove caught in a bale's twine and pulled him off balance through the opening 12 ft to the concrete floor. He was hospitalized 25 days for a severe cerebral concussion/contusion. Recovery is virtually complete, although subject does still experience some coordination and gait problems.

FALL CHRONOLOGY: Subject was standing on straw bales. As he dropped a bale through the haymow opening, his glove caught in the binder twine and pulled him after the bale. He fell head-first through the opening and landed head-first on the concrete floor in the dairy section. He possibly contacted the bale with a portion of his body.

SPECIFIC INJURIES: Cerebral concussion and contusion, with deep left intracerebral hematoma but no skull fracture [HLKB-4]; large (2 x 4 in - 5 x 10 cm) contusion of left temporal area [HLCI-2]; abrasion of left elbow (ELAI-1].

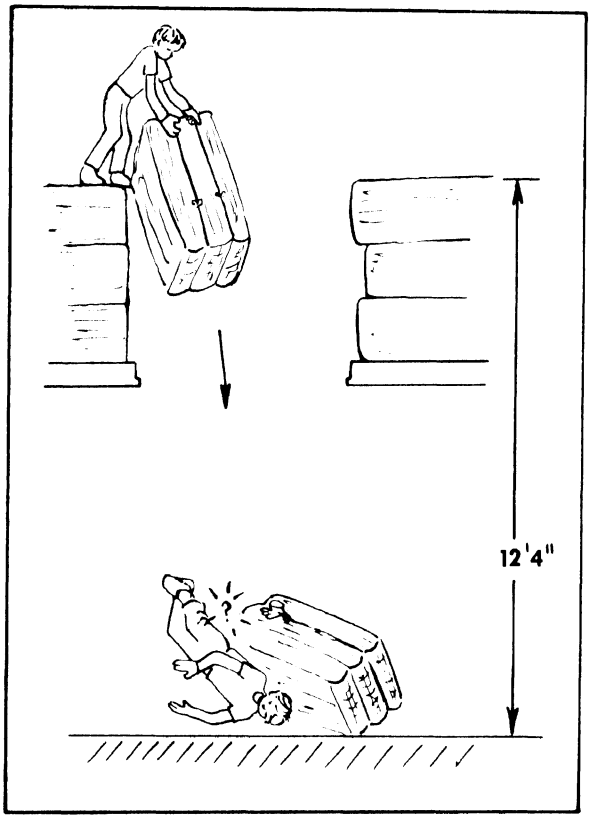
RECOVERY: Almost complete. Subject still had some coordination and gait problems ten weeks after fall.

SOURCES OF DATA: X SUBJECT; X PARENTS;

__ POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: Aunt

OTHER COMMENTS: Subject is rapidly making up missed schoolwork and is articulate.



CALCULATED DATA:

IMPACT VELOCITY: 28 ft/sec (8.5 m/sec)

OAIS: 4

ISS: 20

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 93

SUBJECT: Male, 30 yrs, height and weight unknown

FALL DISTANCE: Approx 12 ft (4 m)

ENVIRONMENT: Roof truss to concrete floor

MAJOR INJURIES: Unknown

SUMMARY: Since the subject could not be contacted, the details of this case are unknown. The subject was apparently standing on the top of a side wall of a building under construction, helping to set a roof truss in place. He "missed his footing" and fell to the concrete floor below. He was admitted to the hospital for observation. Degree of recovery is unknown.

FALL CHRONOLOGY: Subject was probably standing on wall and fell feet-first to the concrete. It is unknown whether his fall was a free-fall or was partially broken.

SPECIFIC INJURIES: Unknown. Ambulance service had no record of injuries and the subject was noted as being in the hospital for "observation".

RECOVERY: Unknown.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;

__ POLICE; __ HOSPITAL; __ WITNESSES;

X OTHER: ambulance service, nearby similar building under construction.

OTHER COMMENTS: The subject was transient with the construction company and neither could be located. Construction had been completed one week before on-site investigation.

UNKNOWN

CALCULATED DATA:

IMPACT VELOCITY: 28 ft/sec (8.5 m/sec)

0 AIS: Unknown

ISS: Unknown

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 94

SUBJECT: Male, 56 yr 4 mo, 5 ft 9 in (1.75 m), 155 lbs (70.3 kg)

FALL DISTANCE: 10 ft 9 in (3.3 m)

ENVIRONMENT: Second-floor windowsill to gravel and asphalt

MAJOR INJURIES: Fractured ribs, lacerations on arms, scalp, and around eye

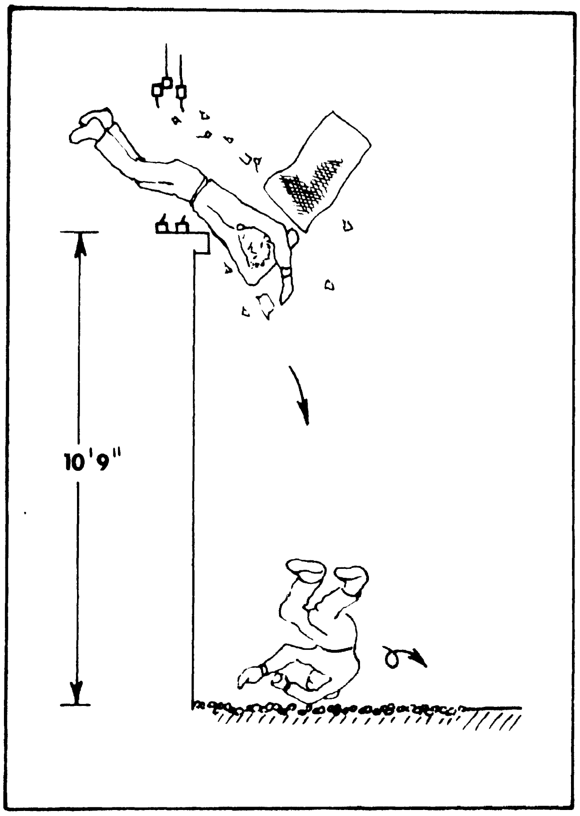
SUMMARY: Subject claims to have been thrown through the window of his living room during an argument (all involved had been drinking). He fell nearly 11 ft, landing on a gravel and asphalt surface. The subject was knocked unconscious and received lacerations beside the right eye, on both arms, and on the scalp, and fractures of three ribs on the left side. He was hospitalized two days. He is completely recovered.

FALL CHRONOLOGY: According to the subject, he was thrown head-first through the window of his second floor apartment by two companions. The subject was propelled out of the window with some force, breaking two panes of glass and a screen as he went through. He came to rest at a 90° angle to the direction of fall, seven feet from the building. The impact sequence is unknown, but the subject probably landed on his right side on pea gravel over asphalt in the paved alley way below his window. He was unconscious for up to one hour before being discovered. SPECIFIC INJURIES: Subject declined to sign medical release and there is some question as to the accuracy of his recollections. He indicated his injuries as glass lacerations of both forearms, the upper right scalp, and beside the right eye [RBLI-2, FRLI-1] concussion [HUKB-3]; and three fractured ribs on the left side [CLFS-3].

RECOVERY: Appears completely recovered. Has 6-8 in (15-20cm) scars on both forearms.

SOURCES OF DATA: X SUBJECT; __ PARENTS;
X POLICE; __ HOSPITAL; __ WITNESSES;
X OTHER: Neighbor who found him

OTHER COMMENTS: Subject was intoxicated at time of fall, and weather was cold and dry.



CALCULATED DATA:

IMPACT VELOCITY: 26 ft/sec (7.9 m/sec)

OAIS: 4

ISS: 22

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 95

SUBJECT: Male, 37 yrs 10 mo, 5 ft 8 in (1.73 m), 155 lbs (70.3 kg)

FALL DISTANCE: 7 ft 2 in (2.2 m) then 11 ft 10 in (3.6 m)

ENVIRONMENT: Ladder to metal roof to concrete sidewalk

MAJOR INJURIES: Skull fracture of frontal area, fracture left femur and fibula and right tibia, fracture right wrist.

SUMMARY: Contractor was installing windows at the third floor level of a house when he stepped too high on a ladder. The bottom of the ladder slipped out causing the subject to fall 7 ft to porch roof then free fall 12 ft from porch to sidewalk below. Subject's injuries include fractures of the skull, midshaft of left femur, left fibular neck, and right proximal tibia, a shattered right distal radius, and abrasions of the forehead and left knee. He was hospitalized 48 days. Subject still walks with crutches and has some swelling and a limited range of motion in his wrist.

FALL CHRONOLOGY: Subject was working on a ladder at third floor level of a house when the ladder slipped suddenly, throwing him off. He first fell to a metal porch roof, landing on his feet, but off balance. He continued off the front of the roof to the smooth concrete sidewalk below. Subject probably landed face down, striking first with his left knee and right hand. The knee probably rolled him to the right driving the right side of his forehead onto the sidewalk. He came to rest on his left side.

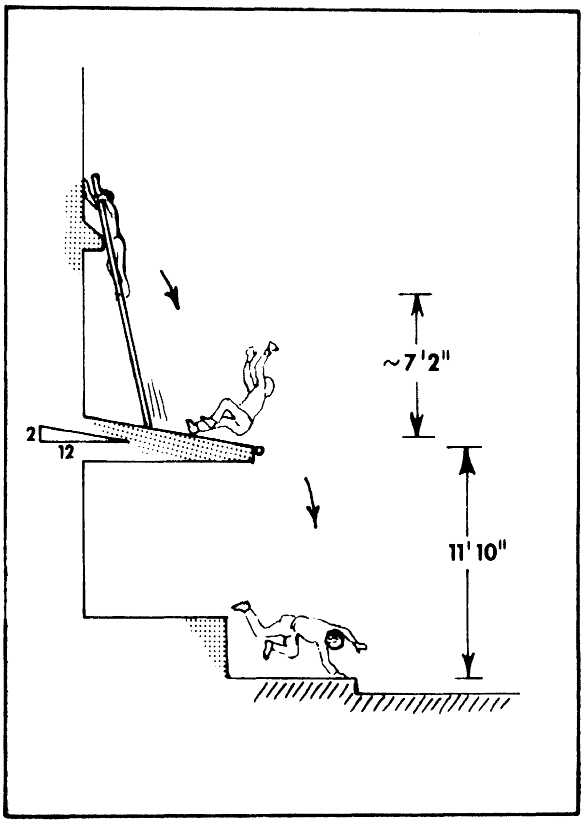
SPECIFIC INJURIES: Skull fracture involving right frontal bone extending longitudinally downward and possibly involving the right frontal sinus [FSFS-2]; fracture of midshaft of left femur [TLFS-3]; nondisplaced fracture of proximal end of left fibula [LLFS-2]; comminuted fracture of distal end of radius of right wrist [WRFJ-3]; nondisplaced hairline fracture of proximal right tibia [LRFS-2]; abrasions of left knee [KLAI-1].

RECOVERY: Walks with crutches, still has swelling and limited range of motion of right wrist (as of four months after fall). Is in physical therapy.

SOURCES OF DATA: X SUBJECT; __ PARENTS; __ POLICE; X HOSPITAL; X WITNESSES;

X OTHER: wife

OTHER COMMENTS: Subject was dazed momentarily, but did not lose consciousness. He tried to stand immediately, but could not.



CALCULATED DATA:

IMPACT VELOCITY: 20 ft/sec (6.1 m/sec), then 27 ft/sec (8.2 m/sec)

OAIS: 3

ISS: 14

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 96

SUBJECT: Female, 5 yrs. 1 mo., 43 in. (1.09 m), 37 lbs. (16.8 kg)

FALL DISTANCE: 17 ft. 7 in. (5.4 m)

ENVIRONMENT: Window and porch roof to asphalt street

MAJOR INJURIES: Skull fracture, cerebral contusion, subgaleal hematomas

SUMMARY: Child apparently leaned against window screen and pushed it out. She then tumbled about one ft. (.3 m) to porch roof, rolled off roof, and fell an additional 18 ft. to the asphalt street. Injuries included a linear skull fracture in the left parietal area, a cerebral contusion, hematomas in the parietal and occipital areas, and numerous bruises, especially to dorsal surfaces of hands and feet. The subject was hospitalized for 12 days and has completely recovered from fall injuries.

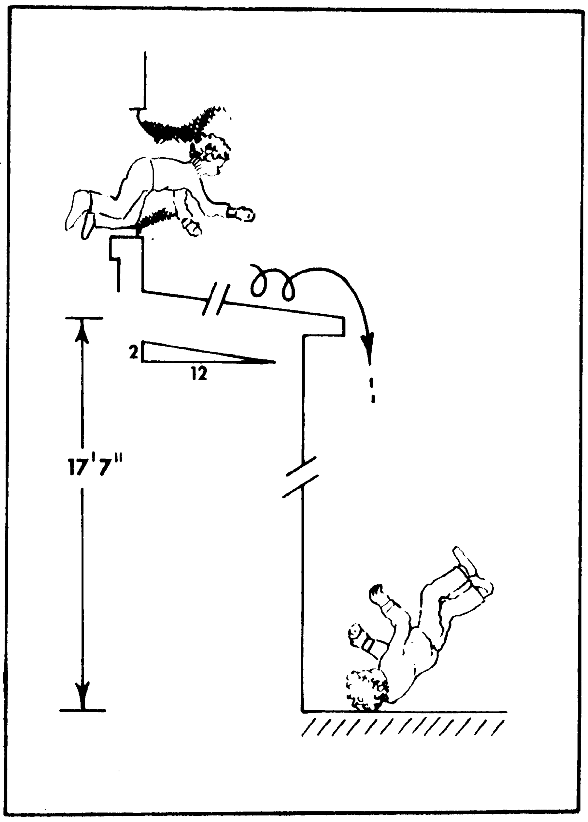
FALL CHRONOLOGY: Child fell from screened third-floor window onto a porch roof immediately below the window, then rolled down the roof and off the edge, free-falling to the asphalt street below. Mother thinks that the subject was playing with a toy beside the windowsill and lost her balance. The child probably fell forward out the window, rolled down the roof, and rolled sideways off the roof. Child probably landed on the left rear part of her head. Toys were found on the roof and street.

SPECIFIC INJURIES: Linear undisplaced skull fracture of left parietal bone from posterior aspect to coronal suture, with cerebral contusion [HLKB-4]; multiple undisplaced fractures in inferior occipital area [HBOI-1]; multiple contusions of dorsi of both hands and both feet and upper back [WBCI-1, QBCI-1, BSCI-1].

RECOVERY: Mother indicates full recovery from fall-related injuries.

SOURCES OF DATA: X SUBJECT; X PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES; X OTHER: Grandfather

OTHER COMMENTS: Subject is a developmentally-retarded child.



CALCULATED DATA:

IMPACT VELOCITY: 33 ft./sec. (10.1 m./sec.)

OAIS: 4

ISS: 17

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 97

SUBJECT: Male, 64 yrs 4 mo, 5 ft 2 in (1.57 m), 142 lbs (64.4 kg)

FALL DISTANCE: 9 ft 9 in (2.7 m)

ENVIRONMENT: Flat roof to flat roof

MAJOR INJURIES: Fractured left acetabulum, dislocated finger

SUMMARY: Subject was helping carry a 4 x 8 ft (1.2 x 2.4 m) sheet of plywood from first to third floors of firehouse. In order to turn corner in stairwell at second floor, subject had to step through open window onto flat roof and hold plywood while his partner turned the corner. The wind was blowing strongly and it caught the plywood like a sail, pushing the subject off the roof. He fell nine feet landing on a tarpapered flat roof above the first floor. His injuries included a fractured left hip, a dislocated finger in his left hand, and lacerations. He was hospitalized 78 days and had recovered enough to ambulate with crutches.

FALL CHRONOLOGY: When wind blew the sheet of plywood, the subject was shoved off-balance laterally off the end of the roof. He landed on his left side, probably with his left arm extended, on another flat roof. He also probably struck his forehead on the roof, breaking his glasses frames.

SPECIFIC INJURIES: Fracture of medial aspect of left acetabulum, with inward displacement [PLFS-3]; dislocation of left middle finger [WLDJ-1]; laceration above left eyebrow [FSLI-1]; contusion of left hip in trochanter area [PLCI-1]; abrasion left lateral ankle [QLAI-1].

RECOVERY: Subject expected to be in traction for nine weeks total, then to undergo prolonged therapy. He was not too optimistic about being able to walk normally again. He was non-weight-bearing on crutches at discharge.

SOURCES OF DATA: __ SUBJECT; __ PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: Fire department, subject's wife.

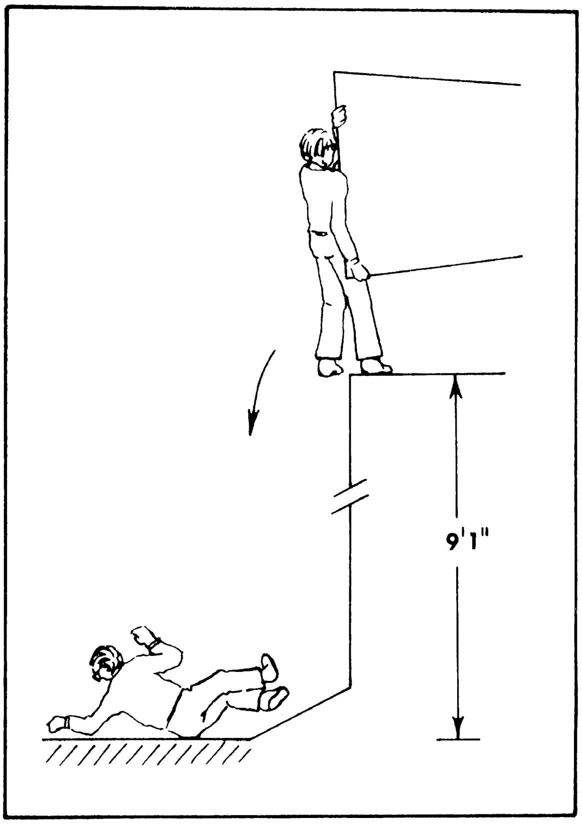
OTHER COMMENTS: Subject was still in hospital at time of investigation and was not available for interview. His wife was able to provide details.

CALCULATED DATA:

IMPACT VELOCITY: 22 ft/sec (6.7 m/sec)

OAIS: 3

ISS: 10



FREE-FALL STUDY CASE REPORT

CASE NUMBER: 98

SUBJECT: Male, 9 yrs 11 mo, 4 ft 0 in (1.22 m), 60 lbs (27.2 kg)

FALL DISTANCE: 10 ft 0 in (3.1 m)

ENVIRONMENT: Fire escape to sandy ground

MAJOR INJURIES: Minimal compression fracture T-6 and T-7 anterior bodies

SUMMARY: Student fell part way down a second floor fire escape, slipped off the steel landing and fell 10 ft to the sandy ground. He got up and went into the building. Then he fainted and was taken to the hospital where he remained three days. X-rays disclosed a minimal compression fracture of T-6 and T-7 vertebral bodies. Subject had no other injuries and has apparently recovered completely.

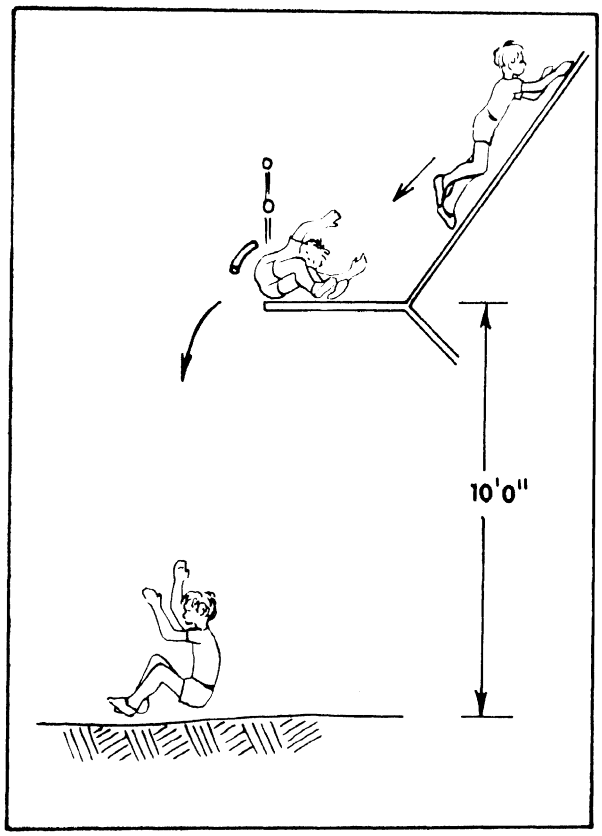
FALL CHRONOLOGY: Student tripped and fell from half way up the second flight of fire escape stairs to the second floor platform. He rolled off fire escape landing to the sandy ground below, impacting on his buttocks.

SPECIFIC INJURIES: Minimal compression fractures of anterior borders of T-6 and T-7 vertebral bodies [BSFV-2]; minor head injury with fainting [HUKB-1].

RECOVERY: Apparently complete. Subject refuses to wear prescribed back brace.

SOURCES OF DATA: X SUBJECT; X PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES; X OTHER: classmate

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 23 ft/sec (7.0 m/sec)

OAIS: 2

ISS: 5

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 99

SUBJECT: Male, 20 yrs, height and weight unknown

FALL DISTANCE: 25 ft 0 in (7.6 m)

ENVIRONMENT: Bridge to concrete highway

MAJOR INJURIES: Fractured right ankle, chipped bone in jaw

SUMMARY: Worker was standing on a small wood walk at a construction site for a highway overpass. He was using a claw hammer trying to clear away concrete when he lost his balance and fell to the center of the concrete interstate highway below. He was hospitalized for a fractured right ankle and jaw.

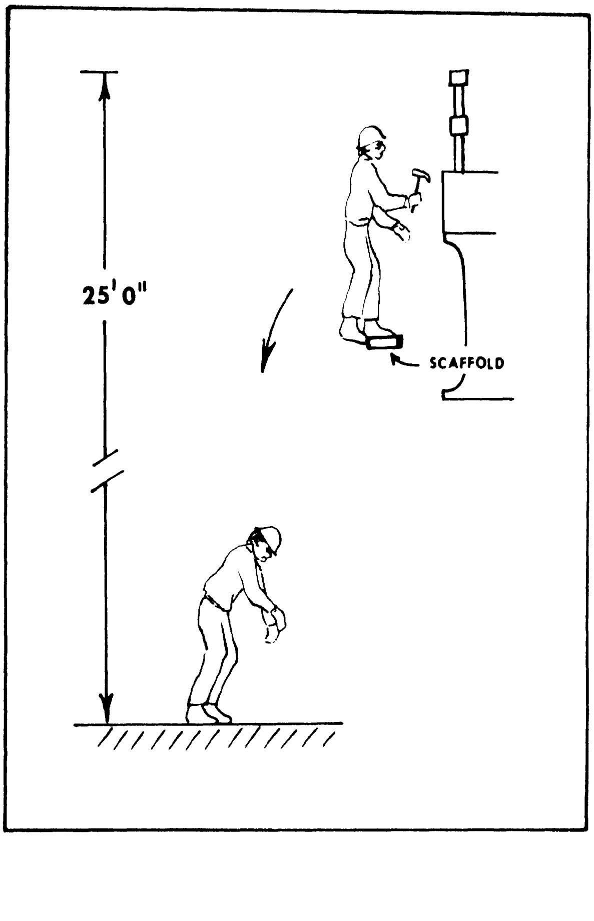
FALL CHRONOLOGY: Worker was standing on plank walkway attached to steel girders of bridge overpass. He lost his balance and fell feet-first onto concrete. He probably rolled onto side or fell to prone position, impacting jaw.

SPECIFIC INJURIES: Fractured right ankle [QRFJ-2]; chipped mandible [FIFS-2].

RECOVERY: Undetermined

SOURCES OF DATA: __ SUBJECT; __ PARENTS;
X POLICE; __ HOSPITAL; __ WITNESSES;
X OTHER: Neighbor

OTHER COMMENTS: There may have been additional injuries. No hospital report was available and subject was not located.



CALCULATED DATA:

IMPACT VELOCITY: 40 ft/sec (12.2 m/sec)

OAIS: 2

ISS: 8

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 100

SUBJECT: Male, 39 yrs 8 mo, 6 ft 3 in (1.9 m), 170 lbs (77.1 kg)

FALL DISTANCE: 5 ft 9 in (1.8 m)

ENVIRONMENT: Fell to concrete

MAJOR INJURIES: Concussion, fracture in right parietal bone, inflammation of right ear.

SUMMARY: Subject slipped on wet soapy porch of his residence. He felt OK after fall but by next morning had severe headaches and convulsions, with continued bleeding from ear. Subject was then hospitalized and was treated for a linear fracture of the right parietal bone, concussion, and ear inflammations. He was discharged nine days later in stable, improved condition.

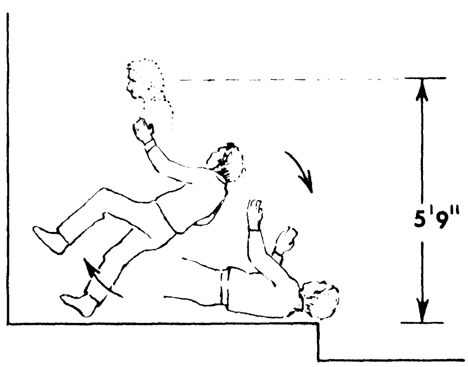
FALL CHRONOLOGY: Subject walked onto wet soapy front porch. As he got to a point near his front door, his feet slipped out from under him and he fell, rotating quickly. He struck his right side and right side of head on concrete, possibly on edge of porch.

SPECIFIC INJURIES: Non-depressed linear oblique fracture of right parietal bone, with concussion and bleeding from right ear[HRKB-2]; abrasions right upper arm and right side [ARAI-1, CRAI-1]; inflammation of external and middle right ear [HROE-1].

RECOVERY: Stable, but full recovery uncertain at time of investigation.

SOURCES OF DATA: X SUBJECT; __ PARENTS; __ POLICE; X HOSPITAL; __ WITNESSES; X OTHER: wife

OTHER COMMENTS: Subject refused to go to hospital until morning after the fall. This was not a true free-fall, but was investigated because subject's wife assisted in investigation of Case #99 in same city.



CALCULATED DATA:

IMPACT VELOCITY: 18 ft/sec (5.5 m/sec)

OAIS: 2

ISS: 6

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 101

SUBJECT: Male, 4 yrs, 3 ft 5 in (1.04m), 29 lbs (13.2 kg)

FALL DISTANCE: 11 ft 2 in (3.40 m)

ENVIRONMENT: Second story window to concrete patio

MAJOR INJURIES: Left parietal skull fracture, basilar skull fracture - fatal

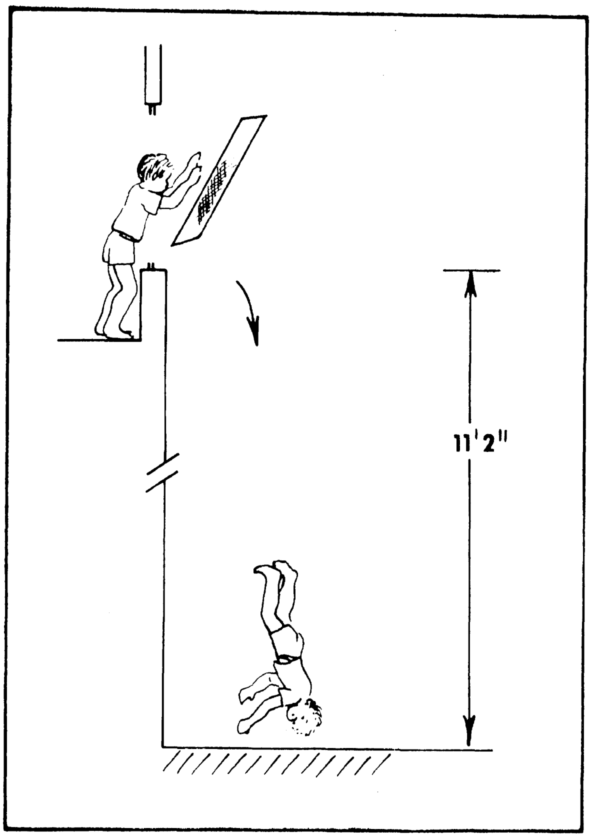
SUMMARY: Child was at an open second-story window, watching children playing in courtyard. He pressed against screen, pushing screen out, and fell 11 ft. to the concrete patio below. Child sustained a left parietal skull fracture and a basilar skull fracture. He expired after 2 days hospitalization.

FALL CHRONOLOGY: Child fell forward through open bedroom window, dislodging screen. Child was leaning against window screen. It came loose and the child fell through the window opening. He probably landed on the top of his head.

SPECIFIC INJURIES: Left parietal skull fracture [HSFS-2]; basilar skull fracture [HIFS-4]; cerebral edema [HUKB-4]. Autopsy was performed.

RECOVERY: Fatal 18 hrs post-impact due to cerebral edema.

SOURCES OF DATA: __ SUBJECT; __ PARENTS; X POLICE; __ HOSPITAL; __ WITNESSES; X OTHER: Neighbor, physician



OTHER COMMENTS: Case in litigation and mother awaiting resolution before authorizing release of autopsy report.

CALCULATED DATA:

IMPACT VELOCITY: 26 ft/sec (7.9 m/sec)

OAIS: 5

ISS: 16

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 102

SUBJECT: Male, 3 yr 8 mo, 39 in (0.99 m), 39 lbs (17.7 kg)

FALL DISTANCE: 11 ft 6 in (3.5 m)

ENVIRONMENT: Edge of porch roof to wooden porch step

MAJOR INJURIES: Contusion of left kidney, minor head injury

SUMMARY: Child was playing on a nearly flat porch roof outside second story apartment. He apparently slipped off the edge of the roof and fell 11 ft., landing on a wooden porch step. The step was loose and turned over, rolling the child onto the pavement. Injuries include minor head injury, a contused kidney, and multiple abrasions to the left side of the face, elbow, and thigh. He was hospitalized for 2 days and has fully recovered.

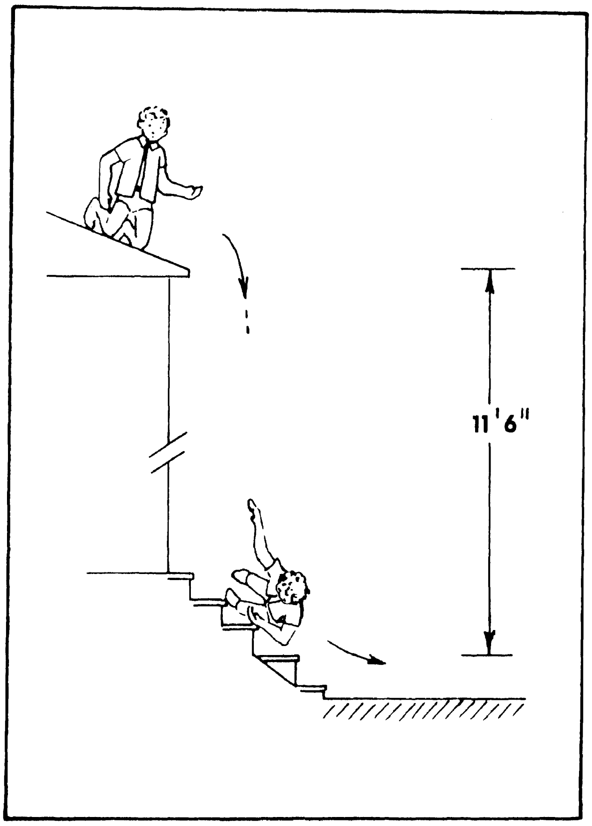
FALL CHRONOLOGY: The child either stepped off the edge of the porch roof or slipped and rolled a very short distance before reaching the edge because he fell straight down to the porch steps below. He impacted the second porch step from the bottom, landing on his left side, nearly horizontal, aligned with the step. The step was loose and when it was impacted it tipped over away from the porch, causing the child to roll onto the cement sidewalk.

SPECIFIC INJURIES: Momentarily dazed and disoriented [HLKB-1]; contusion of left kidney [MLCK-3]; contusions left lower lateral chest wall [CLCI-1]; abrasions to forehead, left cheek, chin, left elbow, left thigh [FLAI-1, ELAI-1, TLAI-1].

RECOVERY: Complete. Remnants of bruise on underside of left elbow as of 4 weeks after fall.

SOURCES OF DATA: X SUBJECT; X PARENTS;
__ POLICE; X HOSPITAL; __ WITNESSES;
__ OTHER:

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 26 ft/sec (7.9 m/sec)

OAIS: 3

ISS: 11

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 103

SUBJECT: Male, 2 yr 4 mo, ht unknown, 35 lbs (15.9 kg)

FALL DISTANCE: 21 ft 2 in (6.5 m)

ENVIRONMENT: Third floor window to hard, grass-covered soil

MAJOR INJURIES: No major injuries

SUMMARY: Child had been put in top bunk of bunk bed for afternoon nap. He apparently heard friends outside, crawled to the bottom of the bed and pushed against the window screen to see better. The screen came loose and the child fell through the open window 21 feet to the lawn below. He was up and moving within a few moments. Injuries included abrasions and contusions of the abdomen, trunk and extremities, and soreness of the neck. Child was hospitalized for 4 days. Recovery is complete.

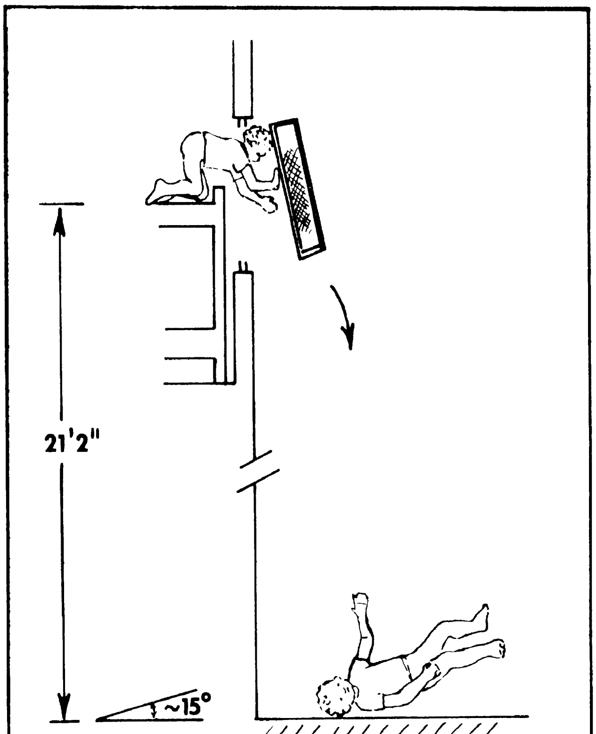
FALL CHRONOLOGY: Child fell from bedroom window adjacent to bunk bed. The window was open with the screen in place. The child apparently leaned against the screen, which came loose. The child fell probably head first from an all-fours position, landing on hard-packed dry soil. Injuries suggest that he impacted nearly flat on his back or possibly somewhat to right side.

SPECIFIC INJURIES: Pain in neck and abdomen [NWPM-1, MAPD-1]; abrasions of right lateral abdomen, right thigh, left lower arm, and lower back (some of these could have been caused by the window frame) [MRAI-1, BIAI-1, TRAI-1]. No loss of consciousness.

RECOVERY: Complete. Child was stiff for a few days after fall.

SOURCES OF DATA: X SUBJECT; X PARENTS;
__ POLICE; X HOSPITAL; __ WITNESSES;
__ OTHER:

OTHER COMMENTS: Child was wearing only a shirt when he fell, as he was supposed to be napping. Neighbor who discovered him took time to dress him before going to hospital.



CALCULATED DATA:

IMPACT VELOCITY: 36 ft/sec (11.0 m/sec)

OAIS: 1

ISS: 3

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 104

SUBJECT: Female, 12 yrs 6 mo, 4 ft 10 in (1.45 m), 80 lbs (36.3 kg)

FALL DISTANCE: 33 ft 10 in (10.3 m)

ENVIRONMENT: Skylight dome to smooth concrete

MAJOR INJURIES: Fractures of left foot, left ankle, and both pubic rami, emphysema of right chest.

SUMMARY: Subject was jumping on a domed plexiglas skylight on the roof of a sewage pumping sub-station. The skylight broke and she went through, falling 34 ft to the concrete floor of the station. Injuries included fractures of the left second, third and fourth metatarsals, left talus, and both pubic rami; subcutaneous emphysema of right chest, and abrasions. She was hospitalized 19 days. Recovery is good, though not yet complete.

FALL CHRONOLOGY: Subject was apparently jumping on a domed plexiglas skylight when the dome broke causing her to fall feet first to the smooth concrete floor of the pumping station. She landed feet-first, immediately below the skylight, and was found lying on her back with her left leg turned under her right.

SPECIFIC INJURIES: Bilateral fractures through inferior pubic rami with minimal separation and displacement [PAFS-3]; fractures of shafts of second and third metatarsals of left foot and fractures at bases of third and fourth metatarsals of left foot, all with minimal displacement [QLFS-3];nondisplaced fracture through neck of left talus [QLFJ-2]; subcutaneous emphysema of right anterior chest [CROI-1]; abrasions to forehead and left hand [FSAI-1, WLAI-1].

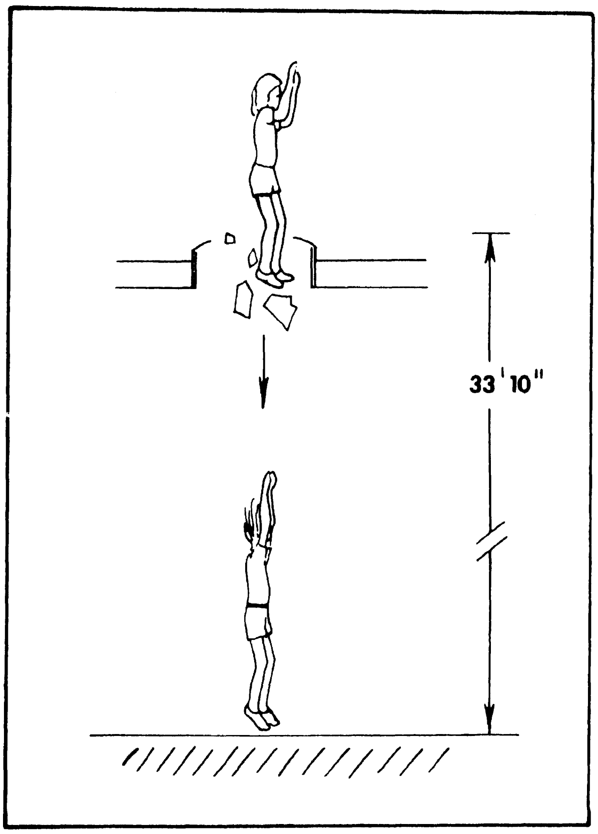
RECOVERY: Full recovery was probable (as of 5 weeks post-fall). Occasionally has "wierd" dreams about fall and pains "all through" her trunk. Stillcasted and on crutches.

SOURCES OF DATA: X SUBJECT; X PARENTS;

X POLICE; X HOSPITAL; __ WITNESSES;

X OTHER: Sewer department superintendent

OTHER COMMENTS: As she fell, subject left finger marks on a side wall but this contact could not have slowed her impact velocity. Subject was in excellent physical condition at time of fall.



CALCULATED DATA:

IMPACT VELOCITY: 46 ft/sec (14.0 m/sec)

OAIS: 3

ISS: 11

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 105

SUBJECT: Male, 3 yrs 1 mo, 3 ft 1 in (0.94 m), 36 lbs (16.3 kg)

FALL DISTANCE: 14 ft 2 in (4.3 m)

ENVIRONMENT: Window to concrete sidewalk

MAJOR INJURIES: Skull fracture right orbit, cerebral concussion and contusion

SUMMARY: While playing in upstairs bedroom child pushed a toy box to window, climbed on it, and pushed on screen. The screen fell out causing child to tumble about 14 ft. to concrete sidewalk below. Child was hospitalized for one week with a skull fracture of right orbit, cerebral concussion and contusion. He appears completely recovered.

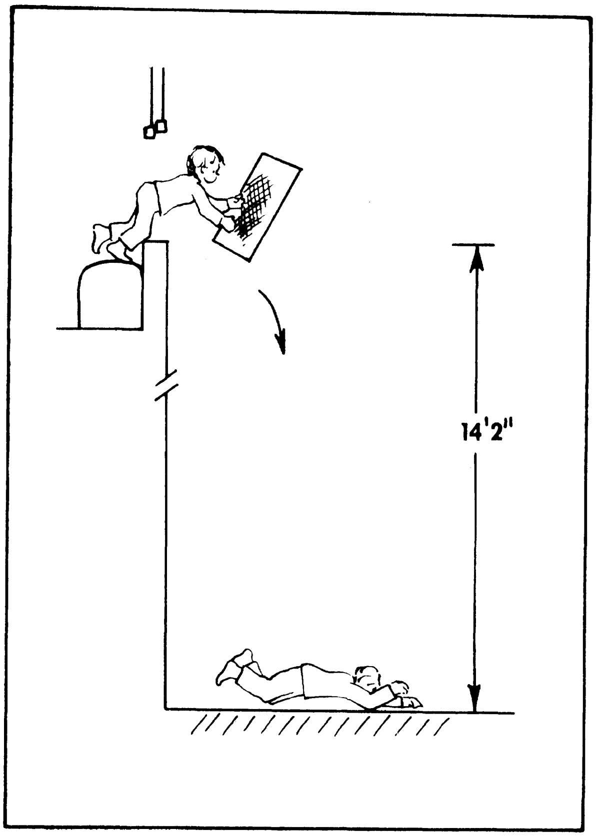
FALL CHRONOLOGY: Child climbed onto toy box which he had pushed under bedroom window, and pushed against center of screen which popped out, causing him to lose balance. He fell, facing out, to concrete sidewalk below. Impact point was 4'4" (1.3 m) from side of house. Impact orientation "flat on stomach", with head slightly turned to left.

SPECIFIC INJURIES: Undisplaced fracture through right frontal bone anteriorly which extended through superior orbital rim, cerebral concussion and contusion [HRKB-2]; abrasion right frontal area, ecchymosis right eye [FCAI-1, FRCE-1]; laceration of right lip [FILD-1].

RECOVERY: Complete. No neurological deficits.

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; X HOSPITAL; __ WITNESSES; __ OTHER:

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 29 ft/sec (8.8 msec)

0 AIS: 2

ISS: 5

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 106

SUBJECT: Female, 2 yrs 0 mo, 2 ft 10 in (0.86 m), 34 lbs (15.4 kg)

FALL DISTANCE: 14 ft 9 in (4.5 m)

ENVIRONMENT: Window to concrete sidewalk

MAJOR INJURIES: Fractured skull, fractured left clavicle, cerebral concussion

SUMMARY: Child was in bed, next to window, and may have been attracted to children playing outside. She pushed through screen, and fell nearly 15 ft to concrete sidewalk below. Injuries included concussion, fractured skull and left shoulder bruises, hospitalized for 4 days.

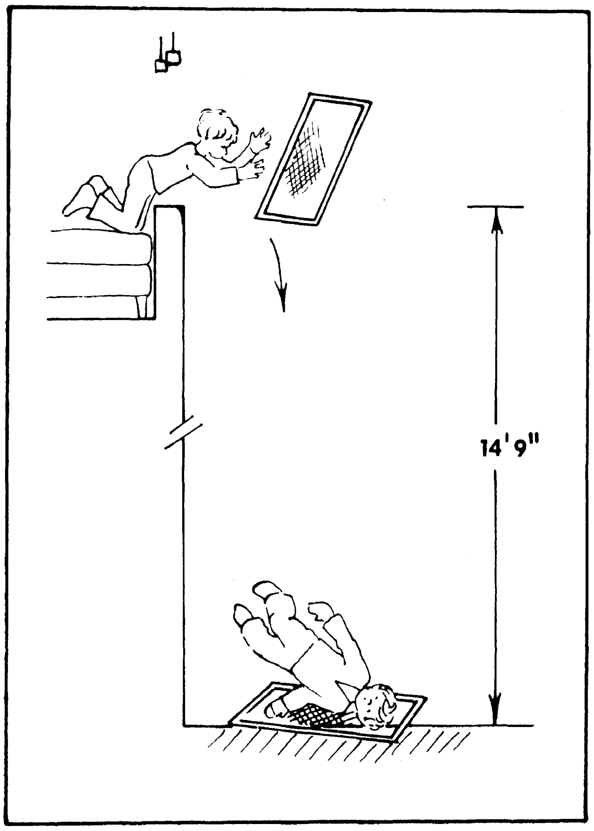
FALL CHRONOLOGY: Child in bed, leaned against screen to watch boys playing basketball in yard beside house. The screen pushed out and child lost balance and fell 14 ft 9 in (4.5 m) to concrete sidewalk below, landing on vertex of head and left shoulder.

SPECIFIC INJURIES: Cerebral concussion without loss of consciousness, linear fracture of skull at vertex [HSFS-2]; undisplaced fracture of left clavicle[SLFS-2]; abrasions to left temporal area of face, left shoulder, and left hip [FLAI-1, SLAI-1, PLAI-1].

RECOVERY: Apparently complete. Child showed no aftereffects when observed.

SOURCES OF DATA: X SUBJECT; X PARENTS; X POLICE; X HOSPITAL; X WITNESSES; X OTHER: baby sitter.

OTHER COMMENTS:



CALCULATED DATA:

IMPACT VELOCITY: 30 ft/sec (9.1 m/sec)

OAIS: 2

ISS: 9

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 107

SUBJECT: Female, 5 yrs 10 mo, 3 ft 10 in (1.17 m), 43 lbs (19.5 kg)

FALL DISTANCE: 16 ft 2 in (4.9 m)

ENVIRONMENT: Porch railing to concrete

MAJOR INJURIES: Linear skull fracture, left side hemiparesis, contused eyes.

SUMMARY: Child was standing on a chair on second story porch watching children going to school. She leaned too far over the railing and fell 16 ft to concrete sidewalk below. Injuries include a linear skull fracture, nerve damage to arms and legs left side, eyes swollen and black. Child was in a coma 2½ weeks, hospitalized 11 weeks. Degree of recovery is unknown.

FALL CHRONOLOGY: Child was standing on a chair, leaning over the porch rail. She leaned too far and fell forward over the rail. Apparently child landed on her left side, with her head impacting on a concrete sidewalk and her body hitting the hard gravel of the driveway. She came to rest on her right side.

SPECIFIC INJURIES: Linear skull fracture, from left to right across skull; comatose or semi-comatose for 2½ weeks; left side hemiparesis [HLKB-5]; both eyes severely contused [FBCE-2].

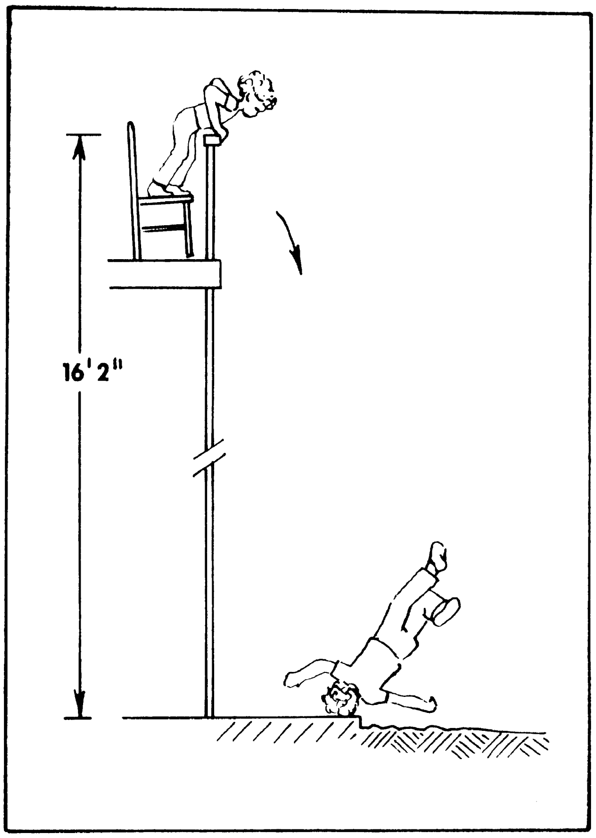
RECOVERY: Hospitalized 11 weeks. Subsequent progress not known, except that hemiparesis was clearing.

SOURCES OF DATA: __ SUBJECT; __ PARENTS;

X POLICE; __ HOSPITAL; __ WITNESSES;

X OTHER: Grandmother

OTHER COMMENTS: Medical records not available.



CALCULATED DATA:

IMPACT VELOCITY: 31 ft/sec (9.5 m/sec)

OAIS: 5

ISS: 29

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 108

SUBJECT: Male, 45 yrs 2 mo, 5 ft 6 in (1.68 m), 165 lbs (74.8 kg)

FALL DISTANCE: 22 ft 0 in (6.7 m)

ENVIRONMENT: Ladder to hard, frozen ground

MAJOR INJURIES: Bilateral fractured ankles, vertebral compression fracture

SUMMARY: Subject was helping a neighbor by clearing ice from his roof. He fell from ladder, 22 ft, to bare, hard frozen ground. Subject was hospitalized 13 days for treatment of a closed fracture of right ankle, displaced fracture of left heel, and compression fracture of first lumbar vertebra. Complete recovery is unlikely.

FALL CHRONOLOGY: Subject was at edge of roof of two-story house, facing the house. He fell from ladder to hard, frozen ground. He landed crouched, on both feet. Subject says he did not hit the ground with his buttocks or roll, but sprang back from a crouched to a standing position.

SPECIFIC INJURIES: Compression fracture body of L1 wedged anteriorally to about 2/3 normal height [BIFV-3]; severly comminuted fracture of distal end of the right tibia [LRFS-3]; very comminuted fracture of left calcaneus [QLFJ-3].

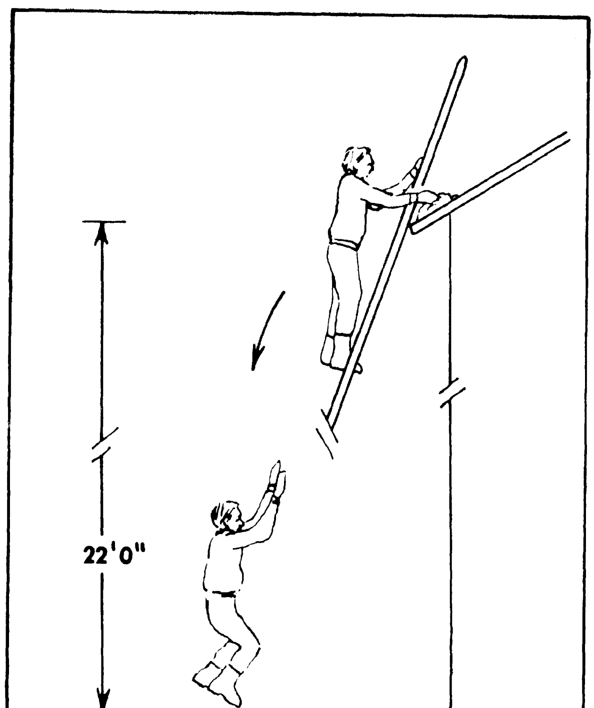
RECOVERY: Incapacitated for prolonged period - still on crutches seven months after fall. Anticipates permanent damage to ankles with traumatic arthritis.

SOURCES OF DATA: X SUBJECT; __ PARENTS;

X__ POLICE; X HOSPITAL; X WITNESSES;

X OTHER: Son

OTHER COMMENTS: Psychiatric consultation necessary to calm patient during hospitalization.



CALCULATED DATA:

IMPACT VELOCITY: 37 ft/sec (11.3 m/sec)

OAIS: 3

ISS: 18

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 109

SUBJECT: Male, 3 yrs 4 mo, height and weight unknown

FALL DISTANCE: 25 ft 7 in (7.8 m)

ENVIRONMENT: Porch railing to asphalt driveway

MAJOR INJURIES: Skull fracture and subdural hematoma, fractured wrist: Fatal

SUMMARY: Child was playing alone on 3rd story porch and climbed onto railing. Observed by neighbor to fall to driveway below. He suffered a fractured skull with subdural hemorrhage and a fractured wrist. The injuries proved fatal 3½ hours after the fall.

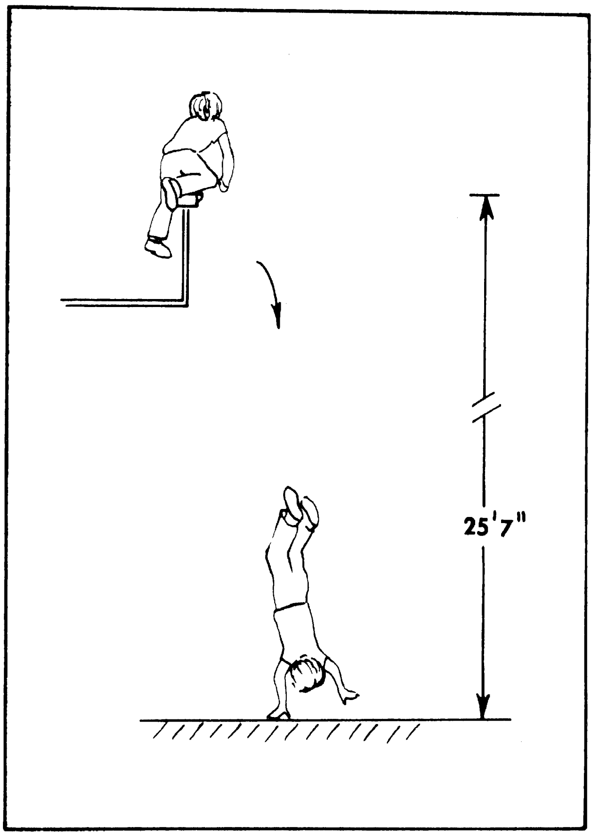
FALL CHRONOLOGY: Child climbed 3rd story porch railing, apparently facing outward, and lost his balance. He landed essentially head first on an asphalt driveway.

SPECIFIC INJURIES: Fractured skull, with subdural hematoma which compressed the brain [HWKB-5]; fractured wrist [WUFJ-2].

RECOVERY: Critical condition and unconscious after fall. Fatal 3½ hours post-impact.

SOURCES OF DATA: __ SUBJECT; __ PARENTS; X POLICE; __ HOSPITAL; X WITNESSES; __ OTHER:

OTHER COMMENTS: Medical and autopsy report not available.



CALCULATED DATA:

IMPACT VELOCITY: 40 ft/sec (12.2 m/sec)

OAIS: 5

ISS: 29

FREE-FALL STUDY CASE REPORT

CASE NUMBER: 110

SUBJECT: Male, 3 yrs 4 mo, 3 ft 2 in (0.97 m), 32 lbs (14.5 kg)

FALL DISTANCE: 17 ft 2 in (5.2 m)

ENVIRONMENT: Garbage can "elevator" to concrete

MAJOR INJURIES: Right parietal skull fracture, severe brain trauma: fatal

SUMMARY: Subject was playing with brother, being raised in a garbage can "elevator" by a rope. At the second floor level, the subject panicked and tilted the garbage can. He fell out, flipped in the air and landed on a concrete patio after falling 17 feet. He was hospitalized in a terminal state with a skull fracture and severe brain trauma. He expired 7 hours after the fall.

FALL CHRONOLOGY: Subject was at second floor level, inside a garbage can that was suspended by a rope. Subject tilted the can and slid out, face down. He rotated one complete turn in mid-air and landed head-first on the right side of his head.

SPECIFIC INJURIES: Non-depressed linear skull fracture in right temporal parietal region, with severe cerebral trauma (non-responsive eyes, loss of pulmonary function, deep coma) [HRKB-5]; contusion and hematoma, right forehead and temporal regions [FSCI-1, HRCI-1]; abrasions of mouth and nose [FCAI-1]; abrasions to lower anterior chest and front of both thighs [CCAI-1, TBAI-1].

RECOVERY: Subject expired 7 hours after fall.

SOURCES OF DATA: __ SUBJECT; X PARENTS;
__ POLICE; X HOSPITAL; X WITNESSES;
__ OTHER:

OTHER COMMENTS: Subject's 15-year-old brother was witness to entire fall and described fall sequence.

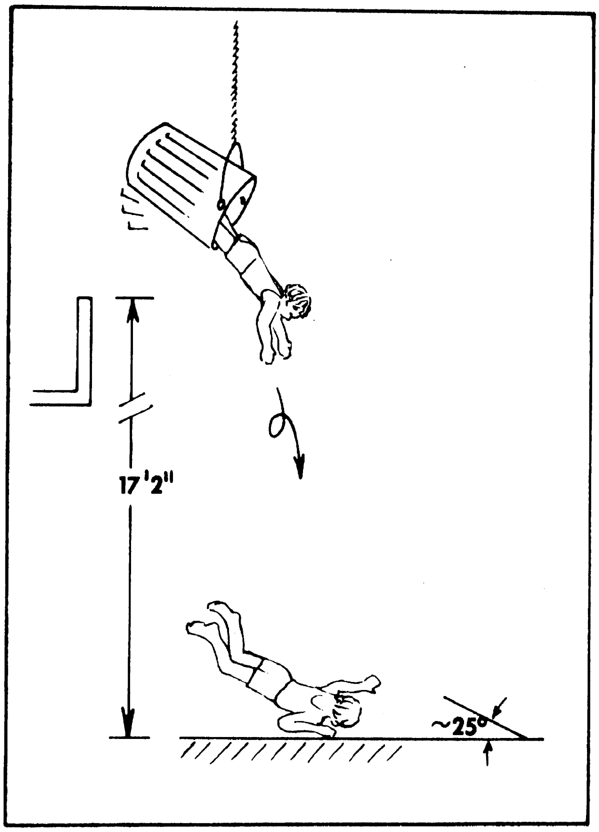
CALCULATED DATA:

IMPACT VELOCITY: 32 ft/sec(9.8 m/sec)

OAIS: 5

ISS: 26

This case was simulated. Responses do not account for fracture (See Chapter 3).
Est. peak head accel: 782-813 g's
Est. peak head normal force: 4619-4633 lbf (20,500 - 20,600 N)
Est. peak head deflection: .59 in (1.5 cm)



APPENDIX B

COMPUTER SIMULATION OF HUMAN FREE FALLS

APPENDIX B

COMPUTER SIMULATION OF HUMAN FREE FALLS

The computer simulations of human free falls conducted as a part of the free-fall study were made with the MVMA Two-Dimensional Crash Victim Simulator, developed at the University of Michigan Highway Safety Research Institute. This model includes the following features in its representation of the human body:

1. A nine-mass, ten-segment body linkage;
2. An extensible, two-joint neck and a realistically-flexible shoulder complex;
3. Energy-absorbing joints;
4. Time-dependent muscle activity level;
5. Contact-sensing ellipses of arbitrary size, position, and number which define the body profile; and,
6. General and arbitrarily-defined nonlinear materials with energy-absorbing capability for all parts of the body.

This model is completely documented in the three-volume report, "MVMA Two-Dimensional Crash Victim Simulation, Version 3" (Bowman, et al., 1974)* and in the "MVMA 2-D Tutorial System"(Bowman, et al., 1977). It is described in less detail in,"The MVMA Two-Dimensional Crash Victim Simulation," (Robbins, et al, 1974).

A. <u>Fall Conditions</u>

Position and velocity conditions at impact were estimated from real life case data and used to initialize the free-fall computer simulations. Body orientation at impact was estimated from information obtained by interviewing free-fall victims and eye witnesses and also by checking injury details recorded in hospital records. The position

* References for Appendix B are located at the end of Appendix B.

in space was arranged so that at simulation "time zero" the body part of first contact was tangent to the impacted surface.

For these simulations, three velocity conditions must be specified at impact. For all cases investigated, the z-component (vertical) of the impact velocity was considerably greater than the x-component (horizontal). At impact the z-velocity of the body center of gravity was determined as $\sqrt{2gh}$, where h is the vertical distance between the pre-fall and time-zero (impact) center of gravity positions. Drag effects during the fall were considered negligible. From the duration of the free fall, the vertical impact velocity, and the pre-fall and time-zero body orientations, an overall body angular velocity at impact was estimated. Using case data and the estimated angular velocity, the x-component of velocity of the body CG at time zero was also estimated.

The impacted surfaces for the cases simulated were all hard and unyielding in comparison with any part of the human body (typically, they were slate, concrete, ice, terrazo, and asphalt). They were, therefore, assumed to be infinitely rigid for the computer simulations. Appropriate coefficients of friction for interaction between each of these surfaces and each part of the body (e.g., head, clothing, shoes) were estimated from handbook data (Weast, 1971).

Several simulations were repeated to determine the effects of falls onto non-rigid surfaces. Modeling of soil properties in these simulations is discussed in Section H.

B. The Body Linkage

1. The Model. The MVMA-2D body linkage is illustrated in Figure B-1. (The orientation shown here is of a seated automobile occupant.) Ten physical links are represented. The human spinal column is more or less continuously flexible

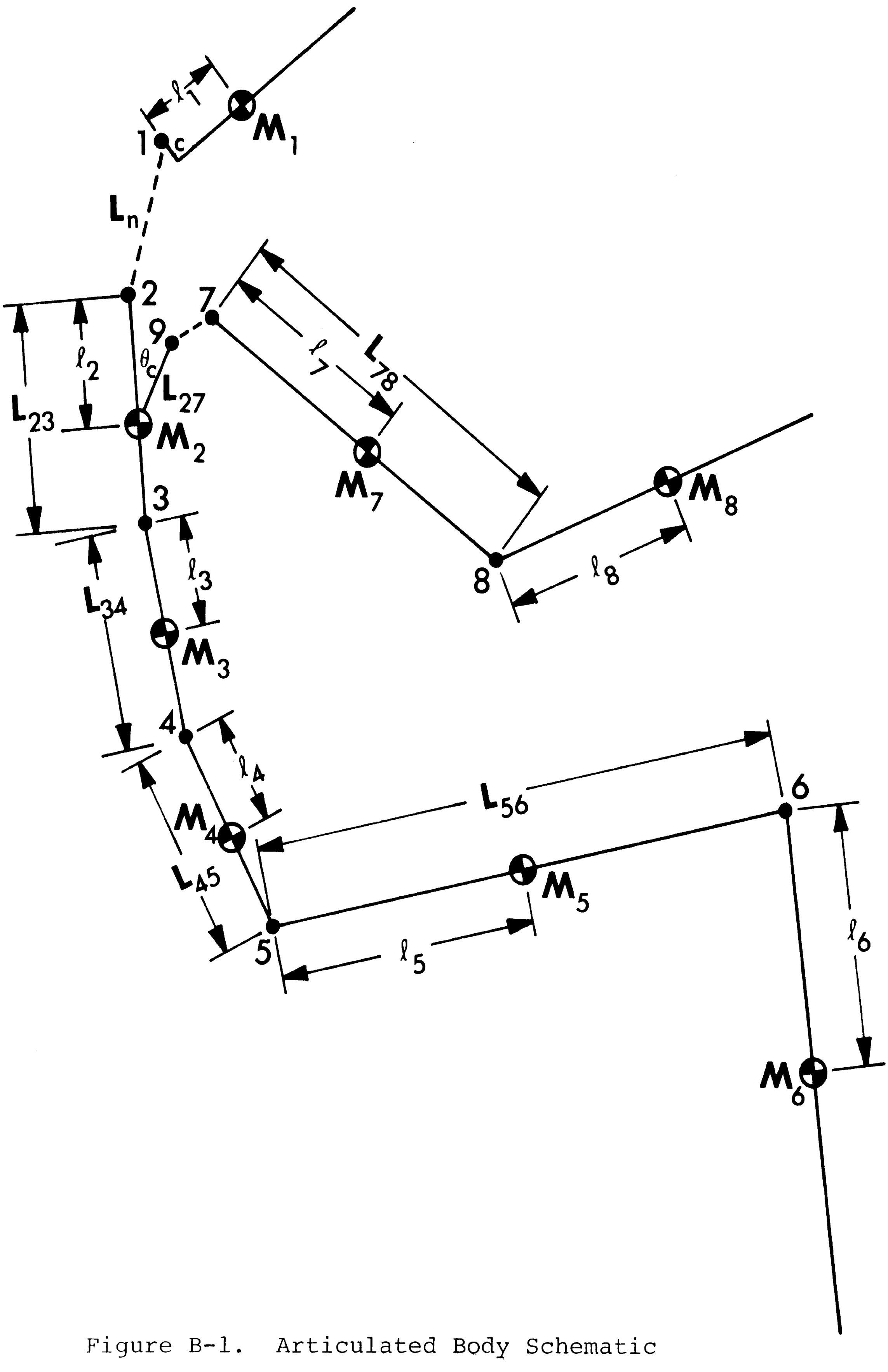


Figure B-1. Articulated Body Schematic

since it is composed of thirty-three vertebrae and intervening fibrocartilaginous discs. The model simulates flexibility of the combined thoracic and lumbar spines by two articulations, which connect three torso links. These are joints 3 and 4 in the figure. Flexibility of the cervical spine is accounted for by two articulations, one at the occipital condyles and one at the seventh-cervical/first-thoracic juncture, joints 1 and 2, respectively.

Nine masses are associated with the ten links. The neck link L_n is extensible and compressible and has nonzero mass* while the shoulder link (9-7) has no mass but is included in the model to account for sagittal-plane claviscapular shrugging motions. All other links are inextensible and articulate at the joint positions illustrated.

2. Link Data Requirements. Arm contacts with the struck surface were not considered to be of importance for any of the cases simulated, so arm links were eliminated by appropriate selection of input parameter values. Thus, link-length data required for each simulation were the quantities L_n (at t = 0), L_{23}, L_{34}, L_{45}, L_{56}, ℓ_1, c, ℓ_2, ℓ_3, ℓ_4, ℓ_5, and ℓ_6, all illustrated in the Figure B-1. ℓ_1, ℓ_2, ℓ_3, ℓ_4, ℓ_5, and ℓ_6 locate the centers of mass of the links with respect to articulation points. The quantity c is the rearward offset of the condyles articulation from the superior-inferior head axis. The remaining quantities are link lengths.

The only anthropometric data available for the freefall victims were height and weight. However, given height, weight, age, and sex, it was possible to derive necessary dimensions for the link lengths of primary significance using results from various anthropometry studies (Damon, et al, 1971; Snyder, et al., 1972; Snyder, Spencer, et al, 1975). The primary links are: 1) head-neck height; 2) total torso height;

*Neck mass is distributed at the end points of the neck link.

3) femoral length; and 4) lower leg length. These are among the anthropometric dimensions illustrated in Figure B-2.

Good data for these basic body length dimensions are of primary importance; length dimensions for the separate model links which comprise these more basic dimensions have a secondary importance. They introduce physically-present flexibility to the linkage and should therefore be included in any good analytical human-body kinematics model. As values for these lengths must be included in MVMA-2D data sets, the values for model link lengths L_n (0), L_{23}, L_{34}, and L_{45} were derived from the basic dimensions previously mentioned.

3. Torso Link Data. Work at HSRI dating from the earliest whole-body motion models (1967) has provided the following torso link ratios* for 50th-percentile-stature males: $L_{23}/L_T = 0.552$, $L_{34}/L_T = 0.252$, $L_{45}/L_T = 0.196$, $\ell_2/L_{23} = 0.589$, $\ell_3/L_{34} = 0.445$, $\ell_4/L_{45} = 0.386$, where L_T is the total torso height, and all other parameters are illustrated in Figure B-1.

Given L_T for any individual, values for the parameters L_{23}, L_{34}, L_{45}, ℓ_2, ℓ_3, and ℓ_4 that are satisfactory for whole-body motion simulations can be obtained by using these ratios. For example, with a total torso height of 22.75 inches, L_{23} is 12.59 inches and L_{34} is 5.75 inches.**

4. Neck Link Data. With torso link data determined in this manner and using other anthropometric measures, like head-neck height, it is possible to estimate neck length for any member of the population. The basic scaling assumption is that neck length is a constant proportion of total spinal column length, independent of stature, sex, or age.

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* For free-fall simulations, dynamic response is insensitive to these ratios.

** To simplify presentation of material, SI units are not included in the text. Conversion constants for SI units will be found on page 37 of this appendix.

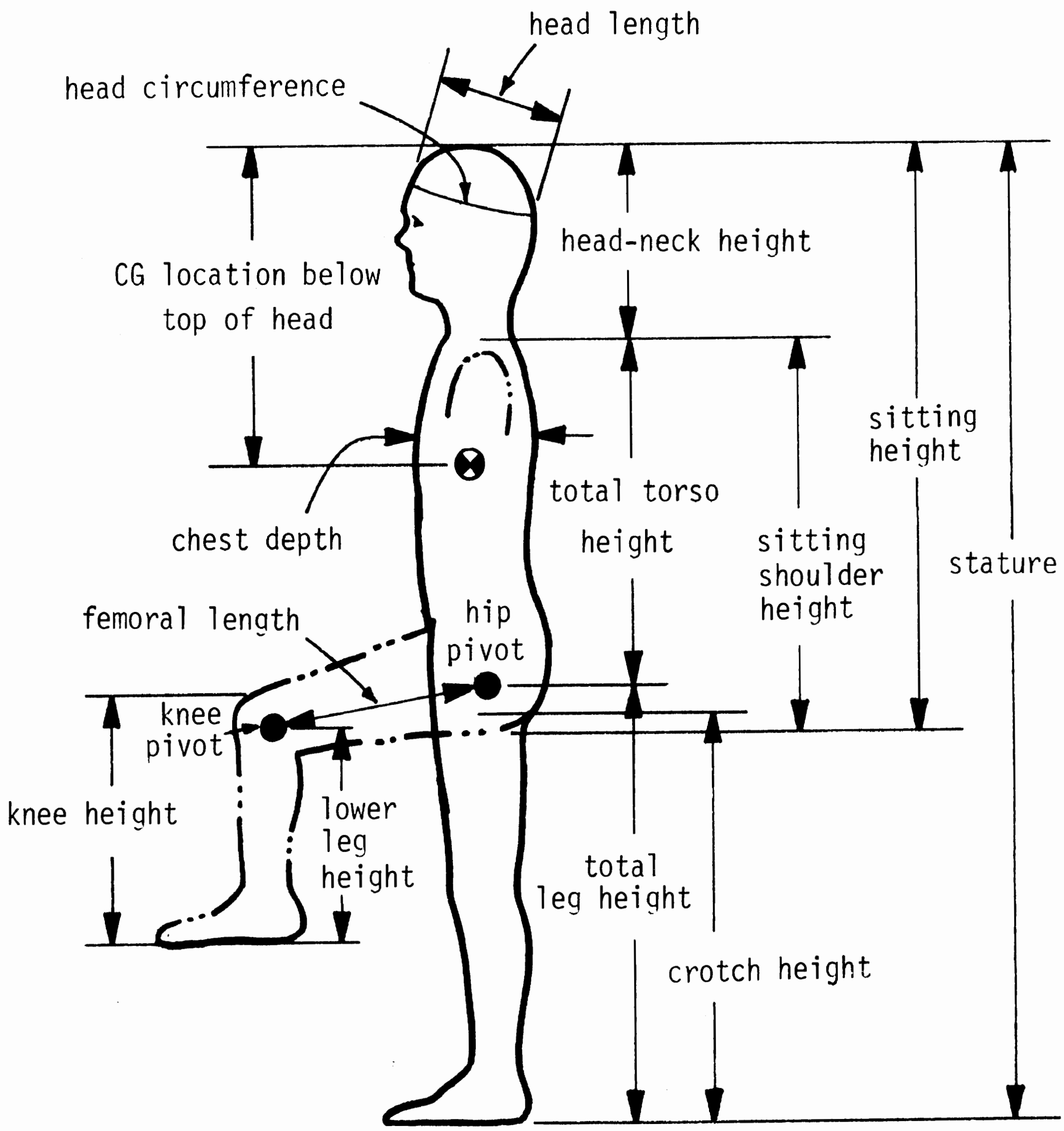

Figure B-2. Anthropometric Dimensions

$$\frac{L_n}{L_s} = \text{Const.}$$

Figure B-3 illustrates a three-element model of the spinal column, together with the head.

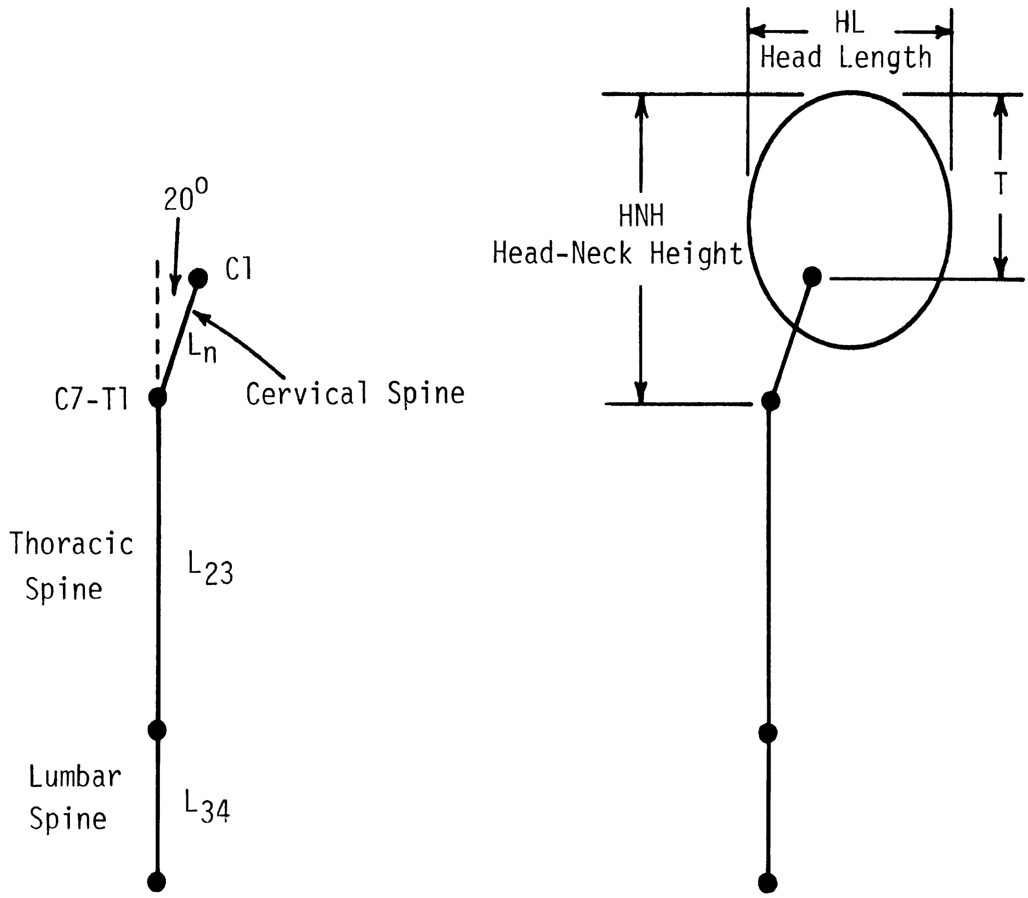

Figure B-3. Head and Spinal Column Dimensions.

Using a nominal 20° seated-position neck angle,* the spinal column length can be expressed as

$$L_s = L_n + L_{23} + L_{34} = (HNH - T)/\cos 20° + L_{23} + L_{34},$$

where HNH is head-neck height and T is the dimension from the top of the head to the occipital condyles. Since head-neck height, L_{23}, and L_{34} can be calculated for each case subject as previously explained, L_s can be evaluated if T is known. To obtain T for any individual, the assumption is made that T/HL is a population constant. For adult males, the average value of T can be taken to be 12.8 cm and HL, 19.0 cm (Snyder, Chaffin, and Foust, 1975). Therefore, T = .674 HL, and L_s is determined.

Measurements of the straight-line neck length from C1 to C7-T1 from x-rays of average stature adult males indicate a value of 4.41 inches (Schneider, et al., 1976). Using the previously-presented torso link data for this population group, we may express total spinal column length as $L_s = L_n + L_{23} + L_{34} = 4.41 + 12.59 + 5.75 - 22.75$ in. Consequently, the population constant which relates neck length to total spinal column length is

$$\frac{L_n}{L_s} = \frac{4.41}{22.75} = .1938.$$

Hense, for any member of the population:

$$L_n = .1938\ L_s, \text{ or}$$

$$L_n = .1938\ [1.064\ (HNH - .674\ HL) + L_{23} + L_{34}].$$

(Here, as previously explained, $L_{23} = .552\ L_t$ and $L_{34} = .252\ L_T$, where L_T is total torso height.)

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* Average for five adult males (Schneider, et al, 1976; Ewing, et al, 1975)

5. Location of Occipital Condyles. The quantities ℓ_1 and c in Figure B-1 define the position of the head center of mass with respect to the occipital condyles in a coordinate frame fixed to the head. ℓ_1 is the distance measure along the inferior-superior head axis, and c is the rearward offset of the condyles from this axis (measured parallel to the Frankfort Plane). These quantities are both assumed to be proportional to head length as population constants. Average data for adult males have been determined to be HL = 19.0 cm, ℓ_1 = 4.16 cm, and c = 2.47 cm (Schneider, et al, 1976). Hence,

$$\ell_1 = .219 \text{ HL}$$

and

$$c = .13 \text{ HL}$$

C. Relation of Body Parameters to Body Mass*

Good biomechanical and anthropometric data are important for successful use of any whole-body motion simulator. A researcher will sometimes have good data for one segment of the population, for example, 35 to 40 year old males of 50th percentile stature and weight, but incomplete data for other segments of the population. By applying scaling relations to reliable data obtained for one segment of the population, it is generally possible to develop reasonable data for the rest.

The method of scaling is a reasonable substitute for direct biomechanical and anthropometric measurement. Its use in this study was influenced by all data available for the population segment of interest. Engineering judgment was used in complementing the available data with that obtained by scaling. The development of relations for body link lengths in the section above is typical of much of the

* Material in this section has been adapted from the MVMA 2-D Tutorial System (Bowman, et al, 1977).

scaling that was used in the computer study of human falls.

However, for some types of biomechanical parameters, the only available data on which scaling could be based were less directly applicable. Often, only the body mass was available. But body mass alone, if used with care, can be the basis for reasonable scaled values. An understanding of the assumptions made in deriving scaling relations of this type is important so that the results may be used intelligently. This is also important in allowing the modeler to make a subjective estimate of how good his scaled values are likely to be. The scaling relations given in Figure B-4 are valid, given the following conditions:

1) All internal and external length measures of the "scaled" biomechanical system (subscript 2) are proportional to the corresponding measures of the "scaled to" system (subscript 1) by the same proportionality constant. That is, linear scaling in size is assumed.

2) Corresponding body parts of the two systems have equal mass densities.

3) Corresponding anatomical elements of the two systems have the same material constitutive properties. This means that material parameters such as Young's modulus (E) are the same for corresponding elements while the strengths of the elements will not be the same if they are of different size.

It is clear from these conditions that biomechanical scaling will be better between some segments of the population than between others. The first condition, linear scaling in size, is probably the primary weakness in human scaling since body proportions are functions of age and sex. For example, better results can be expected for scaling from 35-44 year-old males to 18-24 year-old males than from 35-44 year-old males to 6-9 year-old females. Nevertheless the above conditions indicate that scaling between human population sets is more justified than scaling from lower primates to humans, which is a common technique used in the development of human injury tolerance data.

Where less directly-applicable data were available, fall simulation data were developed using some of the relationships in Figure B-4. In particular, the moment-of-inertia and viscoelastic-parameter relations (for joints) had to be used in the simulations.

	M = mass
LENGTH:	$L_1 = L_2 (M_1/M_2)^{1/3}$
AREA:	$A_1 = A_2 (M_1/M_2)^{2/3}$
VOLUME:	$V_1 = V_2 (M_1/M_2)$
MASS:	$m_1 = m_2 (M_1/M_2)$
MOMENT OF INERTIA:	$I_1 = I_2 (M_1/M_2)^{5/3}$
DAMPING COEFFICIENT:	$C_1 = C_2 (M_1/M_2)^{2/3}$
LINEAL SPRING CONSTANTS:	$K_1^{(n)} = K_2^{(n)} \ (M_1/M_2)^{(2-n)/3}$
	where $F = K^{(1)}\delta + K^{(2)}\delta^2 + \ldots$
TORSIONAL SPRING CONSTANTS:	$K_{1\theta}^{(n)} = K_{2\theta}^{(n)} \ (M_1/M_2)$
	where $T = K_\theta^{(1)}\Delta\theta + K_\theta^{(2)}(\Delta\theta)^2 + \ldots$

Figure B-4. Parameter Scaling Relations.

D. Joint Properties

Resistance to motion between adjacent body links is present in joint structures of the human body. There are passive resistances that result from deformation of both soft and hard tissues. In addition, active resistances are present at a joint whenever the musculature connecting the links is in a contracted state. Both passive and active viscoelastic joint elements are represented (as composite, lumped-parameter structures) in the MVMA 2-D model.

The MVMA 2-D joint model is explained fully in Bowman, et al., (1974 and 1977). The passive elements include non-linear springs with energy-dissipating ability and linear, rate-sensitive dampers. The active elements are series combinations of spring and damper components, where the spring and damping coefficients are both functions of the time-dependent level of muscle activation. It was felt that only contraction of leg muscle was signficant in any of the fall cases, so the knee joint was the only one for which active elements were represented (and then only for foot-first falls).

Joint parameter data developed at HSRI for males of 50th percentile weight and stature (MVMA 2-D baseline data set, 1976) were scaled to values appropriate for the individual case subjects by using the scaling relations presented in the preceding section. The data that were developed in this manner include the elements which resist elongation and compression of the neck link.

"Baseline" joint range-of-motion data from the HSRI 50th-percentile-male data set were used for all simulation subjects more than 17 years of age (17, 19, and 21, all males). Since there are virtually no useful range-of-motion data for children in the literature, the baseline data were adjusted by arbitrary percentages to obtain values for children which represent greater flexibility.

For the one-year old subject, joint range-of-motion data were increased by 20%. For subjects of age two, 15% was used. For subjects from three to six, 10% was used. Ranges of motion for the thirteen-year-old were 5% greater than the baseline data. While it is felt that these ranges of motion are not unreasonable, it is worth noting that the impact accelerations and forces that are the focus of the fall simulations are not sensitive to range of motion.

E. Masses and Moments of Inertia

1. Link Data. Two sources were used to establish "base data" for body link masses and moments of inertia. These were the HSRI 50th-percentile-male data set (1976) "Development and Evaluation of Masterbody Forms for Three-Year Old and Six-Year Old Child Dummies" (Reynolds, et al, 1976). The study by Reynolds, et al contains data on body-segment mass and moment of inertia for masterbody forms for three-year-old and six-year-old children.

It is important to have separate base data for children since a linear size relationship between children and adults is not a good approximation. The scaling relations of Section C of this appendix are better used for adult-to-adult and child-to-child scaling. In this study, for example, segment-mass and moment of inertia data were derived for case subjects of age one, two, and three by scaling the masterbody three-year-old data on the basis of body mass. As indicated in Figure B-4, the first and 5/3 powers of the mass ratio are the appropriate scaling constants for masses and moments of inertia, respectively. Data for the six-year-old were obtained similarly by scaling the masterbody six-year-old data. Baseline 50th percentile-male data were scaled for all other case subjects (ages 13, 17, 19, and 21).

Two special considerations were used. First, since arm links were not included in the fall simulations, as explained in Section B, an effective mass of fifty percent of total arm mass was arbitrarily added to the upper torso link. Second, as head size is not linearly scaled even within a population group for which other body proportions are almost linearly related, body segment masses and moments of inertia were scaled by the relations in Figure B-4 on the basis of ratios of "headless" body masses, not total body masses. The independent determination of head mass and moment of inertia values is explained below.

2. Head Data. Of several functions of anthropometric dimensions that were thought might correlate highly with head mass, the circumference of the heads of five male cadavers correlated best with head mass ($r = .922$). This is a finding reported by Schneider, et al (1976), who used data from a study by Chandler, et al (1975). Thus, where C is the head circumference of the case subject and $\overline{m}$ and $\overline{C}$ are the average head mass and circumference of the cadavers, the head mass of the case subject is obtained from the following scaling relation:

$$m = \overline{m}(C/\overline{C}).$$

Transverse head moment of inertia correlated well ($r = .978$) with the following quantity:

$$[(\text{menton to vertex})^2 + (\text{head length})^2] \times [\text{head circumference}].$$

Since the menton-to-vertex measure was not available for the free-fall simulation subjects, this result was used indirectly. The demonstrated correlation of this function with moment of inertia was used by Schneider and Bowman to scale the averaged cadaver moment of inertia to a value for a population segment for which average measures were known for the menton-to-vertex height, head length, and head circumference (a group of military personnel). The head mass for this same group was estimated in the manner previously explained. These values are designated I^* and M^*. Using these mass and moment of inertia data, together with the reasonable assumption of a linear size relationship for head (not body) measures for the entire population, it is possible to estimate the head moment of inertia I for any case subject by

$$I = I^*(m/m^*)^{5/3} ,$$

where m is the previously-determined head mass.

F. The Body Profile

In order that the computer model can predict force-producing interactions between the simulated human and his environment, sets of potentially-interacting, geometrical profiles must be defined along with the other input data. For the free fall simulations, the environment is simply defined. It consists entirely of a single, horizontal line representing the struck surface. While it could be assigned a general set of material properties, the struck surface was designated as rigid for these simulations, as explained in Section A.

The contact-sensing body profile in the MVMA Two-Dimensional model is a set of ellipses of arbitrary number and dimensions, fixed to body links at arbitrary positions. Material properties may be assigned for each ellipse, or any ellipse can be specified as rigid. For each of the fall simulations, the profile of ellipses was defined so as to: 1) approximate the body dimensions of the case subject, and 2) provide reasonably accurate resistance to body deformation, as a function of body part. The development of material property assignments is in section G. The remainder of this section deals with development of parameter values for the undeformed, geometrical profiles of the case subjects simulated. Five ellipses are defined.

1. Head Ellipse. Two primary considerations went into assigning head ellipse parameter values. First, the "head length" dimension (anterior-posterior) of the subject is best represented by assigning HL/2 as the A-P semi-axis dimension of the head ellipse. Second, in order to predict the effect of impacts near the top of the head

most accurately, the S-I semi-axis dimension is taken as the head CG-to-vertex distance. The ellipse is centered at the head center of gravity.

While head length is a standard measure in anthropometry studies, the CG-to-vertex dimension must be determined indirectly and required data are available for only certain population segments. Since both dimensions are needed, however, to describe the head ellipse for each case subject, values for the CG-to-vertex dimension were obtained by assuming that the ratio (CG to vertex)/(head length) is a population constant. A similar assumption was made in order to establish the location of the occipital condyles with respect to the head CG in Section B, and also in the scaling for head moment of inertia in Section E. Ewing, et al. (1972) determined that for adult males the head CG averages 2.13 cm above tragion (and 1.3 cm forward). Snyder, Chaffin and Foust (1975) determined that the corresponding tragion-to-vertex and head-length measures are 12.8 cm and 19.0 cm. Hence, for a head length of 19.0 cm, the CG-to-vertex dimension is 12.8 - 2.13 = 10.67 cm, and the assumed population constant is

$$\frac{\text{CG to vertex}}{\text{head length}} = .5616 \ .$$

Consequently, the A-P and S-I ellipse semi-axis lengths are taken as

$$b = HL/2$$

and $a = 1.123\ b$.

2. <u>Chest Ellipse</u>. The A-P diameter of the chest ellipse was assigned the value for chest depth, i.e., where CD is chest depth, the A-P semi-axis dimension is $b = CD/2$. The ellipse center was positioned longitudinally at the CG of the upper torso link. Therefore, an implicit assumption was made that chest depth is measured at the upper torso

CG.* On the basis of sparse anthropometric data, the ellipse center was positioned anteriorly from the upper torso CG by about 10% of the chest depth. The S-I length of the chest ellipse approximates the length of the upper torso link ($2a = .82\ L_{23}$).

3. Hip Ellipse. The hip ellipse was centered at the hip joint, the articulation between links 4 and 5 in Figure B-1. It was arbitrarily defined as a circle of radius equal to the chest A-P semi-axis length, i.e., the hip circle diameter equals the chest depth.

4. Knee Ellipse. The knee ellipse, like the hip, was defined as a circle. It is centered at the knee joint and a simple rule was established on the basis of anthropometric data to approximate an appropriate radius. Where A is age in years, the radius was set to 2.5 inches for subjects 15 years of age or more and to 1. + A/10 inches for subjects less than 15.

5. Foot Ellipse. The MVMA-2D model does not have an articulation at the ankle. Consequently an ellipse of dimensions similar to the foot's attached to the end of the lower leg link will not produce reasonable foot forces unless the assigned material properties artificially account for the torsional resistances to flexion and extension at the ankle. No useful data of this sort are presently available, and therefore a simpler foot model is used. A circle is used as the foot ellipse. It is positioned at the end of the lower leg link, tangent to the underside of the heel, the part of the foot which must take the greatest load in a foot-first fall. Radii of the foot circles for the simulated case subjects are not important for this foot model, but smaller values were used for children than for adolescents and adults. Values used range from 1 inch for age 1

* By the results in Section B, this is 0.325 L_T below C_7-T_1, where L_T is total torso height.

to 3 inches for adults.

G. Material Properties

Material properties are prescribed for each of the body contact ellipses. The MVMA-2D model does not use defined constitutive properties, but instead requires load-deflection characteristics and information relating to hysteretic energy loss and permanent deformation upon unloading.

Little information is available in the literature that is relevant to unloading characteristics of body parts. It is clear, however, that almost all loading energy is lost upon unloading from large deformations since fall victims rebound to a height that is insignificant compared with the fall height. For the free-fall simulations, restitution coefficients of 0.1 were assumed for all body parts except the chest, and permanent deformations were assumed to be ten percent of the maximum deflection. The unloading parameters for the chest are defined more accurately on the basis of experimental data as reported later in this section. It should be mentioned that the primary impact responses predicted in the MVMA-2D model simulations are not affected by the accuracy of the unloading parameters; peak accelerations and peak forces occur during loading, not during rebound.

1. Head Properties: Adults. McElhaney, et al. (1973, and King et al, 1973) have reported A-P and L-R static load-deflection curves measured by Messerer (1880). The A-P curves for twelve fresh, intact cadaver heads (all adults) are shown in Figure B-5 and were used in this study as the basis for modeling skull stiffness. Shown in the figure is what is judged to be the best two-segment fit to the twelve curves. The portion of the curves for deflections less than 0.04 inches is unimportant since its energy content is negligible.

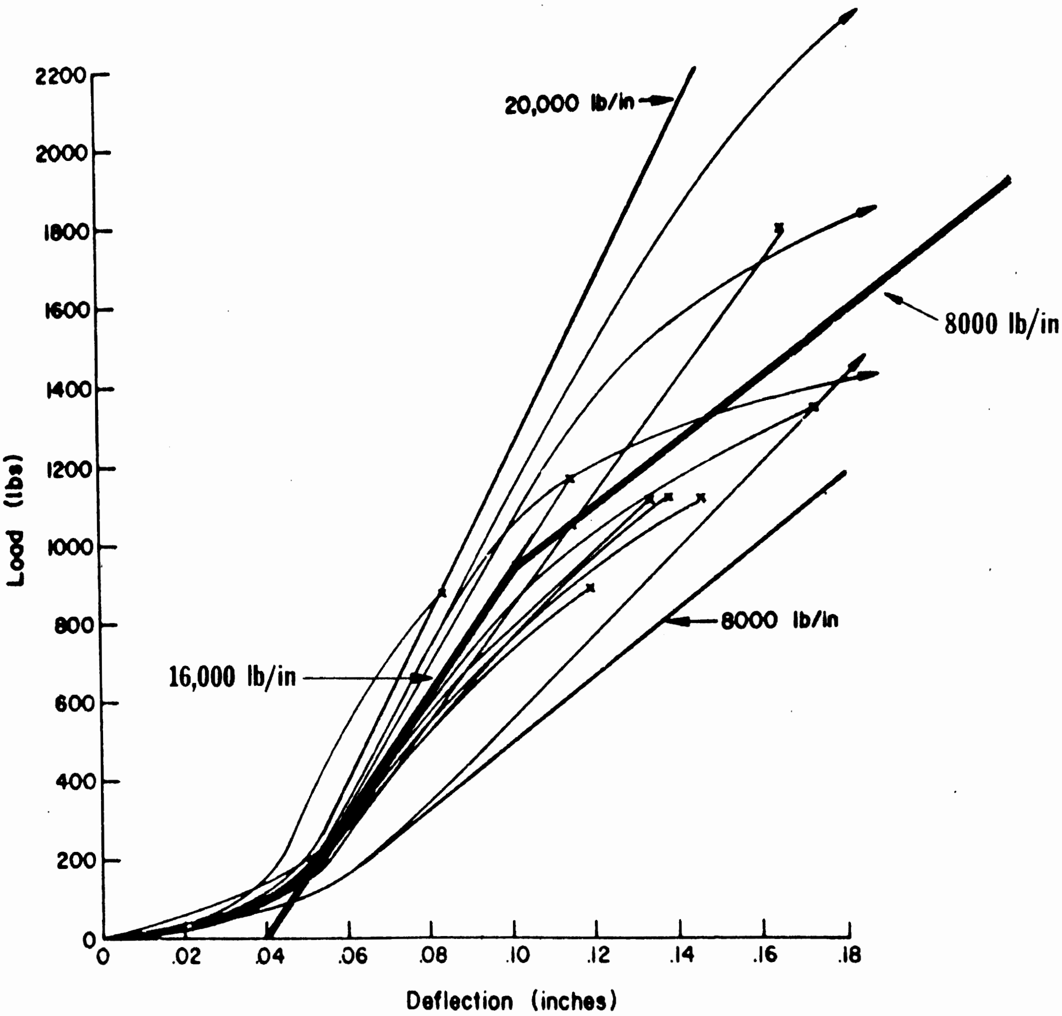

Figure B-5. A-P Static Force-Deflection Curves for the Adult Head

Both the anterior and posterior hemispheres of the skull deform significantly in a static test since the skull is subjected to external forces on both sides. Thus, in a static test, the skull behaves like two (nonlinear) springs in series, as illustrated in Figure B-6. The effective stiffness for such a system is less than for either component. For example, if each component is linear, then

$$k_{eff} = \frac{K_1 K_2}{K_1 + K_2} = \frac{K_1}{1 + \frac{K_1}{K_2}},$$

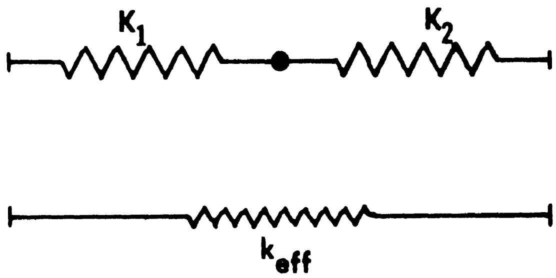

Figure B-6. Effective Stiffness of Springs in Series

which is clearly less than both K_1 and K_2. If K_1 and K_2 are equal, which is probably approximately true for the anterior and posterior hemispheres of the skull, then $k_{eff} = K_1/2$.

Since the curves in Figure B-5 were obtained for static loading, the two-segment fit is not completely appropriate for use in simulation of an impact event. During impact loading, the absence of an external force on one side of the skull limits deformations primarily to one hemisphere. In terms of the simple model shown in Figure B-6, the impact stiffness is K_1 or K_2, both of which are greater than k_{eff} from a static test.

For the purpose of developing a force-deflection curve for head impact, it was assumed that the stiffnesses of the two skull hemispheres are equal. It is necessary, then, to determine the characteristics of identical single-hemisphere, nonlinear components of a series element which has the two-segment (nonlinear), best-fit, static curve of Figure B-5 as a loading curve. The derivation of the component curves will not be presented here, but results are shown in Figure B-7.

The derived single-hemisphere loading curve illustrated in this figure would be appropriate as the head loading curve for A-P impact if the opposite hemisphere did not undergo deformation. However, while most of the total deformation can be expected to be in the impacted hemisphere, some must be associated with flexure of the opposite hemisphere. Therefore, the true impact loading curve lies within an envelope bounded above by the single-hemisphere curve and below by the total-skull curve. As no means could be determined for placing the curve within this envelope, the dashed mid-line curve was taken as the head loading curve for impact of the adult skull. The parameters of the two-segment curve are $K' = 1.5\ \bar{K}$, $\alpha' = \bar{\alpha}$, and $\delta'_r = .75\ \bar{\delta}_r$. As $\bar{K} = 16000$ lb/in, $\bar{\alpha} = .5$, and $\bar{\delta}_r = .06$ in from Figure B-5, the slopes of the two segments of the impact loading curve are $K' = 24000$ lb/in and $\alpha'K' = 12000$ lb/in, with the first segment ending at $\delta'_r = .045$ in.*

2. Head Properties: Children. Because calcification of the human skull continues until adulthood, the stiffness of the child skull is less than the stiffness of the adult skull. Accordingly, the adult static and impact loading curves of the preceding section are inappropriate for use in child fall simulations.

No data for properties of the child skull are available in the literature. Child skull loading curves were therefore established in the following manner. 1) The

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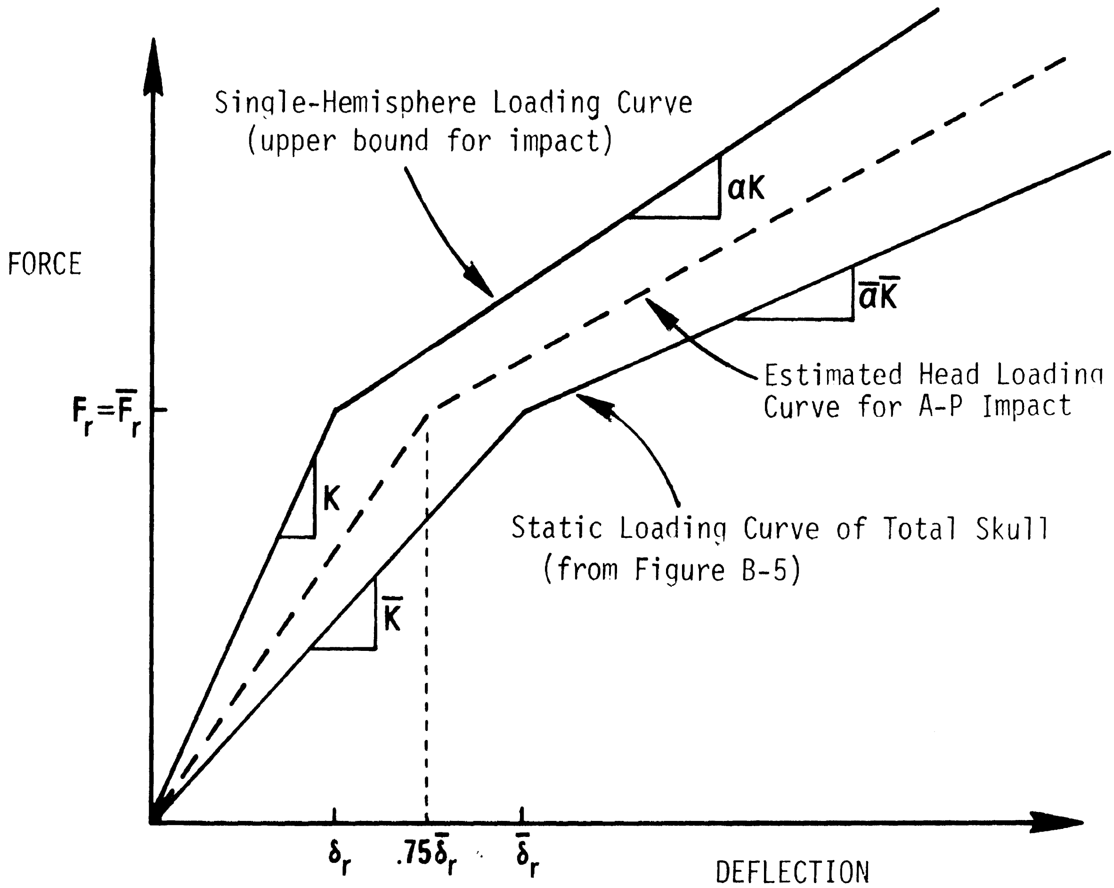
* The stiffness of 24000 lb/in compares with Stalnaker's (1970) value of 26000 lb/in determined for small deflections by driving point impedance testing of a single cadaver skull.



$K = 2\bar{K}$	$F_r = \bar{F}_r$
$\bar{\alpha} = \alpha$	$\delta_r = \bar{\delta}_r/2$

$\bar{K}$ = slope of first segment, total skull

K = slope of first segment, single hemisphere

$\bar{\alpha}$ = ratio of slope of second segment to slope of first segment, total skull

α = ratio of slope of second segment to slope of first segment, single hemisphere

$\bar{\delta}_r$ = deflection at end of first segment, total skull

δ_r = deflection at end of first segment, single hemisphere

$\bar{F}_r$ = force at end of first segment, total skull

F_r = force at end of first segment, single hemisphere

Figure B-7, A-P Load-Deflection Curves for Human Head assumption is made that the form of the child skull static loading curve is similar to that of an adult, i.e., it consists of two straight-line segments with slopes $\bar{k}$ and $\bar{\alpha}\bar{k}$. 2) The same relationships are assumed to hold between the static and impact loading curves for children as were previously determined for adults, i.e., k' = 1.5 k, $\alpha' = \bar{\alpha} = .5$, and $\delta'_r = .75\ \bar{\delta}_r$. 3) The deflection at the end of the first unloading segment is assumed proportional to head length. 4) The ratio of the child skull stiffness to adult skull stiffness, $r = \bar{k}/\bar{K}$, is estimated as a function of age so that for any age A, the static skull stiffness is

$$\bar{k}(A) = r(A)\ \bar{K}.$$

$\bar{K}$ is the established adult, static skull stiffness (for the first loading segment), 16000 lb/in. The age-dependent fraction r(A) is shown in Figure B-8.

The dependence of skull stiffness on age illustrated in the figure was estimated by taking into account the following considerations: 1) The skull stiffness at birth is very small in comparison with adult stiffness. 2) The skull may be expected to follow the normal growth curve, which means that, as a function of age, the stiffness should increase rapidly to a plateau at about six to nine years and then increase further. 3) When calcification is complete, the skull stiffness becomes independent of age. The parameters used for this curve largely reflect the judgment of a physical anthropologist consulted during the study (Reynolds, pers. comm., 1976). On the basis of communications with him, skull stiffness was assumed to reach 75% of adult stiffness at the 6-to-9 year plateau, 90% at age 13, and 100% at age 20, where calcification is assumed complete. The birth-point on the curve [r(0)] was estimated by hypothesizing that the ratio of the skull stiffness of the newborn child to adult skull stiffness may be

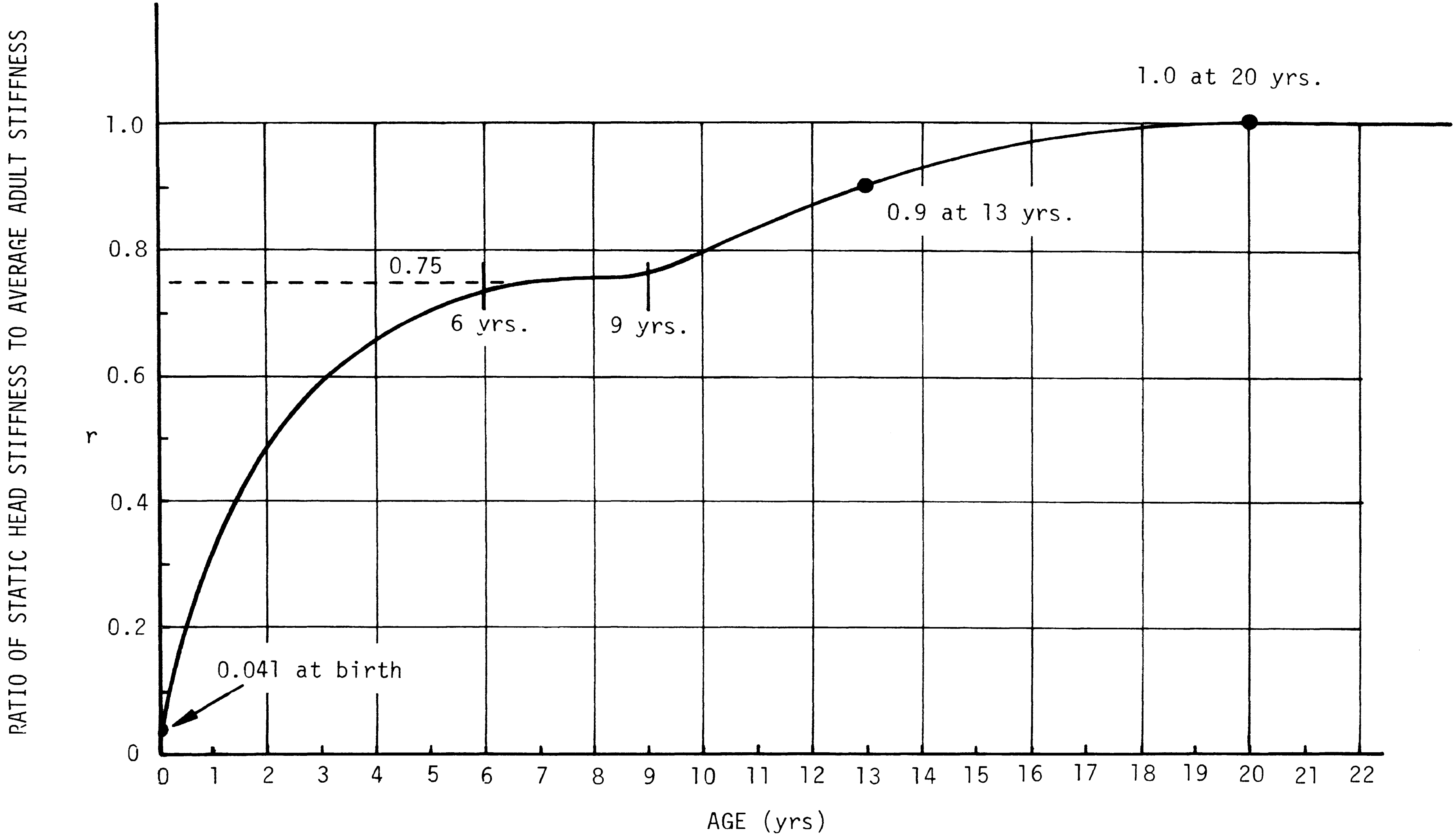


Figure B-8. Age-Dependent Static Head Stiffness, Normalized by Average Adult Stiffness approximated by the ratio of compressive strengths of the newborn child femur and the adult femur, since it was possible to establish the latter ratio from various data in the literature (Yamada, 1970). This analysis predicts a skull stiffness at birth of 4.1% of adult stiffness. It should be noted that for ages greater than about one year, the curve in Figure B-8 is not sensitive to the value of r(0) so long as the correct value of r(0) is between 0 and about 0.2, which is surely the case.

The following example illustrates determination of the impact loading curve parameters of the skull of a child of age 13 with a head length of 7.3 inches (18.54 cm). The static skull stiffness (first segment) is found as previously described as:

$$\bar{k}(13) = r(13) \times 16000 \text{ lb/in.}$$

From Figure B-8, r(13) is 0.90, so

$$\bar{k}(13) = 14{,}400 \text{ lb/in.}$$

The slope of the second segment of the loading curve is $\overline{\alpha k}$, or 7200 lb/in since $\bar{\alpha}$ is .5. $\bar{\delta}_r$ is scaled by head length as previously described to obtain the deflection at the end of the first segment as

$$\bar{\delta}_r = \frac{18.54}{19.0} (.06 \text{ in}) = .0585 \text{ inches},$$

where .06 inches is the adult $\bar{\delta}_r$ value, 19.0 cm is the average adult head length, and 18.54 cm is the example 13-year old's head length. This completely establishes the static loading curve. The parameters for the impact loading curve are then

$$k' = 1.5\,\bar{k} = 21600 \text{ lb/in}$$

for the first segment and

$$\delta'_r = .75\,\bar{\delta}_r = 0.0439 \text{ inches}$$

for the deflection at the end of the first segment. The second-segment stiffness is .5 k', or 10800 lb/in.

3. Chest Properties. Lobdell, et al., (in King and Mertz, 1973), report blunt impact force-deflection response of the chest for male and female, embalmed and unembalmed cadavers. Figure B-9 shows the average force-deflection curve for eight unembalmed, adult cadavers for 16-mph impacts with a 51 lb. striker.* Standard test procedures were used with a striker of six-inch diameter. Six of the cadavers were male and two were female, but there were no significant differences in peak dynamic loads (13%, max-to-min).

The curve in the figure was judged to be appropriate as a baseline for an average adult male.** This curve was parameterized and represented by a piecewise-linear form for loading. Figure B-10 illustrates the parameterized curve. Since saturation is characteristic for dynamic chest loading except for extreme deflections, the loading curve is made constant at 1100 lb at 3.0 inches, where dynamic unloading begins for the impact-test curve in Figure B-9.

Unloading curves of quadratic form are computed by the simulation model. The coefficients of the quadratic curve are functions of two material properties which must be prescribed together with the loading curve. These two inputs define the unloading hysteresis as functions of the "turn-around" deflection. The first is the ratio of permanent deflection to turn-around deflection. For the response curve in Figure B-9, this ratio is greater than 0.5. For this study a constant value of 0.5 was assumed, independent of turn-around deflection. The second property is

* Lobdell, et al., adjusted their original data by a constant 150 lb. to account for maximal muscle tensing.

** Lobdell, et al., suggest that their skeletal deflection curves differ from total thoracic deflection by 1/2 to 3/4 inch. The total thoracic deflection shown includes 1/2 inch of soft-tissue deformation.

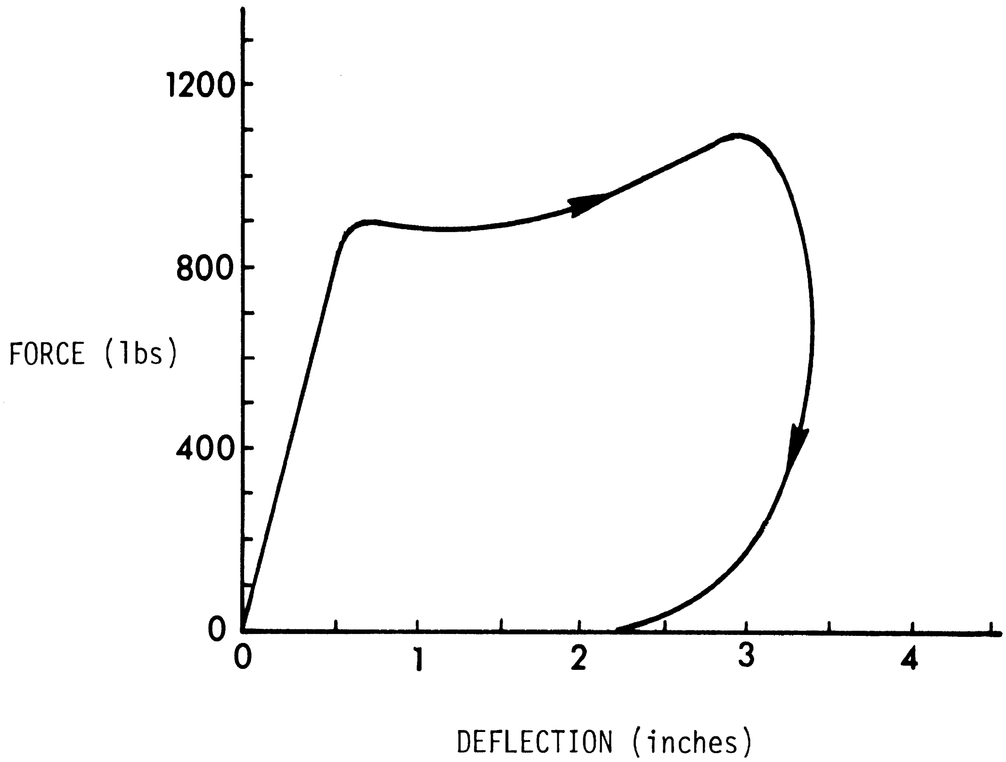


Figure B-9. Average dynamic force-deflection characteristics of the chest for unembalmed cadavers using 51 lb. striker at 16 mph

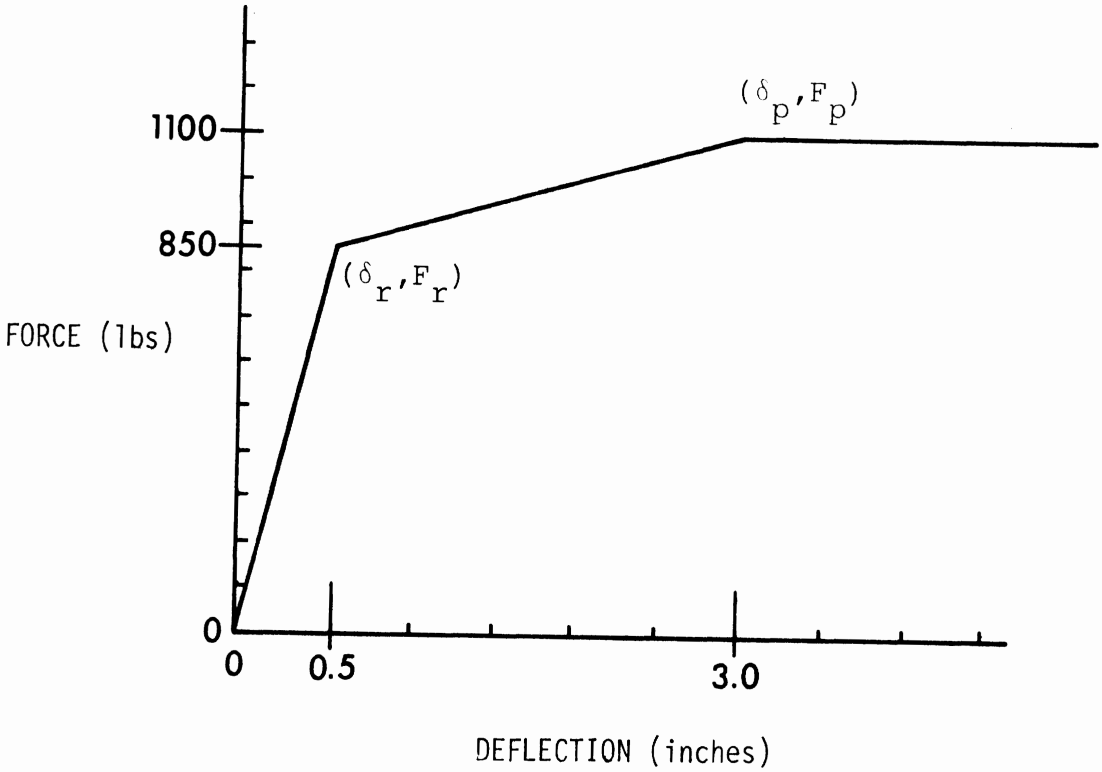


Figure B-10. Idealized Chest Loading Curve the restitution coefficient, or coefficient of elasticity. This is the fraction of total loading energy not lost to hysteretic absorption upon complete unloading. Figure B-9 shows nearly all area (energy) under the loading curve to be lost. Therefore, a value of 0.05 is taken as appropriate if the turn-around deflection is greater than or equal to two inches for unloading from the baseline loading curve. Since all materials are elastic in the limit as deflections approach zero, the restitution coefficient for zero deflection is 1. A value of 0.6 is estimated for a deflection of one inch from curves in the reference. The points and line segments just described define a piecewise-linear representation of the restitution coefficient associated with unloading from the loading curve in Figure B-10, as a function of turn-around deflection.

Scaling of this parameterized chest data to obtain child data was done using techniques discussed and illustrated in Sections C, D, and E. The initial segment of the loading curve is parameterized by its slope and end-point deflection. The slope is a linear stiffness coefficient and was therefore scaled on the basis of the cube root of the body-mass ratio.* The segment lengths δ_r and $(\delta_p - \delta_r)$ were scaled by the chest-depth ratio (See Figure B-10 for δ_r, δ_p, F_r, and F_p). The saturation force level F_p was scaled to be proportional to the value F_r established as the first-segment slope multiplied by δ_r. For unloading, the ratio of permanent deformation to turn-around deflection was held constant at 0.5 for all subjects. Segment end-point deflections for the deflection-dependent restitution coefficient were scaled on chest depth.

4. Hip Properties. There are no data in the literature that are useful for developing a reasonable loading

* The "average adult male" is assigned a body weight of 167 lb and a chest depth of 9 inches.

curve for the hip ellipse. It was found in simulating the dummy drop tests that a hip stiffness of three times the chest stiffness gave predicted pelvis g-levels that were in good agreement with test results. Therefore, quite arbitrarily, hip force-deflection curves for the human subjects were set as three times the chest curves. The permanent-deformation ratio and restitution coefficient were taken as constant, however, both 0.1.

5. Knee-Femur Properties. Proper definition of the loading properties of the knee is difficult for any simulation model that does not have a large number of degrees of freedom. Even then, the task would hardly be easier because of the non-availability of pertinent data. The phenomena that could reasonably be considered in predicting knee-load response to impact include compression of the patella, displacement of the patella, bowing of the femur, and pivoting of the pelvis in response to axially-transmitted femur loads. In the MVMA 2-D model, these phenomena can be represented only through the material properties assigned to a knee ellipse. Their effects cannot be represented by a superposition of force-deflection curves since all require independent degrees of freedom. Deflections of the knee for impacts of the types investigated in this study are expected to be affected most significantly by bowing of the femur resulting from axial and transverse impact loadings at the distal end of the femur and inertial pelvic loadings at the proximal end.

Data are available from which an effective "knee stiffness" can be estimated which will represent resistance to deflections associated with femur bowing. Yamada (1970) presents results reported by Motoshima (1960) for load-deflection curves in bending of wet femur bones of human adults. Curves for bending in the anteroposterior and lateromedial directions are virtually identical. Other data from Motoshima's work allow calculation of length of the femurs tested (ultimate deflection divided by ultimate specific deflection). The load-deflection data for bending, the length data, and the assumption that the bone bends with constant curvature allow calculation of a load-deflection curve for axially-applied end loads that induce bowing. It is also possible to calculate the compressive stiffness of the femur bone from the femur length and data given by Yamada for compressive breaking load (p. 49) and ultimate percentage contraction (p. 20) since the loading curve is shown to be linear to failure (p. 52). Both the bowing and compression curves for axial loading are found to be nearly linear, with slopes of 3751 lb/in and 40,500 lb/in, respectively. Thus, the effective "knee stiffness" for axial loading of the femur was taken to be (3751) x (40500) ÷ (3751 + 40500), or 3433 lb/in.

For transverse loading at the knee, bending of the femur, rather than bowing, is the more appropriate mode for knee-ellipse deflection. Therefore, for loading in this direction, Motoshima's load-deflection curve for femur bending may be used. This curve is less linear than the bowing curve but is reasonably approximated by a linear loading with slope 1251 lb/in.

Thus, the knee stiffness is bounded by 3433 lb/in for knee-impact loads along the line of the femur and 1251 lb/in for knee loads perpendicular to the femur. Femur angles of $\theta = 0°$ and $\theta = 90°$ in Figure B-11 produce these relative loading directions. As there were no means of establishing values of stiffness for impact angles between 0° and 90°, a linear interpolation on θ was arbitrarily used:*

$$k(\theta) = k(0) + \frac{\theta}{90°} [k(90°) - k(0)]$$

for $0 \leq \theta \leq 90°$, where $k(0) = 2 \times 3433$ lb/in and $k(90°) = 2 \times 1251$ lb/in.

* It might also have been reasonable to interpolate linearly on the function $\sin\theta/\sin 90°$.

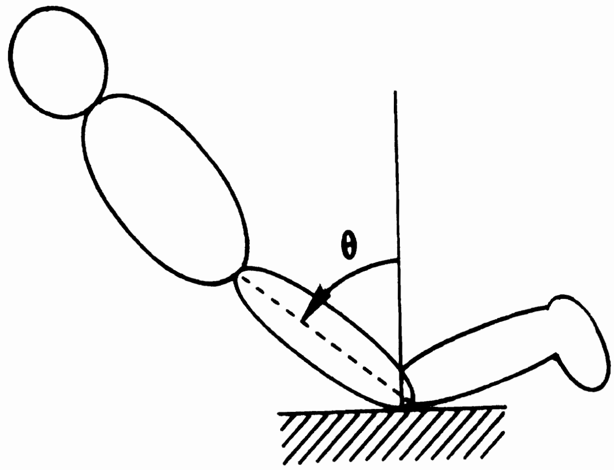


Figure B-11. Femur Contact Angle

Here, factors of 2 are introduced for k(0) and k(90°) since the single knee ellipse in the MVMA 2-D (planar) simulations must produce the combined load for simultaneously striking knees in a real free-fall impact.

It is not possible to prescribe as input to the MVMA 2-D model a material stiffness that has a dependence on impact angle, such as expressed in the foregoing result. Stiffnesses, that is, load-deflection curve slopes, can be prescribed only as functions of deflection. Therefore, in order to make use of the above result for knee stiffness, it was necessary to estimate the femur angled at knee impact for each simulation. This approach was used since it was not practical to make a second run of each simulation using a knee stiffness evaluated with the femur angle θ at knee impact established from a first (trial) run. With the aid of the two test runs, a procedure was developed for predicting the angle θ for both head-first falls and foot-first falls. This procedure proved to be realiable enough in predicting θ so that it was necessary to repeat only two simulations. Error introduced into k (θ) by differences between predicted and actual simulation values for θ are probably not significant in comparison with variance of k(θ) from true human knee-femur stiffness since numerous assumptions were made in establishing $k(\theta)$.

Evaluation of the expression for $k(\theta)$ was considered to give a knee-femur stiffness appropriate for an adult of average size. The weight of such an "average adult" was taken as 147.5 lb., the average of adult male and female average weights, 167 and 128 lbs (Damon, et al., 1971). Stiffnesses for simulation subjects of mass M were then scaled from the value of $k(\theta)$ by the cube root of the mass ratio, $(Mg/147.5)^{1/3}$.

6. Foot Properties. It was explained in Section F that the MVMA-2D model does not have an articulation at the ankle. It was not possible to find torque-deflection data for the ankle that might be used to define an ellipse material that would artificially account for foot articulation. Accordingly, for falls onto the head, the foot stiffness was arbitrarily taken as one-fourth of the scaled knee stiffness at $\theta = 0$ (the smallest value in the range 0° to 90°). These values may be most appropriate for the simulated head falls in which the fall victim landed on the front of his body (Cases 21, 59, 110, and 61) so that foot deflections should have been due largely to articulation at the ankle.

For all simulated foot-first falls, the impact orientation was such that foot articulation at the ankle should not have significantly affected the peak foot load, which was surely transmitted almost directly through the heel. For these falls, it was felt that tibia bowing might be the most significant factor in reasonable representation of the effective foot stiffness. Motoshima's results for bending of the long bones of the lower leg (Yamada, 1970) indicate that the fibula may be neglected in comparison with the tibia, which has a force-deflection curve nearly identical to that for the femur. Since the femur and tibia are also nearly equal in length, the results previously determined for knee-femur stiffness apply for the foot-tibia stiffness; that is, the expression for $k(\theta)$ is applicable and the values determined for $k(0)$ and $k(90°)$ may still be used. However, θ is now interpreted as the lower-leg angle at impact, which is always known as an initial condition for foot-first falls.

H. Falls Onto Soil

In all free-fall cases simulated in this study, the fall victim struck a surface that was unyielding in comparison with any part of the human body. A variety of surfaces were involved, but all could be accurately represented as infinitely rigid for the computer simulations. In order to contrast forces and g-loadings predicted for these falls with the dynamic response for less severe impact conditions, four of the simulations were repeated: first, for a fall surface of "Nevada sand" and, second, for "lawn soil."

In work done to ensure that the landing pads of the Lunar Module used in the Apollo space-flight program had sufficient surface area to support the LM on possibly-soft lunar soil, a series of tests were performed with several kinds of soil (Aero Nutronic, 1965). The firmest soil studied was Nevada sand (120 mesh), compacted to 94 lb/ft^3. The resistance force as a function of penetration depth was determined for spherically-shaped probes of 2.5-inch and 4-inch diameters (D) and for a 4-inch diameter disk. The force-penetration depth curves are shown in Figure B-12. These tests show the resistance force to have a nearly linear dependence on penetration depth and also show the resistance to be nearly proportional to the cross-sectional area of the probe. Thus, the force per unit of penetration per unit cross-sectional area of the probe is nearly constant, independent of both penetration depth and probe area. For penetrations less than

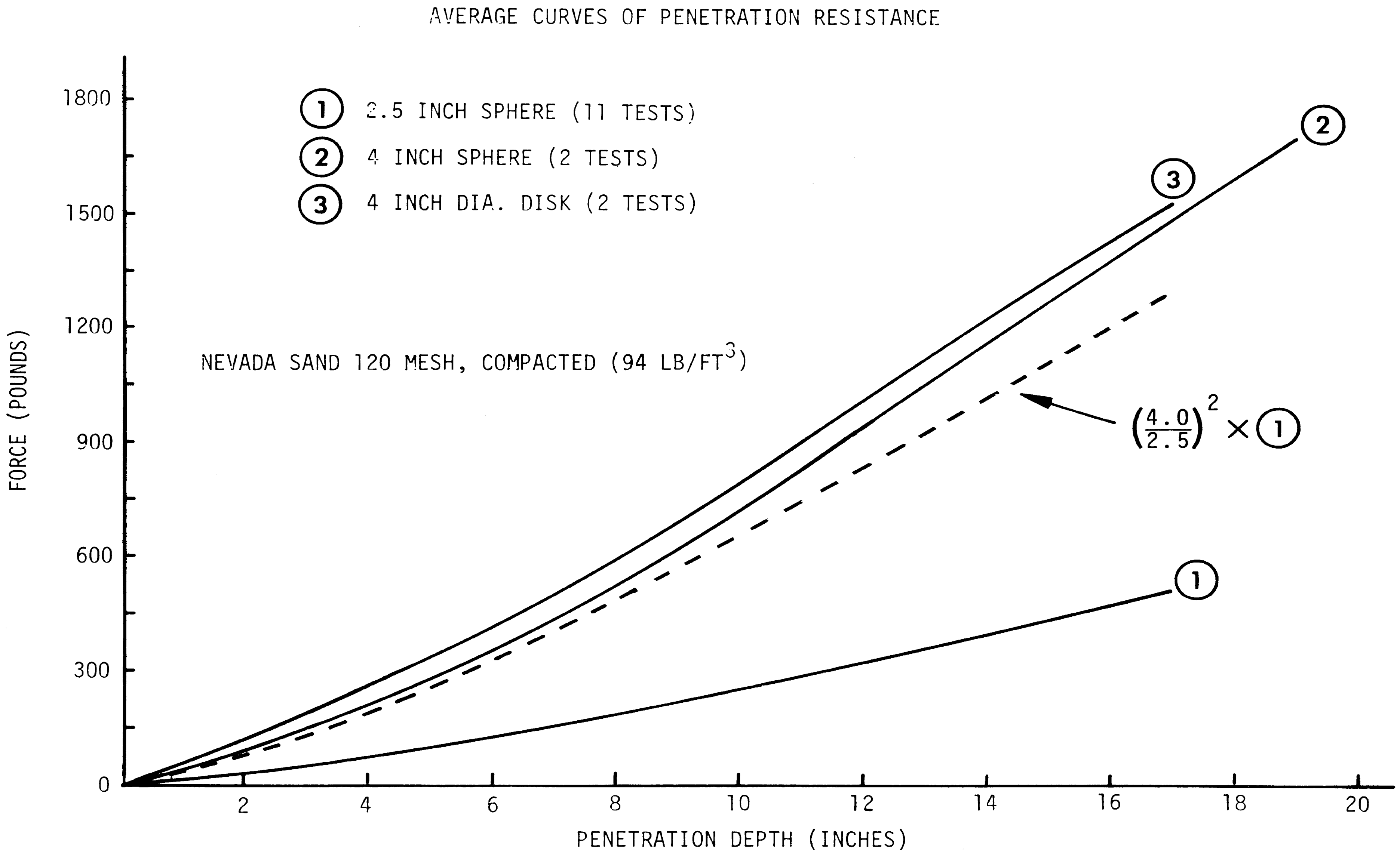


Figure B-12. Force-Penetration Curves for Compacted Nevada Sand about eight inches, the resistance force is reasonably well represented by

$$F_{\text{Nevada sand}} = [5.92 \text{ lb/in/in}^2 \times A] \times \delta$$

where A is the cross-sectional area $\pi D^2/4$ and δ is the penetration depth. The expression on the right-hand side of this relation has the form of a deflection multiplied by a linear stiffness coefficient,

$$k_{\text{sand}} = 5.92 \text{ lb/in/in}^2 \times A.$$

Four simulations were made for hypothetical falls onto Nevada sand. Except for the impact surface, the data sets were identical in every respect to the "preferred-orientation" input data for Cases #21, 59, 61, and 87. These are all head-first falls, and for the soil falls, the impact dynamics were investigated only for the duration for which the head was the only body part in contact with the soil. In accordance with the relations determined above, the effective soil stiffnesses for these four cases were taken to be 5.92 lb/in/in^2 multiplied by estimates of cross-sectional head area for the respective subjects. These estimates were taken as $C^2/4\pi$, where C is the head circumference.

Although Nevada sand was the firmest soil for which directly applicable data was available, it was desired to simulate falls onto firmer soil as well since Nevada sand is much softer than soils that are typically involved in free-fall impacts. Soil penetrometer data from the on-site investigations indicate that typical lawn soil can be expected to be about eight times as "stiff" as sand. Therefore, four simulations for "lawn-soil" impact were made with soil stiffnesses of

$$k_{\text{soil}} = 47.4 \text{ lb/in/in}^2 \times A.$$

Table B-1

Conversion Constants Relating English and SI Units

Length

1 inch = 2.54 cm
1 mile = 1.609 km

Area

1 in^2 = 6.4516 cm^2

Volume

1 ft^3 = 0.02832 m^3

Mass

1 lb = 0.4536 kg

Force

1 lb = 4.4482 N

Load-deflection stiffness

1 lb/in = 1.7513 N/cm

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APPENDIX C

MEDICAL RECORDS RELEASE FORMS

HIGHWAY SAFETY RESEARCH INSTITUTE
Institute of Science and Technology
Huron Parkway and Baxter Road
Ann Arbor, Michigan 48105
(313) 763-3582
THE UNIVERSITY OF MICHIGAN

MEDICAL RECORDS RELEASE

TO WHOM IT MAY CONCERN:

I hereby authorize the temporary release of complete medical records and x-rays concerning my fall on ___________ to Dr. Richard G. Snyder, Head, Biomedical Department, HSRI, The University of Michigan, Ann Arbor, Michigan. This information is for medical research purposes only and will be kept in confidence.

____
(Signature)

____
(Address)

____
(Date)

Figure C-1. Medical Records Release Form - Adult Subject.

HIGHWAY SAFETY RESEARCH INSTITUTE
Institute of Science and Technology
Huron Parkway and Baxter Road
Ann Arbor, Michigan 48105 (313) 763-3582

THE UNIVERSITY OF MICHIGAN

MEDICAL RECORDS RELEASE

TO WHOM IT MAY CONCERN:

I hereby authorize the temporary release of complete medical records and x-rays concerning the fall of ____ to Dr. Richard G. Snyder, Head, Biomedical Department, HSRI, The University of Michigan, Ann Arbor, Michigan. This information is for medical research purposes only and will be kept in confidence.

____
(Signature)

____
(Relationship to Patient)

____
(Address)

____
(Date)

Figure C-2. Medical Records Release Form - Child Subject.

APPENDIX D
HEAD EFFECTIVE MASS

APPENDIX D

HEAD EFFECTIVE MASS

"Effective mass" is the term used for a lumped mass for which dynamic response to impact against a rigid surface will approximate a primary response of a more complex system subjected to the same impact conditions (See Figure D-1). Different definitions are possible. In general, definitions are based on holding constant some basic response parameter. It may be maximum deflection, maximum acceleration, maximum absorbed energy, or some derived paramater such as a Head Injury Criterion (HIC) number.

In this study, effective head masses were calculated on the basis of holding maximum absorbed energy constant. For each of seven subjects for which head falls were simulated with the MVMA 2-D model, discussed in Appendix B, maximum simulated head deflections were noted. The area under the head loading curve to maximum head deflection is in each case the maximum head absorbed energy, which must also equal the maximum absorbed energy and hence the impact kinetic energy of the effective mass. Therefore, the effective head mass may be calculated as the area under the head loading curve in the MVMA 2-D simulation divided by half the square of the impact velocity.

The ratios of head effective mass to total body mass and head effective mass to total head mass were determined for each of the seven subjects. The subjects ranged in age from one to 21, and various impact angles were represented. The two mass ratios were not determined to be sensitive to body orientation at impact*, but apparent relationships were demonstrated between these ratios and total body weight. These are shown in Figure D-2. Since subject 59 was the only adult in this group (age 21), the ends of the curves toward higher body weights are not well established.

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*The range of ratios of effective head mass to total body mass was .13 to .25 with a mean of .183 and a standard derivation of .017. There was no noticeable relationship to impact angle.

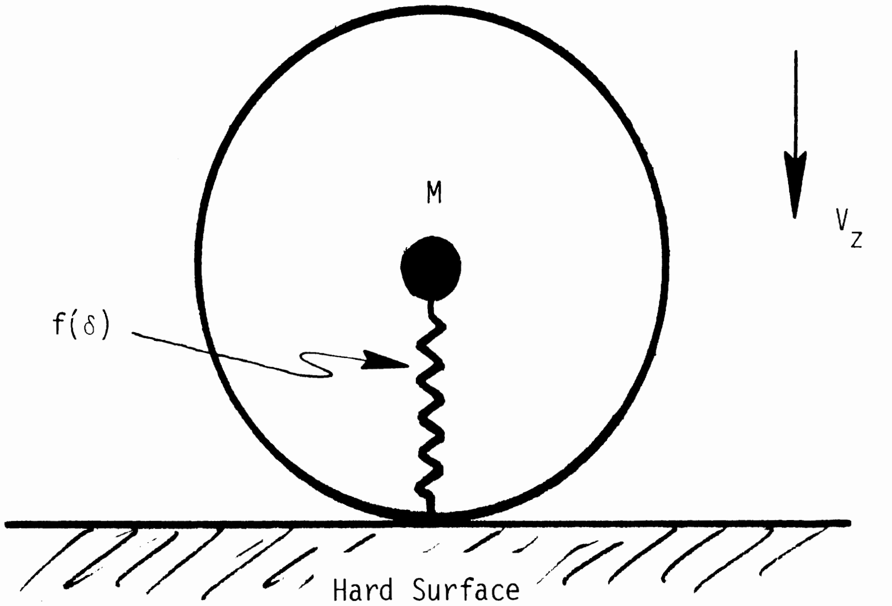

Figure D-1. Lumped Mass M with Head Load-Deflection Relation $F = f(\delta)$

Using these curves to determine head effective mass as a function of either total body weight or total head weight and total body weight, it should be possible to estimate the dynamic response parameters for the head for any subject in a head-first fall with any impact orientation for any impact velocity which results in a maximum deflection for which the head loading curve for such a subject, as developed in Appendix B, is valid. All response parameters of interest are derivable from a computer solution of the simple, single-variable, nonlinear differential equation below:

$$M_{eff}\, \ddot{\delta} = - f(\delta); \qquad \delta(0) = 0; \qquad \dot{\delta}(0) = V_z.$$

Here, M_{eff} is the established effective head mass, $\delta(t)$ is the head deflection, $f(\delta)$ is the nonlinear dynamic head load-deflection relationship for the subject simulated, and V_z is the vertical component of the impact velocity. Response parameters determined from the solution of the differential equation can be plotted against injury measures such as maximum head AIS in order to investigate hypothesized head impact tolerance relationships.

This approach to the establishment of injury tolerances may have great potential because it can be applied with a relatively small amount of effort to any large number of head-first falls for which only impact velocity and weight and age of the fall victim need be known. Effective head mass is determined from a curve in Figure D-2 established from whole-body simulations with the MVMA 2-D model, and head loading curves are easily expressed as a function of age as reported in Appendix B.

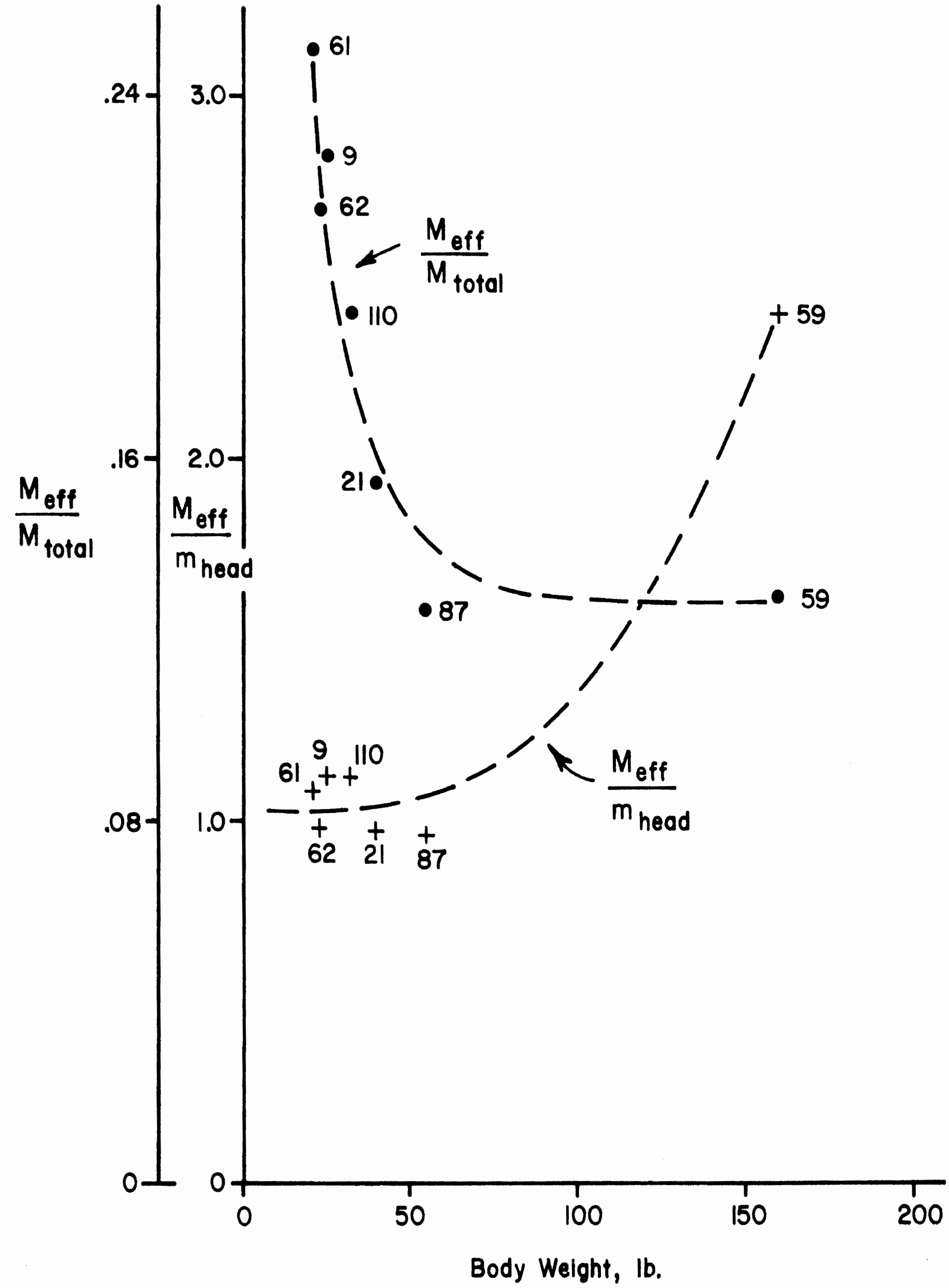

Figure D-2. Relationships between Effective Mass Ratios and Total Body Weight.