9 FACTORS THAT DETERMINE INJURY

THE READINGS:

In Chapter 2 we pointed out that accidents are usually defined as the unexpected occurrence of damage to animate or inanimate objects. We also pointed out: (1) that much of the research concerned with accidents has emphasized their unexpectedness and the factors leading up to their occurrence rather than the nature and prevention of the damaging insults themselves; (2) that this is a very different approach from that successfully adopted in connection with such other pathologies as the infectious diseases; (3) that this difference in approach is not justified by present knowledge; (4) that this emphasis has delayed progress in research and prevention; and (5) that, although "multiple factors" set the stage for accidents to occur, no unexpected injury can take place without the occurrence of one or more of a small number of abnormal energy exchanges which correspond closely to the "agents" of infectious and other diseases.

Viewed in this light, the research discussed in the preceding chapters has been concerned almost exclusively either with the counting of accidents or with the heterogeneous factors which may lead up to their occurrence. Such emphasis would restrict investigation of the characteristics of nutritional diseases to the heterogeneous physical, biological, and behavioral factors which determine diet, or the investigation of poliomyelitis to the factors which lead up to infection with one of the polio viruses. In both these examples, the most effective countermeasures do not stem from such an approach. And in accident prevention this lopsided emphasis has become increasingly indefensible with the development of research concerned with the unexpected insults themselves rather than with the factors leading up to them. Such research is the concern of this chapter.

Injury Specificity

Without exception, all of the forms of energy which may reach the human body can produce injury if either their amounts or their rates of application exceed the corresponding local or whole-body tolerances. This is true whether they are released deliberately or inadvertently. In this respect, also, the forces that are initiated in accidents have their parallels in the infectious disease area, since there too it is the nature and dose of the agent and the susceptibility of the host which determine the resultant disease, not the means, deliberate or inadvertent, by which the agent is brought into action.

The chief forms of energy involved in accidents include the various forms of chemical energy, ionizing and electromagnetic radiation, and mechanical forces performing work (in the physicist's sense of the term). Each of these produces its characteristic type of injury, regardless of the antecedent cultural, social, personal, and environmental causes of the accidents in which it is the cause of injury. The characteristics of the injury are determined by the nature of the energy per se and by the level of body organization at which it is dissipated. For example, in a causal sequence in which bodily damage is produced by ionizing radiation, the primary injury, as is well known to those who are concerned with nuclear accidents, will occur at the cellular and molecular levels, the locus at which the resultant ionization takes place. By contrast, the physical forces which result from the collision of the body with another object, or vice versa, usually result in damage at the tissue and organ levels, and this also holds true regardless of the antecedent causes. Further, in parallel with the specific nature of the lesions produced by the causes of illness, the injuries resulting from the various forms of energy exchange are specific and cannot usually be produced by other means.[1]

If this view of the accident process is foreign to the reader, he should again consider the parallels with the sequences which lead to other types of morbidity. Many and diverse events, for example, may lead to the ingestion of pathogenic microorganisms, and each may be considered a cause of the resultant disease. However, the form of that disease and, in particular, its classification and treatment are determined only by the nature of the pathogens present, and without such agents no such disease can be produced. Precisely the same holds for the various forms of energy as the immediate, necessary, and specific causes of both deliberately and inadvertently initiated injuries, and this will be clearly illustrated later in this chapter.

We have noted that injuries can be produced either by the delivery of above-threshold amounts of energy or by interference with the body's normal energy exchange, metabolism, or physiology. This second group parallels the first in the specificity of the injuries produced and, like the first, may involve either the entire body or only some portion of it. The whole-body case is well illustrated by such antecedent causes as submersion, suffocation, and the inhalation of carbon monoxide and other gases which, through interference with oxygen exchange, produce specific kinds of damage to the entire body. Accidents in which whole-body heat exchange is prevented provide an additional illustration. Finally, local interference with energy transport is excellently illustrated by the specific local results of the various acute interferences with local blood flow, appropriately described by the medical profession as "vascular accidents."*

The Recency of Injury Causation Research

Since the transfer of energy or interference with its exchange is the common denominator of injuries of all types, it might be expected that research would long ago have been undertaken to determine the nature of such interactions and whether injury might be prevented or lessened by their modification. Nevertheless, prior to 1942 there was no literature illustrating work of this type. However, beginning with De Haven's classic paper, published in that year, an extensive and rapidly proliferating literature has developed which, because of its size, can only be sampled here.

The effort represented by this literature often comes as a surprise to those who have not been familiar with this aspect of accident research. Its magnitude is indicated in part by the fact that its cost has already totaled several million dollars in the United States alone, and similar work is under way in a number of other countries. The U. S. Public Health Service by August 1962 had granted approximately $3,600,000 for this purpose,[2] and large expenditures have also been made by other federal agencies and by the aircraft, space, and automotive industries. Such research, however, is still in its infancy, and much remains to be done, particularly with respect to nontransport accidents.

* Many of the points discussed in this chapter, including the specific nature of the injuries produced by the various types of abnormal energy exchanges, are discussed in greater detail in reference 1.

The recency of this research development is especially surprising because the principles involved have been empirically understood and applied for millenia in the development of military devices for protection and offense, and it is ironic that only during the past two decades has there been organized effort to apply these same principles in the prevention of injuries resulting from peaceful pursuits. This lag has resulted in large part from the failure of many accident research workers to recognize as fundamental the problem of injury causation per se. It has also resulted from their substantial lack of familiarity with the significant variables.†

MECHANICAL ANALYSIS OF SURVIVAL IN FALLS FROM HEIGHTS OF FIFTY TO ONE HUNDRED AND FIFTY FEET

—*Hugh De Haven*

Although breakthroughs in science have very frequently resulted from the recognition and investigation of seeming paradoxes, De Haven's work provides one of the very few illustrations of this in accident research. It resulted from his refusal to attribute either to "luck" or to extranatural causes his own survival in a World War I plane crash. As Hasbrook has noted in a subsequent selection, it is remarkable "that although hundreds of combat pilots and observers died as a result of injuries sustained in crashing . . . there is no record of anyone [else] having given any consideration to the direct causes of injury and death in aircraft accidents. . . ." This may have resulted in large part from the tendency of many then as now to attribute the causation of accidents to "bad luck," "acts of God," and similar factors long since rejected in the analytic consideration of other causes of human morbidity and mortality.

DURING THE INTERVAL of velocity change in aircraft and automobile accidents many typical crash injuries are caused by structures and objects which can be altered in placement or design so as to modify the large number of severe and constantly recurring patterns of injury in these accidents. In order conscientiously to approach some of the engineering problems encountered in reduction of the potential injury hazards of windshield structures, seats, instrument panels, safety belts, etc., it was necessary to have some understanding of the limits of mechanical strength of the human body.

The objective in studying the physiologic results of rapid deceleration in the following instances of extraordinary survival—after free fall and impact with relatively solid structures—was to establish a working knowledge of the force and tolerance limits of the body. On the basis of these data certain engineering improvements can be considered for aircraft and automotive design.

Loss of pilots through injury due to the increased landing speeds of military planes has become more and more frequent; this loss and the ever present toll by accident in the automotive field are matters of grave

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† The fact that the medical profession has also largely missed the parallels we are emphasizing here may be due in part to the scant exposure to physics that most physicians have in their medical and premedical curricula.

national concern. Injuries in these fields are mechanical results stemming from localized pressures induced by force and applied to the body through the medium of structure. It is an axiom in the mechanical arts that modification of cause will change results, but the nature and the degree of structural alteration to modify injury to human beings effectively depend on the reactions of the body to abrupt pressure and its distribution. The strength of human anatomic structure and its tolerance of pressure increase are centrally important elements in any proposed increase of safety factors through engineering effort.

Obviously, if the body could tolerate pressure within only narrow limits, few improvements would be worth consideration, since the force and resulting pressure of a severe crash are at best formidable. Evidence, on the other hand, that the body can tolerate the force of an extreme crash —without injury—would indicate that (1) extreme force within limits can be harmless to the body; (2) structural environment is the dominant cause of injury; (3) mechanical structure, at present responsible for recurring injury, can be altered to eliminate or greatly modify many causes and results of mechanical injury, and (4) the greater the evidence of body tolerance of force and pressure, the wider the possibility for considering engineering improvements. Evidence of the extreme limits at which the body can tolerate force cannot be obtained in laboratory tests for obvious reasons, nor can it be gained satisfactorily from most aircraft and automobile accidents, because the variables of speed and angle are difficult to appraise. Estimation of the exact speed of a crash is difficult under most conditions. Also relative movements during structural demolition generally make it impossible to know the position of the body at the time the injuries were sustained and whether the head or some other injured part overtook the structure before it came to a stop or after it had stopped. In these circumstances, the speed, deceleration, impact and force of the body and their relation to the structure can seldom be fixed.

With the thought of overcoming many of these difficulties and in order to observe physiologic reactions to force under more simple conditions, a study of cases of free fall was undertaken. In several of the cases outlined here speed of fall, striking position, deceleration and relation of resultant injuries to structure could be determined with great precision. Other cases are included because of some specific interest or because they are relevant to the cases in which the evidence is clear.

The material is presented with the hope that additional instances of force survival may be closely observed and recorded in order to further an understanding of the strength of the body and the type of structure, position, etc. contributing to force survival.

It is, of course, obvious that speed, or height of fall, is not in itself injurious. Also a moderate change of velocity, such as occurs after a ten-story fall into a fire net or onto an awning need not result in injury, but a high rate of change of velocity, such as occurs after a ten-story fall onto concrete, is another matter. Between these two extremes lies important evidence of physiologic force tolerance.

In using the expression "free fall," a fall free of any obstruction other than that encountered at its termination is implied.

The word deceleration and its derivative decelerative are used in preference to negative acceleration, etc.; "velocity at contact" is preferred to "impact velocity."

The force of gravity—denoted by the symbol g—is used as a measure of the force of a positive or a negative acceleration.

A deceleration exerting a force one hundred and fifty times the normal pull of gravity on a body will increase its normal weight one hundred and fifty times during the time this increase of force acts. Thus, a force of 150 g acting on a man normally weighing 150 pounds (68 Kg.) would increase his apparent weight to

22,500 pounds (10,200 Kg.) during the force interval. This increase of force—and weight—would be distributed over, or applied to, his body as pressure in areas of contact dictated by resisting structure.

The velocities reached in the following cases of free fall are estimated from the acceleration equation $v = \sqrt{(2\ gs)}$, in which the falling object is accelerated by the force of gravity in a vacuum—v being the velocity, g the value of gravity in the acceleration (32 feet [976 cm.] per second per second) and s the distance fallen.

Deductions in velocity made on account of the resistance of the air are rather arbitrary and are estimated on the basis of weight, clothing worn and whether the body was observed to be falling head first, flat or with a tumbling motion. The higher distances of fall are based on an Air Corps technical report.

The estimated forces of deceleration are made from an inversion of the equation for acceleration, $v^2 - 2\ gs$, in which s equals the distance in feet through which a known velocity is decelerated. The resultant expression of decelerative force in pounds must be divided by the force of gravity factor (32 feet per second per second) to give the increase times normal gravity.

Minor contusions and lacerations have been omitted in referring to sustained injuries unless they were of special significance.

Report of Eight Cases

Case 1.—A woman aged 42, 5 feet 2 inches (157 cm.) tall and weighing 125 pounds (57 Kg.), jumped from a sixth floor and fell 55 feet (17 meters) onto fairly well packed earth in a garden plot, landing on the left side and back.

Deceleration and Acceleration of Gravity.—The deceleration distance was about 4 inches (10 cm.) as indicated by marks of the body in the earth. The velocity at contact was 54 feet (17 meters) per second (37 miles [60 kilometers] per hour), and the average gravity increase, 140 g.

Injuries.—There was no evidence of material injuries or shock. Examination of a sample of spinal fluid showed it to be clear and colorless; there were no red cells in the urine. There was no loss of consciousness or abdominal tenderness.

Comment: The superintendent of the building reached the victim immediately after she struck the ground. She raised herself on her left elbow and remarked: "Six stories and not hurt."

Case 2.—A woman aged 27, 5 feet 3 inches (160 cm.) tall and weighing 120 pounds (54 Kg.) jumped from a seventh floor window and fell 66 feet (20 meters) onto a wooden roof, landing head first with progressive contact of the shoulders and the back.

Deceleration and Acceleration of Gravity.—This woman broke through a roof of ¾ inch (2 cm.) pine boards which were supported on 6 by 2 inch (15 by 5 cm.) beams 16 inches (41 cm.) apart and landed lightly on the ceiling below. Velocity at contact was 60 feet (18 meters) per second (40 miles [64 kilometers] per hour). The average gravity increase was unknown. A hole approximately 16 by 16.5 inches (41 by 42 cm.) was sheared in the roof by the force of the fall. Three of the 6 by 2 inch beams were broken.

Injuries.—The scalp was lacerated (occiput), but there was no evidence of other head injuries. The victim suffered abrasions over the dorsal portion of the spine and an oblique intra-articular fracture of the sixth cervical vertebra. There was some spasticity of the abdominal muscles on the right side. Urinalysis yielded normal results. There was evidence of mild shock.

Comment: The fall was first known to have occurred when the woman appeared at an attic door and asked for assistance. She sat up in bed at the hospital later in the day. It is difficult to reconcile the structural damage to the beams with the absence of greater bodily injury in this case.

Another case in which injury occurred under similar circumstances but in which survival was only temporary is summarized as follows:

A man fell 121 feet (37 meters), landing in a supine position on a wooden roof after having jumped from a fourteenth floor. In this case the roof was broken in at one point to a depth of 8 inches (20 cm.), but this point was not directly under the area of force. The average force was undoubtedly in excess of 200 g. The victim walked away from the spot where he landed. His right arm had struck a 12 by 2 inch (30 by 5 cm.) beam and stopped abruptly; the torso had continued in movement, with a resultant tearing action in the shoulder area. There were other injuries. Death was attributed to severance of brachial arteries, hemorrhage and shock. The circumstances in this case are somewhat similar to those in case 2, just described, there being no evidence of loss of consciousness or head injury.

CASE 3.—A woman aged 36, 5 feet 4 inches (163 cm.) tall and weighing an estimated 115 pounds (52 Kg.), jumped from an eighth floor and fell 72 feet (22 meters) onto a fence, face downward.

Deceleration and Acceleration of Gravity.—The distance of the deceleration could not be estimated. Velocity at contact was 65 feet (20 meters) per second (44 miles [70 kilometers] per hour) with minor gravity increase.

Injuries.—There was no evidence of material injury.

Comment: The victim was seen during the fall and landed "jackknifed" over the fence, which was constructed of wood and wire. The fence was broken down part way, and the victim tumbled to the ground. She immediately picked herself up and walked to a nearby clinic for first aid. In this case, chief interest is centered on the patient's having struck a 1 by 4 inch (2.5 by 10 cm.) board, "edge up," at the top of the fence at 44 miles per hour, without essential injury to chest or abdomen.

CASE 4.—A woman aged 30, 5 feet 6 inches (168 cm.) tall and weighing 122 pounds (55 Kg.), jumped from a ninth floor, falling 74 feet (23 meters) onto an iron bar, metal screens, a skylight of wired glass and a metal lath ceiling; she landed face downward, prone.

Deceleration and Acceleration of Gravity.—The decelerative distance must be computed in three stages, combined and confused, totaling 45 inches (114 cm.). The velocity at contact was 66 feet (20 meters) per second (45 miles [72 kilometers] per hour). The average gravity increase was undetermined but was minor except in impact areas.

Injuries.—This woman had minor patterned contusions and an H-shaped laceration on the forehead from the screen wires. All other injuries were minor except in the thoracic area, where there was marked tenderness of the upper ribs on the right side near the anterior axillary line, with slight crepitus. There were slight rigidity of the left side of the abdomen, contusions of the right side of the chest and severe localized ecchymosis 6 cm. above the costal margin. Roentgen examination showed fractures of the fourth, the fifth and the sixth rib on the right side. There had been no loss of consciousness and only moderate shock.

Comment: The fall was witnessed, and there is little doubt that the victim struck a heavy iron bar at the termination of the fall, while speed was substantially 45 miles per hour. The contact was in the thoracic area, with the resultant injury just described. The bar was T-shaped structural iron, 1.5 by 1.5 inches (4 by 4 cm.), 6 feet 6 inches (198 cm.) long and weighing 13.5 pounds (6 Kg.); one end of it was embedded in masonry. The stem of the T was up. There was a fresh, localized bend in the bar 13 inches (33 cm.) deep. That more severe chest and other injuries were not sustained is remarkable, especially in view of the extraordinary demolition of structural steel and glass resulting from the force of this fall.

The woman immediately sat up, rose to her feet and was helped through an adjacent window and given immediate first aid. She was admitted to a hospital and made a rapid, uneventful recovery.

A case in which the conditions of free fall and impact were similar is summarized as follows:

A person fell 100 feet (30 meters) onto a screen with iron supports over a skylight, landing face downward and demolishing these structures. Injuries included fracture of the seventh, the eighth and the ninth ribs on the right side, a right pneumothorax and subcutaneous emphysema; there was moderate shock but no head injuries. At the end of three weeks the right lung was expanded and the patient's temperature was again normal; recovery was uneventful.

CASE 5.—A woman aged 21, 5 feet and 7 inches (170 cm.) tall and weighing 115 pounds (52 Kg.), jumped from a tenth story window, falling 93 feet (28 meters) into a garden where the earth had been freshly turned and landing nearly supine on the right side and back, with the occiput striking the soft earth.

Deceleration and Acceleration of Gravity.—The decelerative distance was a maximum of 6 inches (15 cm.), according to the marks in the earth, which varied for different parts of the body. The velocity at contact was 73 feet (22 meters) per second (50 miles [80 kilometers] per hour), and the minimum gravity increase was 166 g.

Injuries.—This woman fractured a rib on the right side and the right wrist. There was, however, no loss of consciousness and no concussion.

Comment: Several people were standing nearby when this patient struck the ground.

She talked almost immediately and wanted to arise but was not permitted to do so. She entered the hospital, where she remained for twelve days. The earth in the flower bed where she landed had been spaded to a depth of 6 or 7 inches (15 to 18 cm.). The earth packed hard under the force of this fall, and the gravity increase was estimated to have mounted to more than 200 g toward the end of the decelerative movement.

CASE 6.—A man aged 42, of unascertained height and weight, fell 108 feet (32 meters) from a tenth story window and landed on the hood and fenders of an automobile, face downward.

Deceleration and Acceleration of Gravity.—The decelerative distance varied from 6 to 12 inches (15 to 30 cm.) for different parts of the body, and impact due to inertia of the structure was involved. With a velocity at contact of 79 feet (24 meters) per second (52 miles [83 kilometers] per hour) the gravity increases were close to 100 and 200 g without inertia and other consideration.

Injuries.—This man sustained a depressed frontal fracture of the skull, but the immediate cause of this injury was not determined. He had bounced from the car to the pavement. Head injuries observed in like accidents have occurred as a result of bouncing from a decelerative structure to a hard surface.

Comment: This patient survived and is now in good health. Unfortunately, the medical history of the case is not available, but at the time of the accident the patient was reported to have sustained no loss of consciousness, to have slept well, and to have had a good appetite. The force was well distributed except in the area where the fracture occurred.

A case in which the conditions of falling and impact were similar is summarized as follows:

A man fell from the top of a factory building (134 feet [40 meters]), landing face downward on the hood and fenders of a car. The force was not well distributed in the abdominal area. The lower half of the abdomen (below the umbilicus) was strongly supported by the hood of the car; the head and chest struck the fender, which was demolished. There were no material facial injuries and only brief loss of consciousness, with no other indications of head injury from this primary fall. The man bounced from the car to a height of "2 or 3 feet (60 to 90 cm.)" and was observed to land head downward on the pavement after a fall of about 5 feet (152 cm.). There were frontal scalp lacerations at the hair line related to this secondary fall onto the head, and this, in itself, was considered sufficient to cause temporary loss of consciousness. Preliminary roentgen examination showed "a line of decreased density extending upward from the orbital plate close to the coronal suture." The upper portion of the abdomen, i.e., between the thorax and the umbilicus, received little or no support during the deceleration of the speed of this fall, and there was severe shearing stress in this region. There was no apparent intrathoracic injury. The patient died twenty-four hours after the accident, death being attributed to shock. At autopsy no rupture of major internal organs was revealed.

CASE 7.—A man aged 27, 5 feet 7 inches tall and weighing 140 pounds (64 Kg.), jumped from the roof of a fourteen story building, falling 146 feet (44 meters) onto the top and rear of the deck of a coupe and landing in a semisupine position.

Deceleration and Acceleration of Gravity.—The decelerative distance varied, the extreme depth of the dent in the car structure being 8 inches (20 cm.)—about 5 inches (13 cm.) where the head and shoulders struck. The velocity at contact was 86 feet (26 meters) per second (59 miles [94 kilometers] per hour). The gravity increase was not estimated because of the unknown factors of relative movement, inertia of the structure, action of the car springs, etc.

Injuries.—The patient sustained numerous fractures as follows: compound, comminuted fracture of the left elbow; impact fracture of the head and the neck of the left humerus; comminuted fracture through the spine of the left scapula; compression fracture of the seventh and the eighth dorsal vertebra, and fracture through the base of the greater tuberosity of the ischium. He suffered moderate shock but was conscious; there were no chest or head injuries. During the first week in the hospital the abdomen was distended and the patient vomited, probably evidence of some internal injury. In the second week jaundice developed, but otherwise recovery was uneventful. The man returned to work two months later, when the arm was healed.

Comment: The chain of injuries to elbow, shoulder, scapula, and vertebrae indicates that the left arm was subjected to great force, probably before the body was otherwise well supported. It is conjectured that the left arm struck the lower sill of the rear window before the rest of the body struck and dented the roof structure. The suggestion of internal injury may also be related to this abrupt, localized force, or to the "steamer chair" position in which the general force of the fall was taken.

A case in which the position of the body at the moment of impact was similar is summarized as follows:

A woman, who jumped from a seventeenth floor, falling 144 feet (43 meters) in a similar "steamer chair" position, landed on a metal ventilator box 24 inches (61 cm.) wide, 18 inches (46 cm.) high and 10 feet (300 cm.) long. The force of her fall crushed the structure to the depth of 12 to 18 inches (30 to 46 cm.). Both arms and one leg extended beyond the area of the ventilator, with resultant fractures of both bones of both forearms, the left humerus and extensive injuries to the left foot. She remembers falling and landing. There were no marks on her head or loss of consciousness. She sat up and asked to be taken back to her room. No evidence of abdominal or intrathoracic injury could be determined, and roentgen examination failed to reveal other fractures. The average gravity increase was a minimum of 80 g and an average of 100 g.

Case 8.—In this case the history has been reconstructed from a paper by Turner, written in 1919:

The victim of this mishap fell from the top of a cliff 320 feet (96 meters) high. The face of the cliff was "perpendicular from top to bottom" except for a slight projection half way down "which can scarcely be called a ledge for it would be quite impossible to obtain a foothold on it." The beach is described as "an ordinary beach with chalk boulders and a little gravel debris." Turner stated: "Some French laborers were at work on the beach at the time and two of them noticed a falling object against the white of the cliff, saw this strike and bounce from the ledge already described, and hardly realized it was a man until he fell on the beach about fifty yards from where they were working."

The occurrence could be classed as survival of two falls of 160 feet (48 meters) each, the assumption being that the fall was fully checked about midway at the ledge. There is no certainty that the fall was free in the first phase, as the man may have brushed against the face of the cliff prior to striking the ledge. If one assumed that the fall was free after the man bounced from the ledge and if one deducts 50 per cent from the speed of the first 160 foot fall, because of retarding action, the resultant speed would be 41 feet (12 meters) per second as he passed the midway point, equivalent to a fall from 25 feet (8 meters) above.

The velocity on striking the beach can therefore be regarded conservatively, as equaling that of a fall from a height of 185 feet (57 meters)—65 miles (104 kilometers) per hour.

Aside from a large tearing wound of the right knee "where a flap of superficial tissue was torn up on the anterior, external, and posterior aspects of the joint," injuries were largely confined to the scalp where there were "about ten wounds, four of which extended down to the bone."

There was no apparent fracture of the long bones or intrathoracic or abdominal injury. The flap wound was attributed to striking against the ledge in passing, the scalp wounds to stones on the beach. The head struck some object with sufficient inertia to cause a fissured fracture of the skull, and the patient was unconscious for three days.

"The subsequent progress was remarkably good . . . and the only sign of any intra-cranial trouble was . . . slight left facial paralysis . . . with inequality of the pupils, the right being the larger. No further symptoms were noticed, and even these cleared up in a week or ten days."

Turner, in remarking on the comparatively slight nature of the injuries in this case, suggested: "It is just possible that an updraught might have got in beneath the heavy service great coat and exercised sufficient 'parachute' action to considerably break the fall." This, indeed, may have contributed to the result.

The distance of the decelerative action of the beach and the depth of the imprint of the body were not noted. As a decelerative distance of 9 inches (23 cm.) after contact with the beach would limit the gravity increase to 191 g, in view of the other cases in evidence survival can more probably be attributed to the decelerative factor.

Comment

Seven cases of free fall are presented in which the height of the fall was exactly known and the resultant speed conservatively estimated. In estimating the gravitational increases great difficulties stood in the way of exactness. Even in the falls to earth there was variation of the decelerative distance of the fall for various parts of the body; the hand, for instance, might be stopped in a distance of 2 inches, whereas the hips or head might leave a mark 5 or 6 inches deep. In falls to structure these conditions were also greatly confused. A head striking a fender of a car after a long fall might leave a material dent or distortion, but where the feet struck the fender on the other side there might be only a slight mark.

There can be no doubt that gravity increases occurred greatly in excess of those estimated for the cases reported here. In the case summarized in the comment on case 7, in which the fall of 144 feet terminated on a metal ventilator, a typical example is provided of "yield," or "give," in structure poorly designed for the conditions imposed on it. The metal was light and crumpled easily when first subjected to force, but as it assumed its final flattened form, extreme force was required to crumple or flatten it further. It is probable that its resistance induced a gravity increase greatly exceeding 200 g as it took its final form.

Since the blood weighs about twelve times the weight of an equal volume of iron under a force of 100 g and about twenty-five times the weight of iron under a force of 200 g, it seemed probable when this study was undertaken that some progressive sequence of lesions would occur due to hydraulic action of the blood under these excessive conditions. It was thought that these lesions would in themselves serve as some evidence of the force to which the body had been exposed. Absence of evidence of this kind is attributed to the brevity of the force intervals involved in the cases studied.

As distribution and compensation of pressure play large parts in the defeat of injury, it is significant that a deep-sea diver can withstand compensated pressures exceeding 300 pounds (136 Kg.) to the square inch on his body without injury. The pressure rise in the cited cases of velocity change was not high, but it was abrupt and was sustained on one side of the body only. Absence of greater injury in the pressure areas or at their edges and larger indication of bursting effect and injury by distortion is noteworthy.

Two of the cases summarized relate to pure deceleration; 2 represent extensive structural demolition with survival injuries, and 2 others relate to striking specific objects with great destructive force and minor injury.

In cases 1 and 5 the falls were to earth, where the deceleration began without great impact and the decelerative distance could be accurately observed by the marks of the body.

In cases 6 and 7 the falls were onto automobiles, where the force of the body demolished mechanical structure without excessive injury to the body. These decelerations included inertia and other factors which made the deceleration uneven and, in parts, extreme.

In case 2 the force of the fall demolished the roof planking and broke three 6 by 2 inch beams, with only one skeletal fracture and little other injury.

In case 3 a wooden fence was demolished by some anterior portion of the chest or abdomen, with trivial injury.

In case 4 a 1.5 by 1.5 inch structural T-shaped iron bar was bent 13 inches by the anterior portion of the chest, without extensive traumatic result. In this case the circumstances closely resemble those in instances in which a pilot is thrown through an instrument panel, bending and breaking tubular bracing structure, with minor facial and thoracic injuries.

The injuries in cases 1 through 7 can be summarized as follows:

1. There was no skull fracture or concussion in case 1, 2, 3, 4, 5 or 7.
2. Intrathoracic injury was not in evidence in any case.
3. There was no indication of material internal injury in case 1, 2, 3, 4, 5 or 6.
4. Fracture of the long bones of the arm occurred in 1 case only.
5. There was no fracture of the long bones of the legs in any case.
6. Damage to the rib cage occurred in case 4, in which the localized force was high because of the limited area of contact with the iron bar.
7. Pelvic fracture was lacking in all cases except for the fractured tuberosity in case 7.
8. The chain of injury in case 7 to the arm, shoulder, scapula, and vertebrae and the cause have already been referred to.
9. One other vertebral injury occurred, in case 2, an injury of position.

Any of the foregoing injuries can be substantially duplicated in a 5-foot (152 cm.) fall. In correlating the aforementioned injuries with those incurred in many aircraft and automobile accidents the direct relation of force to decelerative distance must be constantly considered. A person who escapes in a high speed crash, fatal to many others, owes his life to some decelerative interval and to a favorable distribution of pressure.

It should be borne in mind that the decelerative distance of an airplane, crashing at a speed of 120 miles (192 kilometers) per hour is seldom limited to a distance of 4 feet (122 cm.) except in the demolished frontal areas. If the pilot's position is to the rear, 4 feet of deceleration will limit the force at this point to an average of 121 g. The average 50 miles (80 kilometers) per hour crash of an automobile usually involves a stopping distance greater than 2 feet (60 cm.) and the passengers could be limited to a gravity increase of approximately 44 g if they were in contact with or otherwise related to the structure. A slip on the street, however, where the head strikes the hard pavement may induce a gravity increase exceeding 300 g because of the small decelerative factor involved. Here the force is highly localized both in time and in area, and the results are often fatal. It is significant that crash survival without injuries in aircraft and automobiles occurs under conditions which are seemingly extreme and that fatal injuries are often sustained under moderate and controllable circumstances.

The mechanical causes of injury and the engineering possibilities for protection are beyond the scope of this paper. It is sufficient to state that the cases reported or summarized here present physiologic evidence of well-known mechanical and physical laws; that the primary causes of injury—impact and localization of force—are defeated when distributed in distance (time) and area (space), and that the brevity of the force interval and compensation of pressure can yield amazing results accidentally or when converted to safety purposes through engineering.

The fact that these survivals occurred when the necessary factors were accidentally contributed is strong evidence of the large increase in safety which can be provided by design.

Conclusions

The human body can tolerate and expend a force of two hundred times the force of gravity for brief intervals during which the force acts in transverse relation to the long axis of the body.

It is reasonable to assume that structural provisions to reduce impact and distribute pressure can enhance survival and modify injury within wide limits in aircraft and automobile accidents.

De Haven's work provided strong evidence: (1) that the human body is far less fragile than had generally been believed; (2) that the "structural environment is the dominant cause of injury"; and (3) that "mechanical structure . . . can be altered to eliminate or greatly modify many causes and results of mechanical injury."

It is interesting that Hippocrates recognized clearly the same relationship between structure and injury, although his discussion of this seems not to have been known to De Haven. Writing *c.* 400 B.C., in his treatise on head injuries, he stated:

> Of those who are wounded in the parts about the bone, or in the bone itself, by a fall, he who falls from a very high place upon a very hard and blunt object is in most danger of sustaining a fracture and contusion of the bone, and of having it depressed from its natural position; whereas he that falls upon more level ground, and upon a softer object, is likely to suffer less injury in the bone, or it may not be injured at all. . . ."[3]

At the time of Hippocrates, penetrating injuries had long been produced by spears and other hard, pointed, and edged objects empirically designed to dissipate their relatively small amounts of kinetic energy in such small areas that local injury thresholds were exceeded. In fact, his awareness of this is clearly indicated by his discussion of weapon design in relation to the type of injury produced. This includes the statement that "weapons of an oblong form, being, for the most part slender, sharp, and light, penetrate the flesh rather than bruise it, and the bone in like manner. . . ."[3] He was also undoubtedly familiar with the reverse principle reflected in the design of shields and other protective gear to dissipate incident energy both in space and in time—an approach with many parallels among contemporary devices designed to prevent injury.*

THE HISTORICAL DEVELOPMENT OF THE CRASH-IMPACT ENGINEERING POINT OF VIEW

—A. Howard Hasbrook

This paper presents an excellent introduction to the remarkably diverse and complex research that has stemmed largely from De Haven's work. Although this paper appeared in 1956, the present state of this field is very similar and progress has continued along the lines discussed. The situation is not, however, as happy as Hasbrook indicates. For example, persons continue to be killed in what he appropriately refers to as "survivable" aircraft crashes, because their seats tear loose from their insufficiently strong anchorages and because footrests and seat backs are not adequately designed to absorb energy and thus cushion the impact of the bodies of the passengers seated behind them.[4]† Many are being killed and injured in late-model domestic and foreign automobiles lacking both pertinent safety features which are optionally rather than routinely installed and others not yet available. Motor vehicles are not being constructed to crash safely under the operating conditions for which they are designed despite the foreknowledge that substantial percentages of those produced will at some time be involved in such accidents.[6] And progress "in the design of objects in the factory, the office, and the home" leaves much to be desired.

* There is a general principle that as the amount of incident energy—and, hence, the amount to be dissipated—increases, devices for protection must act at loci farther and farther from the body. This is illustrated, for example, by the progression from body armor to armored tanks to anti-missile missiles. This also holds for the energy released in accidents, and the papers in this chapter provide several illustrations of this. Further, where protection is not feasible at the necessary distance, the only alternative is to prevent the initiating events, inadvertent or otherwise, from taking place. It is curious that this principle and its implications appear not to have been previously recognized.

† The conclusions of the report in reference 4 include the statements that:

1. The predominant cause of fatal injuries in this accident was chest impingement against non-yielding structure of seat back and/or seat frame.
2. The high percentage of leg fractures can be directly attributed to the aft lateral beam of the seat frame. Although not considered a dangerous-to-life injury, it may prevent timely evacuation of the wreckage.
3. The relatively low occurrence of serious head injury indicates that considerable progress has been made in the protective design of service trays and seat-back webbing.
4. Full protection [by] adequate seat belt restraint in forward facing configurations can be realized only when all environmental structure, with which the occupant invariably will come into contact, is designed to take bodily impact without inflicting serious injury. [This also holds for automobile and truck design. Eds.]

A report by Pearson is also of interest in this context. It concludes that "crucial injuries . . . stem from flailing of the body against injury producing structure within the occupant's environment."[5]

A general distinction is sometimes made between such "energy-storing" materials as foam rubber, which tend to produce a substantial rebound effect, and "energy-absorbing" materials, such as some of the urethane foams, for example, which do not. Energy-absorbing materials are preferred for crash protection.

PROTECTION FROM the injurious effects of "crash impact" originated when man, during the dawn of history, first fashioned a raw-hide shield to protect himself from the clubs, the spears and the arrows of his enemies. From that time until only recently, engineering consideration for designed protection from accidental injury or death was confined almost exclusively to the field of warfare.

The Vikings, for example, used protective head gear and shields; shields, which, when not carried individually, were placed on the sides of their boats for protection during shore attacks. Again, in later history, metal helmets, chain mail and shields were used . . . for protection against injury in combat. Later, during the invasion and the conquest of Mexico, metal breastplates and helmets were worn by the Spanish conquistadors for protection from "crash impacts" of sword points, bullets, spears and arrows.

However, during periods of the Revolutionary War and the Civil War the need for individual personal protection was largely lost sight of, probably due to the need for operational freedom and mobility of the foot soldiers. However, the relatively low power and inaccuracy of the rifles and the pistols used at that time kept the casualty rate at a "reasonable" figure.

Moreover, up to and including the Civil War, the majority of deaths were due to disease. In relation to the catastrophic effects of the plagues and the epidemics that raged throughout the continents of the world, serious injury or loss of life resulting from the use of transportation media available during these years was of minor extent and importance.

However, many injuries and deaths were caused by persons being thrown from horses, chariots, wagons, carriages and even early steam trains. But most of these incidents were looked upon by a superstitious populace as being the result of "bad luck" or acts of God. This reliance on "luck" apparently stifled any development of safety engineering or design for the protection of human life in accidents.

In addition, transportation media, and in particular the horse, did not lend themselves too well to designing for protection from injury in accidents. It is doubtful, for example, that anyone would have seriously considered tying himself to a saddle on a horse for protection against being thrown off, for it was essential, safetywise, to be able to throw one's self clear if the horse should fall accidentally.

Development and use of the gasoline engine in motor cars provided transport at higher speeds and thus created both a greater exposure to accidents . . . and also a greater exposure to severe and fatal injury, due to the velocity of impact.

* * *

Later, aircraft increased the exposure to injury in accidents by virtue of their higher speeds; the force of gravity acting on an airplane falling from a great height also tended to increase the force of impact.

Exposure to serious injury and death was also intensified in early aircraft because the occupants, in most cases, were located in the forward and most vulnerable end of the vehicle. Since these early aircraft were fragile and extremely liable to accidents, due to inadequate control and aerodynamic design, injury and death rates were high. Despite the obvious need for "tying in" the occupant, it was not until just prior to World War I that safety belts were first installed in aircraft, and soon became standard equipment in military aircraft. The need for tying the occupant to his vehicle was demonstrated vividly when Lieutenant Towers, who later became an admiral in the Navy, lost control of his aircraft and was thrown out of his seat in mid-air. Fortunately, he was able to grasp a portion of the airplane and thus was able to hang on until it crashed; he was seriously

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injured. The other occupant was reported to have been fatally injured.

However, installation and use of safety belts was based only on the need for restraining the occupants from falling out of the aircraft in turbulent air or during acrobatic maneuvers. Little or no consideration was given, up to that time, to the possibility that the safety belt might protect occupants from injury or death in a crash. In fact, many pilots would unfasten their safety belts if they knew they were going to crash because they feared that the safety belt might cut them in half. Many pilots felt that they had a better chance of surviving if they were thrown clear of the aircraft. Since postcrash fires were quite prevalent, it is possible that some did survive by being thrown clear.

A paradoxical point in the study of the development of crash-injury concepts was that the human body had been erroneously considered as a rather fragile object, and that protection from injury or death could be obtained only by preventing injury-producing accidents. Thus, accident prevention became the prime consideration in safety thinking and action.

However, the idea that the opposite was the case evolved in the mind of a young flying cadet who was involved in a mid-air collision in Canada during the latter part of World War I. In the resulting crash of two aircraft, this cadet, an American named Hugh De Haven, was the only survivor. During the following months in the hospital, De Haven kept asking himself "Why did I survive when all the rest were killed?" Later on he inspected the wreckage of the two aircraft and found that, of the 4 cockpits, his alone had remained relatively intact. Although most of his friends attributed his being alive to luck, De Haven felt that the intactness of the cockpit structure was the answer; thus was born the first concept of "crashworthiness."

It is worthy of note that although hundreds of combat pilots and observers died as a result of injuries sustained in crashing their disabled aircraft — not from gunfire wounds—there is no record of anyone, other than De Haven, having given any consideration to the direct causes of injury and death in aircraft accidents from an engineering point of view.

After the war, during the '20s, De Haven's interest in impact injuries was heightened by newspaper accounts of so-called "miraculous" escapes from death of persons who had attempted suicide or had fallen from great heights. As more and more information was gathered on these cases, the fact gradually emerged that free-falling humans often escaped serious injury or death if their velocity was partly checked by their striking some light, frangible structure, such as a strong clothesline. Also effective for survival was their final impact in a supine or prone position on an object sufficiently "soft" to bring them to a stop through a relatively long distance, such as would occur when falling into a fire net, onto a light sheet metal duct or soft rubble.

De Haven's insistence that these miraculous escapes were not miracles at all but were due to known physical laws relating to force per unit area (psi) received little consideration. In some quarters, De Haven was even looked upon as a "crackpot." But he continued his studies on the phenomena associated with survival in free falls and, in addition, his attention was directed to injuries sustained in light-plane accidents.

The results of these studies of small-plane accidents indicated that much could be learned about the direct causes of injury and, even more important, the reasons for survival under extremely severe conditions of crash force. Thus was born a new concept, and a new profession—crash-injury research and crash-survival design engineering.

Impetus was given to crash-injury studies of small-plane accidents when De Haven became associated with Dr. Eugene D. DuBois at the Cornell University Medical College in New York in 1942; with the moral support of the Civil Aeronautics Administration and a small fund from the

National Research Council, a statistical study of injuries and their causes in aircraft accidents was initiated.

During World War II, De Haven, in cooperation with Dr. William Geohegan of the Cornell University Medical College, began experimenting with a device, later known as the inertia reel, which, used in combination with two vertical chest straps, would automatically restrain the torso and the head from flailing forward and striking rigid equipment in the cockpit. The development of this device had been due to the results of research studies which showed that most of the serious injuries sustained in aircraft accidents were confined to the head and the upper torso. Puncture wounds of the heart and the lungs, induced by penetration of fractured ribs, and *brain damage associated with and without skull fracture* were prominent results of accidents. Of particular interest was the fact that these types of injuries not only were sustained in completely disintegrated aircraft but also had occurred numerous times in cockpits and aircraft cabins which had sustained little damage. Studies of these latter type accidents, later to be termed "survivable" accidents, also proved that the so-called "dangerous" safety belt did *not* cut people in half. The studies showed further that, when decapitating wounds of the lower torso *had* occurred, they had been sustained in accidents in which the entire aircraft structure had been completely demolished; decapitation, it was shown, had been due to striking lethal objects such as jagged metal skin and fragmented, rigid wing and fuselage wreckage.

In the meantime, some farsighted individuals in the Bureau of Medicine and Surgery of the U. S. Navy and in the Surgeon General's Office of the U. S. Air Force became interested in crash-injury research as a possible means of reducing the casualty rate in the military services. Accordingly, a small contract through the Office of Naval Research was made with Cornell University Medical College to carry on De Haven's studies of injuries in accidents. During the next 5 years, the Cornell group, consisting of a medical analyst, a stenographer, and De Haven, studied small-plane accident injuries.

To obtain information relating to the accidents concerning impact speeds, angles of impact, damage to the aircraft structures, and the medical histories of the occupants, special accident and injury forms were devised; since the Civil Aeronautics Administration was unable to provide anything more than token support (because the Civil Aeronautics Act did not provide for investigation into the causes of injuries—only the causes of the accidents), assistance of a few highly motivated state police and state aviation groups was obtained to conduct the investigations, complete the report forms and send them to Crash Injury Research for study.

Concurrent with these studies, the Cornell group developed a special punch card system and code for the coding of accident and injury data; a special injury scale, by which injuries could be assessed in relation to their seriousness from an engineering point of view, was also devised. This injury scale, which rates injury seriousness in relation to its danger to life under conditions of prompt and adequate medical care, proved to be of great value, providing much more information than the "loose" terms commonly used, such as "serious" and "fatal" [see end of reading for Av-CIR Injury Code]. The scale is divided into 10 parts, the last 4 of which are fatal. From an engineering point of view, with respect to design for survival, it is necessary to know the degree of death, i.e., whether 1, 2, 3 or more areas of fatal lesion had been sustained in combination with other nonfatal injuries.

During this phase of Cornell's crash-injury research studies, other groups and individuals became interested in impact injuries, particularly in relation to accidents involving military aircraft.

The work of Lieut. Col. John P. Stapp (USAF) in developing and operating a high-speed sled for studying high deceleration effects on human subjects is well known. Stapp's work, involving much personal courage, has added immensely not only in arousing world-wide interest in impact injuries but also in producing invaluable data for design engineers.

Two other military groups—the USAF's Directorate of Flight Safety at San Bernardino, Calif., and the U. S. Navy's Aero Medical Equipment Laboratory at the Naval Air Materiel Center in Philadelphia, Pa., began to investigate the human-factors phase of aircraft accidents and produced information which showed that the human body could withstand, without serious injury, crash force of extremely high magnitudes, provided that crash-survival design concepts were utilized in the design of cockpits and restraining gear.

Other individuals and groups who began to sense the importance of studying the phenomena of crash-impacts and resulting injuries were William Stieglitz of Republic Aviation Corporation, A. M. Mayo, John R. Poppen and Stanley Lippert of Douglas Aircraft Company, Herman P. Roth and Charles F. Lombard of Protection, Inc., the USAF's Air Research and Development Command, the Aero Medical Laboratory, and the Cornell Aeronautical Laboratory, to name only a few.

By 1950, as a result of this progressive interest of an increasing number of engineers and safety people in the aviation field, a number of aircraft contained numerous features originally advocated by De Haven's group. Forty G cockpits in fighter aircraft, lightweight, frangible (delethalized) instrument panels, control wheels and tilting seatbacks—the last to protect the heads of persons in passenger cabins—were becoming standard equipment. Shoulder harness, which had proved itself of value during the latter part of World War II, also was being considered for light planes. Such terms and phrases as "crashworthiness," "survivable" and "nonsurvivable" accidents and the word "deceleration" became routine jargon of the industry.

Aside from military aircraft, increased crashworthiness also was being designed into some light planes by strengthening of the cockpit and the cabin structures, providing keel-like lower structures in the bellies of light twin-engine planes, and moving the occupants further back in the airplane.

As the beneficial effects of crash-survival design in aircraft were becoming apparent, safety people in the automotive industry began to wonder whether this same design principle might not help to reduce the extent and the dangerousness of injuries sustained in automobile accidents.

Cornell's Crash Injury Research project turned part of its attention to the automobile accident-injury problem and initiated a research program in co-operation with the Indiana State Police. Following Cornell's lead, other groups and individuals soon turned their attention to this phase of highway safety. This program resulted in the growth of an almost nation-wide study of automobile accidents by many state police groups in co-operation with state medical associations, public health organizations and other safety groups.

The Traffic Institute of Northwestern University, the Institute of Transportation and Traffic Engineering at the University of California, The National Safety Council, Dr. Ross MacFarland of the Harvard School of Public Health, Motor Vehicle Research at Boston, Mass., the U. S. Army's Human Engineering Laboratory, and insurance companies were but a few who saw promise in designing for crash-survival.

Researchers in various parts of the country also began thinking about the use of safety belts and shoulder harnesses in automobiles; others were discussing the need for the crash testing of automobiles with dummies. Doctors in the medical research field, such as E. S. Gurdjian, J. E. Webster, H. R. Lissner and Jacob Kulowski began studying skull and skeletal fractures and brain injury. Scientists working under Edward Dye at the Cornell Aeronautical Laboratory began studying the kinematics of dummies subjected to decelerative forces and the forces necessary to fracture simulated skulls when propelled against various structures.

At the same time, De Haven and the author, who had joined the Cornell project in 1950, were endeavoring to interest the National Advisory Committee for Aeronautics in crash testing some small aircraft in order that decelerative loads imposed on the aircraft and their occupants under survivable crash conditions could be measured.

The NACA conducted these tests in 1953, and the results astounded safety people throughout the aviation industry. Loads of 30 G had been measured in these survivable test crashes of small, lightweight planes. Of even greater importance was the fact that crash-injury records showed that many persons had survived such crash loads with little or no serious injury. These data, plus that derived from many free-fall cases, also served to bolster De Haven's contention that the human body could survive impact decelerations as high as 200 G without dangerous injury if adequate restraint and delethalization could be provided.

NACA's small-plane crashes also paved the way for later crash test programs of military fighter, bomber and civil transport aircraft. From these tests data have become available which will permit engineers to protect people more fully—by design—against the effects of impact loads imposed in survivable type accidents.

Early in 1950, Cornell's Aviation Crash Injury Research project centered its primary investigative attention on civil transport crashes. The resulting crash-survival studies on the Northeast Airlines' Convair 240 accident at La Guardia Airport, New York, and National Airlines' DC-6 crash at Elizabeth, N. J., interested safety engineering groups in the United States and abroad.

Both of these survivable crashes provided proof of the advantages of the crash-survival design features which had been built into these 2 transports and their seats—features which had resulted from crash-injury data obtained from small-plane accidents.

Under the author's directorship, the Cornell Aviation Crash Injury Research project, while continuing to study crashes of civil transports, now co-operates with safety groups of the U. S. Navy, the Air Force and the Army, the Civil Aeronautics Board, the Civil Aeronautics Administration, and various other national and international groups, airlines and manufacturers. Each year sees a widening interest and understanding of the benefits that can be derived from crash-survival design.

An indication of the increasing awareness of the importance of this subject is shown by the fact that the Civil Aeronautics Administration revised its manual of procedure in 1955, wherein CAA safety agents now conduct crash-injury investigations on all survivable crashes involving aircraft in the nonairline category. These data are forwarded by the CAA to Cornell's Av-CIR for study.

Also, the National Advisory Committee for Aeronautics, for the first time in its history, organized a subcommittee devoted solely to flight safety. A large portion of this committee's work is involved with the problems of survival in relation to crash-impact.

The Airline Pilots Association—as a matter of policy—endorsed the need for, and the use of, shoulder harness for all airline cockpit crew members.

Seat manufacturers, both in the United States and abroad, are giving extensive consideration to providing greater safety through improved delethalization and better "tie-down" of the seats. Airframe manufacturers are endeavoring to integrate the seats with better hull and floor structures.

Consequently, the jet liners of tomorrow will contain a degree of crash safety unthought of 15 years ago.

In the automotive field, automobile manufacturers also are giving attention to designing for impact protection. Many items, such as safety belts, improved door latches, padded dashboards and visors, and energy-absorbing steering wheels, now offered in most cases as optional equipment, undoubtedly will become standard equipment on new model automobiles. This advancement in safety design in future automobiles will reduce drastically the high incidence of serious and fatal injury on our highways.

In effect, in the 14 years between 1942 and 1956 a new engineering field has been created, namely that of *crash-survival design engineering*. Undoubtedly, this subject will increase in importance as its value becomes more widely recognized. Thus, it is only a question of a short time before it will be taken up by universities and integrated into their design engineering courses. Once at this point, it can be expected that crash-survival design will increase rapidly in its application; perhaps it will show its effect in the design of objects in the factory, the office and the home which cause serious and fatal injury to people in accidental falls.

Only a brief glance at the number of serious and fatal injuries sustained by persons falling in showers and bathtubs points to the need of designing certain portions of our natural environment to protect the human body from injurious impact during "routine" accidents.

Degrees of Injury*

Terminology Used in Crash Injury Research

†	‡	
1	1	*Trivial* or *None*
4	2	*Minor* "Minor" contusions, lacerations, abrasions in any area(s) of the body. Sprains, fractures, dislocations of fingers, toes, or nose. Dazed or slightly stunned. Mild concussion evidenced by mild headache, with no loss of consciousness.
15	3	*Moderate*—but not dangerous. "Moderate" contusions, lacerations, abrasions in any area(s) of the body. Sprains of the shoulders or principal articulations of the extremities. Uncomplicated, simple or green-stick fractures of the extremities and jaw. Concussion as evidenced by loss of consciousness not exceeding 5 minutes, without evidence of other intracranial injury.
28	4	*Severe*—but not dangerous. Survival normally assured. Extensive lacerations without dangerous hemorrhage. Compound or comminuted fractures, or simple fractures with displacements. Dislocations of arms, legs, shoulders or pelvisacral processes. Fractures of facial bones. Fracture of transverse and/or spinous processes of the spine, without evidence of spinal cord damage. Simple fractures of vertebral bodies of the dorsal and/or the lumbar spines, without evidence of spinal cord damage. Compression fractures of L-3-4-5. Skull fracture without evidence of concussion or other intracranial injury. Concussion as evidenced by loss of consciousness from 5 to 30 minutes, without evidence of other intracranial injury.
45	5	*Serious*—dangerous, but survival probable. Lacerations with dangerous hemorrhage. Simple fractures of vertebral bodies of the cervical spine, without evidence of spinal cord damage. Compression fractures of vertebral bodies of dorsal spine and/or of L-1 and L-2, without evidence of spinal cord damage. Crushing of extremities, or multiple fractures. Indication of moderate intrathoracic or intra-abdominal injury. Skull fracture with concussion as evidenced by loss of consciousness from 5 to 30 minutes. Concussion as evidenced by loss of consciousness from 30 minutes to 2 hours, without evidence of other intracranial injury.
66	6	*Critical*—dangerous, survival uncertain or doubtful. (Includes fatal terminations beyond

* **Based on observations during first 48 hours after injury and previously normal life expectancy.**
† Weighted value for degrees of total injury.
‡ Degrees of total injury.

24 hours). Evidence of dangerous intrathoracic or intra-abdominal injury. Fractures or dislocations of vertebral bodies of cervical spine with evidence of cord damage. Compression fractures of vertebral bodies of dorsal spine, and/or L-1, L-2, with evidence of spinal cord damage. Skull fracture, with concussion as evidenced by loss of consciousness from 30 minutes to 2 hours. Concussion as evidenced by loss of consciousness beyond 2 hours. Evidence of critical intracranial injury.

91 7 *Fatal*—within 24 hours of accident. Fatal lesions in single region of the body, with or without other injuries to the 4th degree.

120 8 *Fatal*—within 24 hours of accident. Fatal lesions in single region of the body, with other injuries to 5th or 6th degree.

153 9 *Fatal*
Fatal lesions in 2 regions of the body, with or without other injuries elsewhere.

190 10 *Fatal*
Fatal lesions in 3 or more regions—up to demolition of body.

HUMAN TOLERANCE TO DECELERATION
—*John P. Stapp*

Retrospective studies of the forces which result in accidental injuries are necessarily lacking in precision since it is usually impossible to reconstruct accurately all the pertinent force configurations. For this reason and because of the need for such information for crash design and other purposes, a series of animal and human experiments was undertaken by Stapp and his colleagues, often at considerable personal risk. These confirmed "the high tolerance to abrupt deceleration" documented by De Haven and provided considerable quantitative information as to the injury thresholds of the types of subjects studied. The resultant data have provided much of the basis for such preventive measures as crash padding and safety belts and harnesses. In addition, they have given designers of spacecraft essential information relative to the maximum rates of velocity change tolerable by human and other passengers.*

IN MILITARY AVIATION the loss of life, incidence of total disability, and time loss justify research on the safety and salvage aspects of accidents. Safety relates to all factors preventing or reducing the occurrence of accidents; salvage is concerned with preventing or reducing the consequences of accidents. One aspect of the salvage problem considers the relationship between force characteristics and their biologic effects, a field of research which has been designated as biodynamics. Motion at high speed involves a risk of accelerative or decelerative forces of rapid onset, great magnitude and comparatively brief duration, capable of injurious or lethal effects

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One figure has been omitted.

* An increasing literature is concerned with experiments designed to determine human injury thresholds. A recent report of Gurdjian *et al.*,[7] for example, describes experimental impacts of instrumented cadavers with automobile glass, and gives entry to a portion of this literature. The last selection in this chapter and other work[8] provide additional information.

to living organisms. By applying known increments of mechanical force to experimental subjects, a dynamic stress analysis can be accomplished to limits of tolerance, defined by signs of reversible incapacitation, or of survivable injury or up to lethal effect. Two main lines of application for this research have existed to date: protection from forces incurred in aircraft crashes, and tolerance to conditions of escape from aircraft during in-flight emergencies.

In order to accomplish precisely controlled exposures of living organisms to predetermined configurations of mechanical force with reasonable safety, the chosen instrument has evolved as a rocket or catapult-powered sled, slipper mounted on rails, carrying the subject, recording and transmitting instrumentation and braking devices, which can be accelerated to the required velocity and then decelerated according to plan.

The factors which can be permutated are (1) orientation of the body with respect to the direction of linear decelerative force, (2) rate of application of the force, (3) magnitude of deceleration, and (4) duration of application.

Aircraft Crash Forces

This investigation was begun in 1946 by the Aero Medical Laboratory of Wright Air Development Center using a linear decelerator, consisting essentially of a rocket-propelled sled which could be decelerated or stopped by mechanical brakes in a predetermined manner. Northrop Aircraft, Inc., of Hawthorne, California, designed, fabricated, maintained and operated the device between April, 1946, and June, 1951. Edwards Flight Test Center, Edwards Air Force Base, California, was chosen as a base of operations because of the availability of a precision built, 2,000 feet long, standard gage, railroad track. The equipment is described in detail in Air Force Technical Report No. 5993, dated February, 1950.

It consisted essentially of a 1,500-pound sled of chromium-molybdenum steel tubing and was approximately 15 feet in length, stressed to more than 100 g with a safety factor of 1.5 and designed to carry a seat or litter and instrumentation. Propulsion of the slipper-mounted sled along the rails was by one to four solid fuel Jato-type rocket motors, providing a thrust of 1,000 pounds each for five seconds. Two braking keels were mounted parallel lengthwise beneath the sled.

The braking action was by forty-five independently pressurized and actuated units in a 50-foot area between the rails, each unit consisting of two parallel pairs of brake shoes 5 by 11 inches in area, closed by pneumatic-hydraulic actuated levers compressing the shoes together and clasping the moving keels attached to the sled, with an action resembling a knife blade being pulled through a vise.

The rate of onset, magnitude, and duration of decelerative force was determined by the velocity of the sled, the number and sequence of brakes used, and the braking pressure.

Four telemetering channels permitted recording of data from accelerometers and strain gage tensiometers. High speed motion picture cameras were mounted both on the sled and along the track in overlapping profile at the braking area to record motion studies of sled and occupant. Velocity was accurately determined by surges induced in series-connected coils along the track when a magnet attached to the sled passed over them, recorded simultaneously with a time signal from a 1,000-cycle crystal oscillator. Velocity was also determined from ribbon frame camera timed exposures at 120 frames per second at the braking area. Table I lists the program of tests and experiments performed with the decelerator through June, 1951.

Table I.—Edwards Air Force Base, California, 2,000-ft. Track (1947 to 1951)

Type of test	*No.*
Performance	29
Acceptance	3
Chimpanzee	88
Dummy	61
Human	73
Total	254

The volunteer human subjects included three flight surgeons, one pilot, two parachutists, two harness makers, a medical technician, an aerial photographer, an aerial gunner, and an ordnance specialist. One of the flight surgeons was also a pilot. Ages ranged from twenty-five to forty-one years, weights from 142 to 206 pounds, heights from 66.5 to 72 inches. The range of body sizes and somatotypes usually encountered in the Air Force was well represented, considering that only twelve subjects were used in the seventy-three experiments. The maximum number of exposures to decelerative forces sustained by any one subject was twenty-six, including the most severe tests of the series. No sedation or medication of any sort was used with human subjects either before or after tests.

Eighty-eight experiments were accomplished with chimpanzee subjects to explore the performance range of the decelerator and to establish safe parameters for human experimentation with the same equipment. The use of animals of the size and ferocity of chimpanzees was justified by the close approximation to human masses, dimensions, and reactions. Subjects were presented to linear decelerations while seated facing forward, seated facing backward, seated sidewise, lying supine feet first, lying supine head first, and lying transversely across the sled while facing to the rear with the back against the bulkhead.

Human subjects were exposed in the forward-facing and backward-facing seated positions only. Concurrently with the evaluation of tolerance limits, development of harness configurations was accomplished. Optimum restraint configuration for the forward facing, seated position was proved to be the shoulder straps, lap belt in 3-inch width nylon webbing, with a pair of tie downstraps known as the "inverted V" to hold the belt and shoulder straps down against the bottom of the seat.

It was established conclusively that very high decelerative force can be sustained by primates, provided there is adequate protection from collision with solid objects. The maximum deceleration sustained by a chimpanzee in this series was from 174 miles per hour to a stop in 27.5 feet in the supine, head first position. This could have been survived with some temporary disability by a human being. It is many times what would be encountered in any automobile collision or plane crash short of complete demolition of the vehicle.

In order to evaluate the effects of impacts of high rate of onset and short duration, capable of lethal effects, a device known as a monorail decelerator was developed. The monorail decelerator consists of a welded steel carriage, sliding on and suspended from a lubricated horizontal rail. Propulsion is derived from an aircraft seat ejection catapult. Velocities varying from 15 feet per second to 47 feet per second were provided in these experiments by varying the powder charge in the catapult cartridges.

The carriage was decelerated by striking a lead cone attached to a frame welded to the rail. The coefficient of restitution of lead is sufficiently low to result in almost complete absorption of the energy of the carriage, thus minimizing rebound. Variations in the deceleration pattern were obtained by using different sizes of cones.

Electronic chronographs recorded velocity at time of impact. Motion studies were made by high speed cameras. Accelerometers and strain gages on the seat and subject recorded directly through trailing wires to an oscillograph during the 30-foot displacement of the carriage from catapult to impact point.

Experiments were performed with anesthetized hogs as subjects. One series determined the effect of impinging the subject against simulated sections of instrument panel, simulated control wheel surface and control stick. A second series evaluated the protection afforded by lap belt alone, lap belt plus shoulder straps, and lap belt combined with shoulder straps and inverted V tie downstraps.

Uninjured survival of anesthetized hogs

occurred in all experiments up to 80 g in the backward-facing seated position and to 125 g in the forward-facing seated position.

The comparative vulnerability of chest, midriff and abdomen to impingement by the simulated instrument panel section, control wheel and stick were determined in lethal experiments. Forces that could easily be sustained without injury while the subject was restrained with webbing caused death when the subject was impinged against the solid test objects. A total of fifty-two experiments have been performed with this device.

A more elaborate short track impact type decelerator having the same performance range has been activated at Holloman Air Force Base. It consists of a track 120 feet long with two rails 5 feet apart on concrete piers 3 feet high. A chrome-molybdenum steel sled is slipper mounted between the cylindrical rails, and can carry up to 350 pounds of payload at a maximum deceleration of 200 g. Maximum velocity is 150 feet per second. Deceleration can be either with the lead cone method of the previously described monorail decelerator or with a braking piston carried by the front of the sled entering a water-filled cylinder by rupturing a frangible stopper and displacing water through orifices in the walls of the cylinder. The orifices can be changed in size or completely closed according to the desired deceleration-time pattern. A trailing cable permits direct recording of a large variety of sensing devices. In other respects, the instrumentation is similar to that used in the monorail decelerator. To date a total of ninety-eight tests have been performed with this device. (Table II.)

Two types of experiments have been carried out at Holloman Air Development Center with a pendulum-type decelerator, consisting of a weighted seat suspended like a garden swing, so that it can be elevated and allowed to drop against a test object or to swing until arrested by a snubbing cable. Anesthetized hogs were used in lethal experiments to determine impact damage to the chest and abdomen on collision with a variety of steering wheels, and a series of human experiments were begun to determine tolerance to deceleration in the forward facing seated position, restrained by a lap belt. The latter series is still in progress and results are incomplete.

TABLE II.—HOLLOMAN AIR FORCE BASE, NEW MEXICO, 120-FT. TRACK (1953 TO 1956)

Type of test	*No.*
Acceptance and Performance	25
Instrumentation	7
Dummy	14
Chimpanzee	26
Human	25
Instrumentation run	1
Total	98

SUPERSONIC WIND DRAG DECELERATION

The human body in free fall, following seat ejection and separation from the seat, is an unstable mass whose flexibility displaces the center of gravity at random so that erratic tumbling and spinning occurs. Wind ram pressure against the drag area presented by the seat and its occupant emerging from the aircraft produces abrupt linear deceleration at the instant of separation. The wind blast can buffet and flail head and extremities and abruptly compress or buffet body walls. The statically measured magnitude of the imposed wind drag deceleration does not express the individual and combined effects of its component factors.

The investigation of decelerations lasting ten to twenty times as long as crash forces, such as would be encountered during wind drag deceleration following exit from aircraft in supersonic flight, has been accomplished at Holloman Air Development Center from April, 1953, to the present. A much higher capacity rocket sled was used, with prolonged deceleration obtained by using water brakes.

This device consists of a test sled weighing 2,000 pounds on which the subject and instrumentation are carried and a propulsion sled on which the rockets are mounted. Both sleds are equipped with fixed scoop water brakes. Water entering the scoops on the test sled is turned 90 degrees through conduits and ejected to the sides. A retarding force of 1 pound for each pound of water passing through the conduit is applied to the sled. The propulsion sled also has fixed scoops but of lower clearance, so that braking begins at a shallower depth of water. The conduits on this sled are 180 degrees, throwing water forward during deceleration. Two pounds of retarding force result from each pound of water passing through the conduits. The total braking force is a function of the pounds of water per second passing through the conduits.

Instrumentation for this device was basically similar to that used in the 2,000-foot track decelerator, with the addition of Pitot tubes and wind pressure gages to measure the impinging wind ram pressures. The high velocities, obtained from as many as twelve propulsion rockets of 4,500 pounds' thrust and five seconds' duration prior to the separate deceleration of propulsion sled and test sled after rocket burn-out, permit prolonged water brake deceleration in the section of track prepared for this purpose. The 3,500-foot track has rails 7 feet apart between which lies a concrete ditch 5 feet wide and 18 inches deep, sloping very slightly for drainage. At the end of the acceleration phase of a run, during which the scoops under the sled go through the dry ditch, a section of the track is reached where frangible masonite dams have been inserted in slots provided in the walls of the concrete ditch. Dam height is adjusted to provide water depth required for the calculated braking pattern. The only limitation on braking distance is the remaining track length. In this way, durations of more than .1 second at 100 g peak, of more than .4 second at 50 g, and of more than 1 second at 25 g plateau are possible.

A lightweight, high velocity rocket sled designed for attaining maximum tolerable wind ram pressures, identical in instrumentation and braking with the sled described, but propelled by up to nine rockets of 1.8 seconds' duration and 7,800 pounds' thrust has been built and used for wind blast tests at Holloman Air Force Base. A maximum velocity of 1,446 feet per second or 996 miles per hour equivalent to Mach 1.3 at ground level has been attained with this device. Chimpanzee and dummy subjects only have been used with it. Table III lists the tests and experiments performed to date with these two sleds.

TABLE III.—LONG TRACK (3,500-FT.)

Type of test	*No.*
Dummy	3
Chimpanzee	50
Human	3
Total	56

RESULTS

Findings in all experiments with human subjects have been reported in detail in Air Force Technical Report 5915 and in *The Journal of Aviation Medicine.*

Human tolerance to linear decelerative force in the forward-facing seated position for exposures of less than .2 second is primarily determined by the rate of application of force (the third derivative of motion, or rate of change of deceleration) and, secondarily, by the magnitude of force, provided that the force is applied to the solid quarters of the body through webbing restraints. The points of reversible incapacitation were reached at 38.7 g when rate of application was more than 1,350 g per second, and at 50 g when the rate of application was 500 g per second or less. (Fig. 2.)

Experiments with chimpanzees indicate that for the same orientation injuries begin at 65 g with 6,000 g per second rate of onset, and at more than 100 g with 1,500 g per second or less rate of onset, with duration of exposure between .1 and .2 second.

Lethal experiments with anesthetized hogs indicate that at rates of onset between 5,000 and 15,000 g per second, for durations between .04 and .08 second, up to 125 g could be sustained with reversible injuries, ranging up to 220 g with serious to fatal injuries.

With respect to orientation, the human body is almost equally tolerant to deceleration in the backward-facing position, pro-

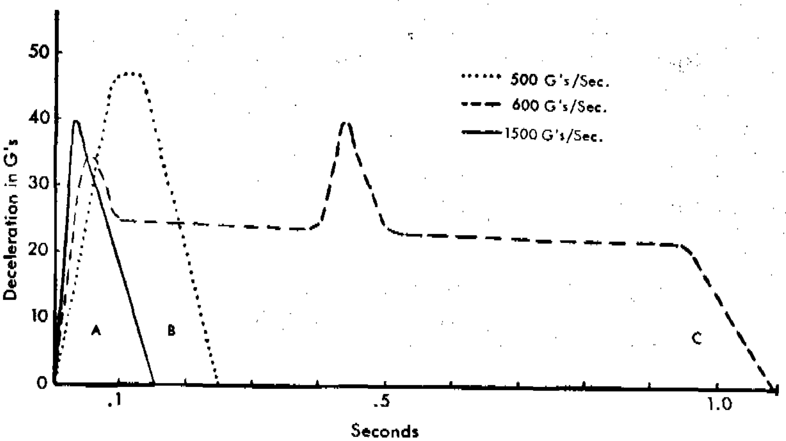

FIG. 2. Human tolerance to linear deceleration limit for reversible incapacitation to: *A*, rate of onset; *B*, magnitude; *C*, duration of decelerative force in the forward-facing seated position.

vided an even, firm backing of energy-absorbing material such as a half inch of felt against sheet steel is used. Experiments did not exceed 35 g in this orientation because no higher exposure was required to provide criteria for backward-facing passenger seats. The human body structure having the lowest failing limit is the vertebral column when force is applied along its length, particularly from buttocks to head in the seated position. With optimum alignment, up to 35 g can be tolerated at less than 500 g per second rate of onset, but with hyperflexion (back bent forward to the limit of motion) this diminished to less than 15 g in one aircraft accident case that was instrumented with accelerometers. The difference is due to diminishing contiguous impinging surfaces between vertebrae in the lumbar spine.

In hogs with vertebral column in optimal alignment, more than 75 g at higher than 5,000 g per second rate of onset was required to produce vertebral fractures. Chimpanzees have been similarly exposed to 65 g without fractures.

In chimpanzees, impact loads against harness of more than 75 pounds per square inch attained in less than fifteen milliseconds can produce fatal damage to the lungs, consisting of hemorrhagic areas of ruptured air sacs.

Prolonged decelerations, in which durations range from .2 to .3 second, demonstrate that hydrostatic pressure effects due to displacement of body fluids have a latent period of .2 second before they are appreciable, and that they are definitely evident at .4 to .6 second of exposure to as low as 10 g at 500 g per second rate of application. The range of the duration versus g spectrum of the decelerator overlaps that of the human centrifuge for exposures of more than two seconds. (Fig. 3.)

The high performance Holloman decelerator has demonstrated that man can tolerate 1,107 pounds per square foot of wind blast in a total time of less than 6.4 seconds, provided it is excluded from the head and that head and extremities are protected from flailing. Chimpanzees have tolerated up to 1,800 pounds per square foot while similarly exposed. With bare head free to flail, a chimpanzee subject died of brain injuries after exposure to 1,200 pounds per square foot of wind blast in a sled ride.

Crash experiments with surplus Air Force and Navy aircraft conducted by Eiband, Black, Preston, Pinkel and other workers at the National Advisory Committee for Aeronautics' Lewis Propulsion Laboratories, by propelling instrumented aircraft occupied by dummies into a runway barrier, confirm the magnitude, duration, rate of application of decelerations and the force measurements accomplished on the rocket sled exposure of human, chimpanzee, and dummy-type experiments. The high human tolerance to abrupt deceleration confirms the observations of De Haven and DuBois on accidental high falls and survivals of high impact aircraft accidents.

not yet reported, in which the seat failed in a manner that caused strangulation of the anesthetized subject by a chin strap of the cloth muzzle, and no other lethal injury. This subject was parachuted down following the estimated opening shock of 35 g. The first two tests were instrumented to show vital signs of heart beat and respiration persisting after ejection and before descent.

Figure 2 shows three curves respectively indicating maxima for each of the three factors other than direction of force, which was transverse to the seated subject from front to

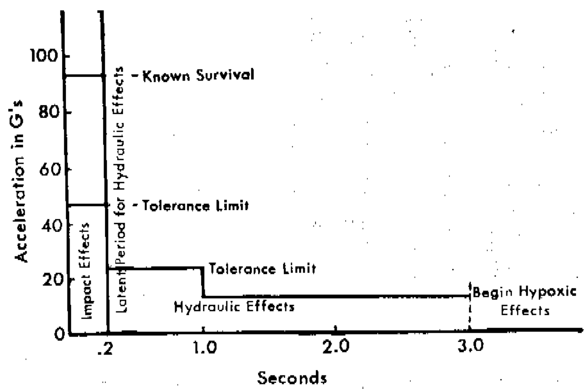

FIG. 3. Time-G effects on human being.

back. Accurate presentation of experimental findings requires all three curves. In the transverse axis, any combination of rate of onset, magnitude and duration can be tolerated which does not exceed the experimentally established boundaries presented by these three curves. In the vertical axis, the limits of tolerance vary with the alignment and position of the vertebral column. With the column in the erect position and maximum area at apposition impinging between vertebrae, forces exceeding 30 g at 500 g per second have been sustained without injury.

If the body is bowed forward to the limit of curving the spine, wedge fractures have been produced by 9 to 14 g at less than 500 g per second in the first and second lumbar vertebrae. They were tilted forward until only the front rims of the vertebral bodies carried the concentrated loading.

The first observation of the effects of supersonic wind drag deceleration during ejection seat escape confirms the range of forces employed in the high performance rocket sled tests performed at Holloman Air Force Base.

The first experimental measurements of these wind drag deceleration forces under conditions of flight were obtained in a series of four downward ejections of chimpanzee subjects in standard ejection seats from an air dropped missile accelerated downward to Mach 1.4 at 20,000 feet at the point of ejection. Analysis of the first two of these experiments is complete and is reported by the Cook Electric Company. Because of mechanical failures in the recovery system, free fall of seat and occupant to the ground produced damage which overshadowed any evidence of injury during escape except in the third of these tests, Hydraulic forces can rise to the point of failure in blood vessels if a latent period of .2 second required to overcome elasticity of tissues and viscosity of body fluids is exceeded.

Another latent period of 2 to 5 seconds or more is required for accelerations in the long axis from head to foot to offset the pumping force of the heart and deprive the brain of oxygen long enough to affect vision and consciousness.

Tumbling in the head over heels direction has been investigated to limits of human tolerance and lethal effect on animals by Weiss and associates in a report published in *The Journal of Aviation Medicine*. Subjects were spun on a turntable while lying on one side. With the heart at the axis of rotation, human beings lost consciousness in twelve seconds at 160 revolutions per minute, and results were fatal for anesthetized animals at 200 revolutions per minute for two minutes. Sperry, Nielsen and associates in free-fall bail-out experiments, with the highest at 45,200 feet, found disorientation, vertigo, nausea and loss of consciousness among the effects encountered. The less dense atmosphere at the greater heights permitted faster tumbling. In the same experiments, the impingement of wind blast at ram pressures higher than 650 pounds per square foot at the instant of ejection caused flailing of the inadequately secured arms of the subjects, overriding all muscular efforts to resist. In two cases, fractures and dislocations resulted at less than 500 knots and 30,000 feet.

With respect to transverse decelerative forces, accident data on human beings compared with experiments on both hogs and chimpanzees indicate that structural failure points on the chest and abdomen impinged against a solid hard surface are practically identical. Aortas can be ruptured by a 2,000 foot-pound impingement of a hog's chest against a conventional steering wheel. Transverse deceleration against a webbing harness that distributes the load on the four quarters of the body indicates very little variation in tolerance, probably less than 10 per cent. It would be a conservative estimate to say that human survival of serious injury begins at two and one-half times the transverse reversible incapacitation point for either forward or backward deceleration. The rate of onset is a potent factor in determining tolerance limit for transverse deceleration. At 6,000 g per second and 70 g peak in a .13 of a second duration one chimpanzee sustained lung injuries similar to those found in explosion blast. The calculated rate of onset and maximum force of impingement against the harness was fifteen milliseconds to reach 75 pounds per square inch. With rates of onset of less than 1,000 g per second up to 150 g peaks have been sustained without injury by chimpanzees. In the longitudinal axis, the vertebral column of the chimpanzee is at least twice as strong as that of a human being because of its lack of lumbar and cervical curves and rigidly supported architecture. The next most vulnerable structure is the central nervous system which reacts with reversible physiologic responses in man, beginning at 30 g, 1,000 g per second rate of onset with vasomotor shock and retinal spasms ranging to concussion signs and retinal hemorrhage at more than 45 g. The rate of onset again is the controlling factor from 30 g up of magnitude. With forces prolonged beyond .6 second, Purcher's syndrome of the eyes was observed in both chimpanzees and humans. Repeated exposures in both humans and chimpanzees do not produce observable accumulative effects.

It can be concluded from all of the foregoing that the structural strength of the human body, its energy absorbing characteristics with respect to brief applications of high dynamic loads, its tolerance to abrupt wind blasts of nearly explosive violence facilitate salvaging the victims of high speed transportation accidents. The application of this knowledge can lead to a great saving of lives and prevention of disabilities.

In reading Stapp's paper, those not familiar with this area should realize that the decelerations indicated by the abscissa of Figure 2 represent the number of times the human subject's effective weight was actually increased. Thus, for example, a 160-lb. man under a deceleration of 35 g has an effective weight of 5600 lb.! Nonetheless, the forces to which this corresponds are daily encountered transiently in motor vehicle and other accidents, in some cases, as shown by De Haven and Stapp, with only relatively minor injury. It is this remarkable tolerance that has convinced many that crash injuries can be substantially reduced—by appropriate modification of the environment—even if it is not possible completely to eliminate such crashes per se.

ACCIDENT SURVIVAL—AIRPLANE AND PASSENGER AUTOMOBILE

—Hugh De Haven

As a result of the findings discussed above, accident research workers have come to regard the problem of transporting people safely in aircraft and other vehicles as substantially one of "packaging." Granting that at least some accidents will occur to packages of any type, they seek to understand the means by which the contents are injured. Since understanding of much of current accident research requires familiarity with the few simple principles which this entails, we are including this early but still excellent introduction to the subject.

* * *

In order to judge the potential value of engineering efforts to cut causes of injury in the automotive field, we should consider some figures on what packaging engineers probably would call "the spoilage and damage of people in transit." Despite everything that has been done to prevent accidents, a total of 35,000 people were killed in motor vehicle accidents in 1950; this figure includes pedestrians as well as people killed in buses, taxis, trucks, etc. Of the 35,000 killed, the National Safety Council estimates that 17,600 were killed in passenger cars alone. In addition to the 17,600 persons killed, approximately 685,000 persons sustained crash-injuries in passenger automobiles. The National Safety Council estimates that the total cost of crash injuries in all motor vehicles last year was $1,850,000,000; thus the proportional loss for medical payments, insurance costs and value of services lost to the nation for persons killed and injured in passenger cars last year was nearly one billion, one hundred million dollars.

Of course, some of the 17,600 persons killed and some of the persons injured sustained their injuries in passenger car accidents which were so severe that no reasonable alteration of automobile structures would have modified the seriousness of their injuries. Preliminary studies by the Crash Injury Research Division of the Indiana State Police indicate, however, that only 16% of fatal passenger car accidents in rural districts of Indiana were so hopelessly severe as to justify classification as "non-survivable"; an additional 18% were sufficiently severe to make such classification debatable. The remaining 66% of fatal Indiana accidents in rural districts (where traffic speeds usually are high) were classed by experienced accident investigators as survivable. In many of the 66% of fatal cases, other people in the same car either escaped uninjured or sustained injuries which normally would not

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endanger their lives. Obviously in these cases crash force alone was not the killer.

Further analysis of Indiana State Police data discloses that about half the fatal, rural accidents occurred at relatively moderate speeds: 21% occurred at estimated speeds of 30 mph or less, and a total of 45% occurred at speeds of less than 40 miles per hour. In considering the 66% of fatal cases which the Indiana State Police classed as survivable and the 45% of fatal accidents which occurred at 40 mph or less, we should bear in mind the fact that stunt drivers repeatedly crash cars head-on at 35 mph without sustaining any injury. Actually without knowing it, these professional drivers who elect to earn their living by avoiding injury in daily crashes apply practical principles which are used by every packaging engineer to protect goods in transit.

The stunt driver, of course, does not design or specially rework a car in order to give himself safety in a 35-mile-an-hour impact. If he did, the car would probably protect him at even higher impact speeds. However, like a packaging engineer who is creating or selecting a package, he calculates predetermined conditions for which the package is suitable. A packaging engineer would not test a packing case by dropping it a few inches; similarly, the stunt driver knows that a 10-mph impact test of a passenger car would not be a sensational stunt and would not fully utilize the protective qualities of the structure. In addition, the stunt driver estimates that the structure would not assure protection in a head-on impact at 60 mph. As a result of long experience gained in previous crashes, he estimates that the passenger compartment will remain substantially intact in a 35-mph head-on impact.

In reaching this conclusion, a stunt driver fulfills the first principle followed by packaging engineers: this principle states that the package should not open up and spill its contents and should not collapse under reasonable or expected conditions of force and thereby expose objects inside it to damage.

The second principle considered by packaging engineers is closely related to the first: it states that packaging structures which shield the inner container must not be made of brittle or frail materials; they should resist force by yielding and absorbing energy applied to the outer container so as to cushion and distribute impact and thereby protect the inner container. Either by good fortune or good design this second packaging principle is represented in most of the protective structures ahead of, and behind, passenger compartments in automobiles as well as in small airplanes.

The third principle of good packaging states that articles contained in the package should be held and immobilized inside the outer structure by what packaging engineers call interior packaging. This interior packaging is an extremely important part of the over-all design, for it prevents movement and resultant damage from impact against the inside of the package itself.

Usually excelsior, paper wadding, padding or blocks are used inside the package to prevent movement of contained units. The stunt driver fulfills this third principle when he jumps behind the front seat and steers the car by reaching over the back of the seat just before the head-on impact. At the last instant he ducks down behind the front seat and braces his body against the seatback, putting his head in contact with it during the abrupt slowdown of the car.

The driver thereby avoids being thrown against dangerous structures inside the car during the crash deceleration—and simultaneously he takes full advantage of the cushioning effects provided by collapse of forward structures. Actually the stunt driver creates for himself the type of protection now provided for personnel in large military transport planes in which the seats are faced rearward so as to fully support the head and body. Further, while thus protecting himself, the stunt driver is also avoiding dangers combatted by the fourth packaging principle.

This fourth packaging principle says that the wadding, blocks, or means for holding an object inside a shipping container must transmit forces to the strongest parts of the contained objects. This principle certainly is not complicated; it simply means that packaging engineers would not ship a valuable piece of furniture inside a crate and try to hold it only by the legs or by an ornament at the top. It would be held in a way which would transmit unusual loads to the strongest part of the framework. It is this principle which governs the placement of safety belts in aircraft so as to transmit crash loads to strong skeletal structures in the pelvic area of the human body.

Although we do not ordinarily think about them, these four basic packaging concepts amount, in fact, to a statement of practicalities. Most of us—even though we are not packaging engineers—apply them to the best of our ability when we pack or ship things. We would not, for example, ship a fragile object loose inside a barrel. Naturally, if an object was fragile and easily damaged, we would endeavor to provide some arrangement to hold it from moving and smashing itself against the inside of a shipping container, either by packing something around it or by supplying some other means for immobilizing it.

In spite of the utter simplicity of this basic packaging principle, which we all understand, most of us definitely ignore its importance to ourselves and our families. We will get into anybody's automobile, go any desired distance at dangerous speeds without safety belts, without shoulder harness, and with a very minimum of padding or other protection to prevent our heads and bodies from smashing against the inside of the car in an accident. The level of safety which we accept for ourselves, our wives, and our children is, therefore, on a par with shipping fragile, valuable objects loose inside a container. The results each year are exceedingly costly. Thousands of people are injured, disfigured or disabled in accidents which, with safer arrangements, would not cause serious injury.

As might be expected, the most frequent types of injury in survivable aircraft and automobile accidents are fractures of the skull, lesions of the brain, smashing of facial bones and other dangerous or disability-producing injuries of the head. It is difficult for engineers and laymen to fully appreciate the fact that the head weighs as much as a ten-pound sledge hammer and packs the same terrific energy when it strikes a dangerous object at 40-50 mph. If the head hits a solid structure which will not dent or yield at such speeds, the head itself must yield, and crushing injuries of the skull and brain cannot be avoided. But if the head hits a light, ductile surface at such speeds, even a fairly strong metal surface will dent and bend and absorb the energy of the blow, thereby modifying the danger of skull fracture and concussion.

The ability of common structures to protect the head at impact velocities of 40-50 mph was observed and reported in 1942 in an analysis of survivals after free falls from heights of 50 to 150 feet; in most of these cases various types of structure—automobiles, metal ventilators, wooden rooftops and hard ground—were struck by the head and body at speeds of 40-50 mph without causing skull fracture, loss of consciousness or subsequent evidences of concussion. The distribution of force in time and area, and the physical principles of pressure compensation which provided these astonishing examples of protection, were outlined in 1944 and were first publicly demonstrated at Cornell University Medical College in 1946 by dropping eggs 150 feet onto an energy absorbing pad only 1½ inches thick without breaking them. These observations, in conjunction with medical data from aircraft accidents, have led to studies of considerable significance to future safety. Supported by the Office of Naval Research, the Cornell Aeronautical Laboratory undertook studies aimed at providing engineering design criteria for modifying the blow-dealing characteristics and injury potential of objects commonly struck by the head in aircraft and automobile accidents. Though delayed by the current cold war and related defense activities, this Cornell-ONR Head Impact Investigation, when completed, should provide engineers with working data for reducing the force of blows, so that the present high rate of critical and fatal head injuries in survivable crashes may be decreased.

Even in airplanes, where safety belts and shoulder harness are used, cockpit and cabin interiors must be designed to minimize the frequency of head injuries. Although use of a safety belt is remarkably effective in protecting those central portions of the body which are immobilized by it, the head and upper portions of the body—which are not held by belts—usually fly forward and smash into adjacent structures at full crash velocities. Shoulder harness used by fighter pilots does an amazing job of protecting the head by restraining the upper torso (and the head) from extreme forward movement. But use of shoulder harness—and safety belts—in automobiles, because of psychological problems, is not even on the horizon as a means of increasing automotive safety. Therefore the chief hope of reducing the high frequency of head injuries in crashes becomes a problem of engineering and redesigning dangerous structures to modify their blow-dealing characteristics.

In working to modify typical causes of excessive head injuries, aeronautical engineers have a definite advantage over safety engineers in the automotive field because passengers in aircraft usually are wearing their safety belts when accidents occur. Although a safety belt does not effectively check the velocity of the head, it contributes materially to safety by limiting the range of the head; it therefore defines to a large extent the area which the head and body are most likely to strike. This permits specific modification of injury potentials in principal target areas.

For example, the seatbacks in early transport planes like the DC-3 had a steel tubing almost directly in front of each passenger's head, and the adjusting mechanism for the seatback held this structure firmly in a dangerous position. This arrangement gave little chance of avoiding injuries of the skull, face, or neck if passengers were flung forward against it. The same type of danger also was a frequent cause of injury in small planes.

A marked reduction of danger has been achieved in many modern aircraft, first by designing metal seatbacks which have, in substance, a low injury potential such as that of a rattan or wicker chair; second, by padding this structure; and third, by arranging the adjusting mechanism so that the light seatback can pivot forward during an abrupt deceleration, thereby moving beyond range of the head and chest. Such a light, ductile and padded seatback, even if struck by the head, virtually assures a light, glancing non-dangerous blow.

A very similar technique has been applied to the heavy gyros and instruments in small planes. Crash Injury Research showed that injuries of a very severe nature were sustained when the head smashed into the instrument panel and struck a solid knob or instrument casing; on the other hand pilots walked away when they were lucky enough to hit the soft metal areas between instruments. As a result, at least one instrument panel has now been redesigned for use in small planes. Instruments in this panel are mounted with shear pins which free them from the panel structure and allow them to fly forward beyond range of the head, thereby cutting the chances of a fatal blow. In other small planes instrument panels of malleable, ductile metal with soft, rounded contours have been produced to replace solid, sharp structures. Sharp knobs, projections, and many other dangerous objects have either been modified in design or moved out of striking range of the head.

Accident-injury data also showed that either because of the stretching of safety belts under heavy loads—or because safety belts often are not pulled up snugly—occupants of the front seats in small planes frequently struck and broke windshields, suffering extensive lacerations of the face with tearing and penetrating wounds. By mounting the windshield in rubber, one small plane now features a safety effect in windshield design; when struck a moderate blow by the head, the windshield pops out of the frame in one piece, thereby offsetting the extreme danger of solid blows and disfiguring injuries implied by windshields which are rigidly held in place.

Control wheels in small planes often were found to set up other needless and excessive dangers. In some planes fatal injuries were caused in moderate accidents because ribs of control wheels bent down under heavy loads, localizing the pressure of the chest on a small, pointed ornamental area over the end of the control column. In other cases control wheels were cast of brittle materials which broke under heavy force or were set in a lower position so that crash force was applied to vulnerable areas of the lower ribs and upper abdomen. In a few makes and models of small planes, pilots were impaled on the control columns from which control wheels had snapped in accidents which caused no serious injury for other occupants of the same plane.

Notice the design of control wheels the next time you are in a small, modern plane. The chances are it will not be a thing of beauty—although beauty can also be designed. In most planes what you will see will be a rugged wheel with an arrangement like a broad palm or pad over the end of the control column and a rim so attached to this pad as to assure distribution of crash force, and thus protect, rather than endanger, the chest under thousand-pound loads.

This same application of protective principles extends to flooring, rudder pedals, turnover structures, the configuration of firewalls and, of course, to seats, safety belts and shoulder harness.

These details, which are designed to provide optimum protection inside the passenger compartment can, of course, provide protection only in accidents which leave cabin structure substantially intact. In six new planes for general and private flying, crash safety engineering has been extended beyond mere installations and details and includes engineering of the cabin and its adjacent structures so that the airplane as a whole is designed to fulfill all four principles of safe packaging. These safety designed planes feature: (1) a passenger compartment that is exceptionally rugged; (2) nose sections which are designed to absorb crash energy and protect the cabin; (3) wings, engine mounts, landing gear and turnover structure arranged to utilize their maximum inherent protective qualities for shielding the cabin; (4) special design in control wheels, instrument panels and seats. In addition to safety belts, each of these modern planes also features shoulder harness.

No one expects that these improvements are going to assure safety for pilots and passengers in high speed accidents where the pilot loses control or runs into a mountain at 100 or more miles per hour. However, in accidents at take-off and landing speeds—and in collisions with trees or wires at minimum flight speeds—the danger of serious injury should be offset to a very important degree.

Not all these improvements for increasing safety in crackups have been achieved without penalties in weight or cost; most, however, have come almost "for free" as the result of learning what caused danger and then modifying known dangers with ingenuity and good engineering.

As an engineering art, the use of structures for protecting the human body in aircraft and automobile accidents is still very young and undeveloped. A great deal of research will be necessary before we know what types and arrangements of structure are best for absorbing the energy of crashes. Even in small planes, which are flown and frequently cracked up by inexperienced pilots, engineers attempting to provide crashworthiness still do not know whether metal monocoque or welded steel-tube structure gives greater safety on a weight-cost basis. And only a beginning has been made in studies for moderating the blow-dealing qualities of structures which surround all of us in aircraft and automobiles.

Progress in the protection of people has been slow, but the fault does not lie entirely with engineers; it lies chiefly with medical groups who have accepted any and all injuries—without endeavoring to understand their causes. Without medical data, engineers have been completely in the dark about many essential matters pertaining to safety. They have had to work without information as to what force the head and body can tolerate, and without statistical data on how often people are dangerously hurt—and by what.

Part of this lack of information can be attributed to inadequate investigation and reporting of accidents. Until Cornell's Crash Injury Research project was initiated in 1942, aircraft accident investigators studied crashes chiefly to determine *accident* causes; actual causes of *injury* rarely were observed or reported. As a result, data were available for efforts to prevent accidents by preventing their causes, but engineers had no data to use for preventing common and unnecessary causes of injury *in* accidents. Except for recent studies undertaken by the Indiana State Police, this blind spot in safety data still applies in the investigation of automobile accidents.

For example, take an accident such as a car skidding off the road and hitting a tree head-on at 40 mph; let us suppose that the driver is killed while one passenger is seriously injured and another is shaken up but unhurt. Reports on such accidents normally state accident causes but leave causes of fatal injury unreported and unknown. However, if such accidents were studied and reported from a crash-injury point of view, they would provide essential safety data. For example, the chief cause of the driver's death might be a crushing injury of the chest due to collapse of the steering wheel; the passenger's chief injury might be severe lacerations of the face and concussion caused by striking a dashboard which set up the injury potential of solid steel. It is quite possible that excessive injuries frequently occur in automobiles under conditions of force which do not justify extreme results. If accident-injury data show that they do, and if the frequency of such injury causes indicates an important need of greater safety, automotive engineers will not hesitate to exert every effort to redesign dashboards, windshields, and steering wheels to give greater protection. However, without specific crash-injury data, engineers cannot be expected to know mechanical factors responsible for common and needless dangers and therefore have no sound basis for judging either the desirability or need of undertaking safer design.

The importance of including reports on causes of injury in the investigation of automobile accidents is strongly suggested by early data from traffic casualty studies undertaken by the Crash Injury Research Division of the Indiana State Police; these data provide evidence that at least one out of ten, and possibly one out of five persons, are killed in survivable passenger car accidents because the door latches are inadequate.

The sequence of events appears to be that cars swerve, roll over, or are struck sufficiently hard to distort the frames of one or more of the doors; people spill out and are either run over by other cars or strike their heads on curbstones or are rolled on by the car itself and are crushed in accidents which leave passenger compartments virtually intact. It will take a considerable volume of statistical material to determine whether this condition occurs in only a few makes and models of cars—or whether it is common to many. The point is that, when sufficient crash-injury data are accumulated, judgment of the danger can be made and safer design can be considered.

Possibly the need of latches and hinges which will hold doors closed during reasonable stresses and strains on a car is not as important as early trends indicate. But possibly improvement of this one detail in automotive design will be of great importance to public safety on the highways—and perhaps this may be only one of many design details which contribute to a huge annual toll of unnecessary traffic casualties.

Today there is very limited evidence for judging what can be done to cut future casualty rates. Available estimates, however, are very suggestive. For example, of the 685,000 injured in passenger cars, the National Safety Council estimates that 87% sustained their injuries in accidents at speeds of less than 40 miles per hour. These approximations do not present the possibility that 600,000 persons could have been spared injury entirely by safer design. But we should bear in mind that stunt drivers can and do protect themselves entirely at 35 miles per hour—and that crackups in airplanes at 40 miles an hour usually are regarded as low-speed mishaps rather than dangerous crashes. These and other facts support the belief that much can be done, design-wise, to increase safety when common causes of injury are known.

The only way to get the facts is to extend the scope of accident-injury studies into the automotive field so that, in addition to having data on conditions causing *accidents*, data on objects and structures causing excessive *injury* will be available.

The need for such data brought about the inception of Crash Injury Research in the aviation field, where the art of packaging people to give optimum protection in accidents now is progressing rapidly. Unquestionably, much of the research on aircraft structures and many of the engineering methods now being developed to give crash protection in aircraft will be useful in future automotive safety design.

Renewed efforts to prevent *accidents* must be made but, at the same time, efforts should be made to cut the chances of *injury* in accidents. Thus, the huge national toll of traffic casualties may be reduced and safety may be increased for you and your families on the highways.

We stated earlier that it is the manner in which energy is transferred rather than the antecedent causes of an accident that determines its injurious results. If this is true, differences in the force distributions within a crashing vehicle should result in differences in the injuries sustained by various passengers, even though the causes of the crash were identical for all of them. Further, it should be possible to verify this by extending De Haven's methods to the study of aircraft and other accidents involving more than one individual.

CRASH SURVIVAL STUDY: NATIONAL AIRLINES DC-6 ACCIDENT AT ELIZABETH, N.J., ON FEBRUARY 11, 1952

—*A. Howard Hasbrook*

This report is one of several similar studies.[4] In considering it, the reader should keep in mind that the causes of the crash, the over-all velocity change to which they were subjected, and the package were the same for all of those involved. The occupants may therefore be considered as being closely analogous to a group of experimental animals whose subgroups—as documented by this report—fared very differently in proportion to corresponding differences in their common intimate circumstances. This is dramatically emphasized by the fact that passengers who survived with minor or no injuries were in at least two instances seated immediately adjacent to persons who were killed. This report demonstrates that such variations—also seen daily in automobile crashes—are understandable in rational terms without recourse to "luck" or to the other explanations to which they are commonly attributed. The extensive studies of automobile accidents conducted by Cornell's Automotive Crash Injury Research program have yielded similar results (see Chap. 10).

PREFACE

Major efforts to increase safety in flying have always been justifiably aimed at preventing accidents. The beneficial results of such work by military and civil aviation safety groups are well known and are reflected in the decreasing fatality rate per hundred million passenger miles of transport flying.

Experience in all safety fields has shown, however, that because of variables in human behavior, accidents will occur despite all preventive efforts.

Some "non-preventable" air transport accidents result in complete demolition of aircraft structure; by the very nature of such accidents and because of the resulting damage to structure, it is known that no amount of realistic structural redesign could alter the injuries sustained by the passengers. However, a percentage of these accidents are in a class which may be termed survivable, or at least partly survivable. Such accidents usually involve impact speeds, deceleration distances, structural damage and impact forces which can be tolerated by human beings without fatal or dangerous injury.

The National Airlines DC-6 accident at Elizabeth, N. J. provides an example of the type of crash which is partly survivable and partly non-survivable. The accident was of a complex nature—as are most such survivable accidents—involving highly diverse conditions of structural damage, injuries, and magnitude and directions of crash force. This accident is covered in full detail in the following report in order to provide, perhaps for the first time, a complete picture of conditions which occur in an extremely severe but survivable transport crash.

In addition, the report shows the type of information which should be obtained from survivable transport accidents in order to permit effective analysis and subsequent presentation of crash survival data which may be of use to engineering and safety groups.

Hugh De Haven
Director
Crash Injury Research

INTRODUCTION

If judgment of accident severity is based solely on the over-all destruction of an airplane, the National Airlines DC-6 accident at Elizabeth, New Jersey would probably be classified as catastrophic and non-survivable.

Complete disintegration of major portions of the passenger cabin—followed by fire—a six hundred foot wreckage pattern and a 140 mph impact speed would seem to justify placing this accident in a non-survivable category with survival of any of the passengers attributable to luck. Furthermore, it would be likely to conclude that little or no crash survival information of value could be obtained from this accident—or from crashes of similar severity.

On the other hand, if judgment of an accident—in which some portion of the cabin remains reasonably intact—is also based on additional factors, information of value for the use of design engineers can be obtained from such accidents. These factors include the known "crashworthiness" of human structure, and the details of the incident, i.e., impact speed, flight path angle, nose-down

Reprinted, with permission, from *Informative Accident Release #15,* October 1953, published by Crash Injury Research, Cornell University Medical College, New York. Portions of the text and most of the illustrations have been omitted. We have also omitted Appendix 1, showing the scale used by Crash Injury Research in classifying degrees of body injury, since it appears in an earlier selection in this chapter.

angle, deceleration distance and other equally important data.

It was found in the National DC-6 accident, for example, that the rear half of the passenger cabin sustained crash force of low magnitude while forward portions of the airplane were being disintegrated. This, along with other detailed information, undoubtedly will be of more than academic interest to groups concerned with decisions relating to the design and use of aft facing and forward facing seats.

In addition, data concerning failures of seats and their attachments—some under conditions of *mean* longitudinal crash force of less than 6G in this accident—as well as on patterns of destruction of the cabin, directions of principal and secondary crash forces, effectiveness of 3,000-lb. safety belts, injuries, and many other pertinent details may be of value to safety groups and design engineers in the consideration of crash survival design requirements for future piston-driven and jet transport aircraft.

The Accident

A National Airlines Douglas DC-6, equipped with fifty forward facing passenger seats, four facing sideward, and four facing backward, took off from Newark, N. J. Airport just after midnight on February 11, 1952; fifty-nine passengers and a crew of four were on board. The weather was clear; the take-off was uneventful. In less than two minutes time after the aircraft cleared the end of the runway, mechanical difficulty occurred; Number 4 propeller was feathered, and Number 3 propeller reversed its pitch.

Unable to climb or even maintain altitude, the pilot attempted to return to the airport but failed; the aircraft struck the roof of a three and one-half story apartment house, while in a partially controlled descent. . . . Skidding from the roof, the airplane rolled to the right and struck the ground of a school yard at approximately 140 mph, in a nose-down attitude of approximately 10 to 15 degrees.

Disintegration of the forward half of the fuselage occurred as the airplane struck, bounced and cartwheeled. The rear half of the cabin—substantially intact—tore free from the wing center section and hurtled through the air, coming to a sudden stop after crashing against a large tree trunk 280 ft. from the point of initial impact with the ground.

All occupants of the aircraft were wearing their safety belts at the time of the crash with the possible exception of one adult, and a four-months old infant held on his mother's lap.

Twenty-seven passengers—four of whom were sitting in aft-facing seats—and the three crew members in the cockpit were fatally injured. The stewardess and thirty-two passengers survived.

The Crash

According to data available to Cornell's Crash Injury Research, the kinematic behavior of major components of the airplane during the crash was substantially as follows:

The aircraft was in a slightly nose-high attitude with the right wing down about 15° when it "bellied" onto the roof of the building (Fig. 2). Skidding across the roof, the plane struck and leveled the low rear parapet of the building to the roof line. Simultaneously, the right outer wing panel was torn off against the front parapet; gasoline from the ruptured tanks cascaded onto the roof and ignited.

Because initial contact with the flat roof was at a low angle, with very little if any rebound, no force of any consequence was transmitted to the seats or passengers.

Skidding off the building, the airplane rolled steeply to the right, with the nose down slightly, and a moment later struck hard ground at about 140 mph.

The stub of the right wing—outboard of #3 Engine—and the cockpit struck first; the forward cabin and center section hit in quick succession. At the same moment, tremendous crash loads—possibly in the order of 50G—were imposed on the center section structure. As the wing stub dug in—and the plane bounced and cartwheeled—the right and bottom of the forward cabin, and the cockpit, began to heave and disintegrate.

The sixteen passengers and one infant who

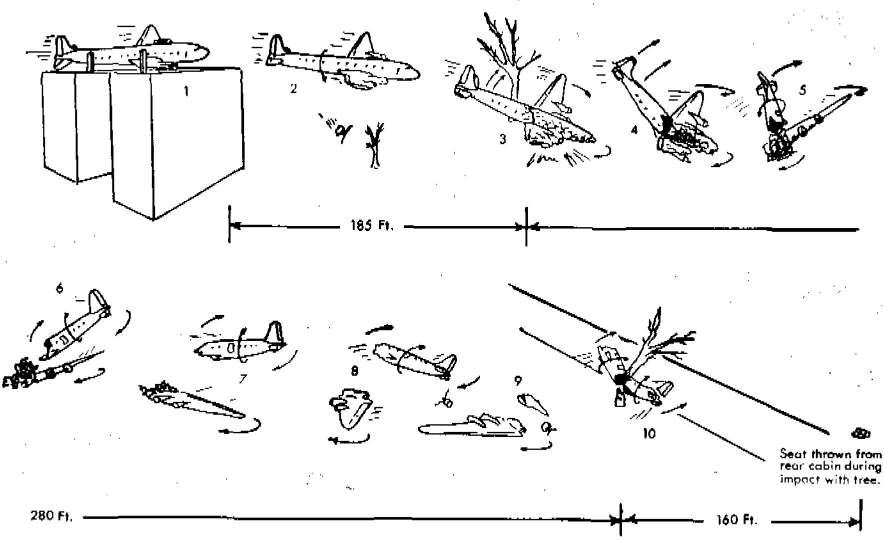


FIG. 2. National Airlines DC-6 February 11, 1952, Elizabeth, N. J. crash. Analysis of *progressive disintegration and kinematics of aircraft.* (*1*) Aircraft bellies onto roof of apartment house, right outer wing panel tears off. (*2*) Plane starts rolling to right, number 4 engine drops to ground. (*3*) Rear cabin starts jackknifing upward at rear spar as plane strikes ground. (*4*) Jackknifing continues and cabin begins to break free as the forward cabin disintegrates and the center section starts cartwheeling. (*5*) Rear cabin continues to tear loose during cartwheeling action. (*6*) Rear cabin tears completely loose in a "snap-the-whip" action as it starts rolling to the right and turning on its own CG. (*7*) & (*8*) Center section continues cartwheeling as rear cabin rolls and turns in "flight." (*9*) Center section comes to rest and burns after having cartwheeled more than 180°. (*10*) Rear cabin, still in "flight," strikes tree while partially inverted and rolling on its longitudinal axis; cabin breaks into two portions and comes to rest around tree.

were seated ahead of the front wing spar were involved in the destruction of the forward cabin area; thirteen died.

At the same moment, a portion of the cabin roof and the right fuselage wall near the sixth and seventh rows of seats collapsed inward as the rear half of the cabin jackknifed upward; two of the four people in these seats survived.

The center section, left wing, the disintegrated forward cabin structure and the intact rear cabin cartwheeled toward a line of trees bordering a nearby street. During this cartwheeling action, the rear cabin structure tore free from the center section and hurtled through the air—rolling clockwise on its longitudinal axis and changing direction approximately 180°. This "free flight" of the intact cabin and lounge ended abruptly when it struck a thick tree trunk.

At the moment of impact with the tree—a few feet above the ground—the cabin was rolling and partially inverted; the roof and the upper right-hand cabin wall failed inwardly. The occupants of Seats 27 and 27A were crushed as the tree trunk was forced part way through the cabin.

Almost simultaneously, the tree trunk broke at its base, and the left side of the cabin and floor structure failed under "explosive" tension loads; the fuselage then jackknifed around the tree with the two pieces of the cabin coming to rest at an angle to each other. . . . This wreckage did not

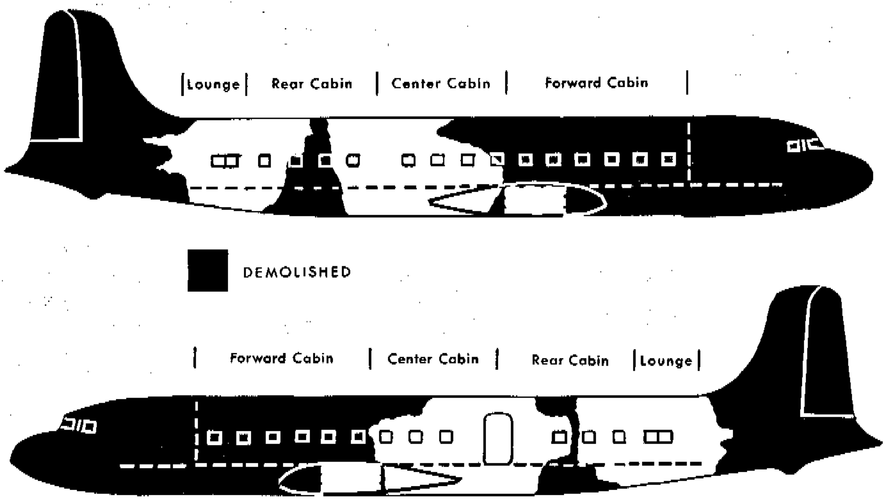


FIG. 4. DC-6 showing areas of cabin which were demolished. *A:* right side; *B:* left side.

burn. Of the thirty-five occupants originally in this portion of the airplane, 8 died, eighteen had varying degrees of injury, and nine sustained minor or no injuries.

While the rear cabin was crashing into the tree, the center section and left wing continued to cartwheel, coming to rest—and burning—after rotating around its vertical axis more than 200° from the direction of original impact. Wreckage and burning debris, the engines, and some of the passengers, still in their seats, were scattered along a 280-foot "wreckage path."

Crash Force, Structural Damage and General Injury Data

The glancing impact with the roof of the apartment building damaged the right outer wing panel, the nacelles, the belly of the airplane and the horizontal tail surfaces. However, the basic cockpit and cabin structure of the DC-6 sustained no appreciable damage, and the passengers did not feel any deceleration until the airplane struck the ground.

As shown in Fig. 2, the airplane was rolling clockwise and skidding—with the nose to the right—when it struck the ground; the initial crash force was from 11 o'clock, and slightly below the horizon. As the forward fuselage belly, the stub of the right wing, and the center section "dug in," the principal crash force came from the right (1 o'clock) and from below the airplane's longitudinal axis. Disintegration of the belly and right-hand portions of the forward fuselage*—as well as the cockpit and the stub of the right wing—occurred almost simultaneously.

The *mean* deceleration of the crash was between 2G and 4G.

The Cockpit: Magnitude of the peak crash force imposed on the cockpit and forward fuselage structure is, of course, unknown. It was certainly more than 6G in the crew compartment since the pilot's 6G seat-rail attachments failed under forward tension loads as the captain was thrown forward at impact. On the other hand, the crew's 17½G safety belt webbings showed evidence of strain but remained intact. However, the buckle cam of the co-pilot's safety belt was missing; apparently, some portion of the damaged cockpit structure sheared off the bolt holding the cam.

* Nose of airplane back to the forward wing spar.

As shown in Fig. 12 [omitted], there was a wide difference in the type of damage sustained in different parts of the cockpit. The right side was completely disintegrated; this is indicated by the fragmented wreckage of the co-pilot's seat. . . . The engineer's seat . . . shows less crushing of structure, and the condition of the captain's seat . . . implies collapse of surrounding structure, rather than disintegration.

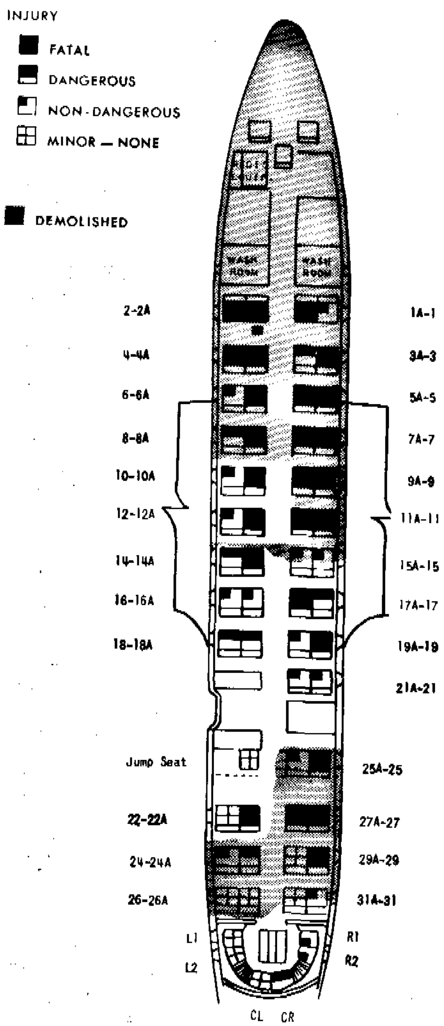


FIG. 5. Diagram showing areas of floor structure which were demolished, in relation to "degree" of injury.

Although the captain may not have sustained fatal injuries at initial impact, subsequent crushing of the cockpit structure as the fuselage collapsed and the center section dug into the ground and cartwheeled caused all three crew members to sustain multiple, fatal crushing injuries. Because of this, the use of shoulder harness and/or higher load factored crew seats probably would have made little difference in the exposure to injury experienced by the cockpit crew, in this accident.

Forward Passenger Cabin Area: The belly, floor, sidewalls and roof of the passenger cabin—ahead of the wing—progressively disintegrated as they were "ground under" after initial ground contact. The first four rows of seats in this area . . . were torn free and demolished. The direction of principal force imposed on these first four rows of seats was the same as that imposed on the forward fuselage structure—initially from the left and below the longitudinal axis of the airplane, and then from the right as the center section dug in. Loads imposed on the seats, seat attachments and the safety belts by the occupants are unknown. However, there was no evidence of failure of safety belt webbings on these seats. This would indicate that any force of reasonably "long" duration exerted on the safety belts was less than a force equal to a static "loop" load of 3,000 lb. on each belt ($17\frac{1}{2}$G).

Of the sixteen adults (and one baby in arms) occupying these seats, thirteen sustained multiple, fatal crushing injuries. Of the four survivors in this area, those in Seats 3A and 8 sustained dangerous injuries; on the other hand, the passengers in Seats 1 and 6, although exposed to great danger from collapsing and disintegrating structure, had non-dangerous injuries. Although they were sitting next to persons who were fatally injured, these two passengers survived because they were not crushed by heavy structure nor did they strike objects or structures with sufficient impact to cause fatal concentrations of force on vital areas of the body.

Since the entire floor structure under these eight seats (1-1A through 8-8A) disintegrated completely, additional seat anchorage strength could not have provided any appreciable increase in crash safety in this area. However, the height and ruggedness of the seat backs may have been an important factor in providing some measure of protection for the heads and torsos of the four survivors.

Of the four people, and one infant in arms, who were sitting in the *four aft facing seats* (1-1A, 2-2A), only one survived; the three other survivors in this area of complete demolition were sitting in *forward* facing seats.

The Center Section Area: When the wing stub and center section struck the ground, heavy crash forces were transmitted to the four double seats* whose aisle attachments were fastened directly to the center section structure. As the wing structure broke up, the cabin walls and ceiling adjacent to the center section collapsed and disintegrated; at about the same moment, the four double seats were torn loose and hurled—with their occupants—under the collapsing wreckage of forward cabin structure.

All the safety belts on these seats remained intact and the webbings showed no evidence of strain. This indicates that the occupants imposed "long period" tension loads of less than 3,000 pounds on the belts and seats. However, three of the quarter-inch aircraft bolts used to attach the aisle sections of the *left*-hand seats to the center section failed, indicating that very high jolt or shear loads may have been transmitted to the seat anchorages while lesser loads were being applied to the belts.

The damage to the two double seats on the right side of the cabin indicates that the seats were crushed by inward collapse of sidewall structure; as might be expected, all four of the occupants were fatally injured.

On the other hand, the two double seats on the left-hand side of the cabin sustained less damage. The occupants of Seats 10 and 12—next to the wall—sustained non-dangerous injuries, consisting mainly of multiple body abrasions and contusions and second degree burns; these burns apparently were caused by involvement with short duration flash fires since the seats showed no evidence of fire damage.

However, the two passengers sitting in the aisle seats were fatally injured; one, the occupant of 12A, sustained a fatal head injury—there is a possibility that he did not have his safety belt fastened at the moment of impact.

The Rear Area of the Forward Cabin: Jackknifing of the fuselage at the rear wing spar caused the cabin ceiling to fold inward and collapse in the general area of Seats 14-14A and 17-17A; of the four people in these seats, two survived, with a multiplicity of severe injuries.

Break-up and collapse of the floor structure under Seat 15A-15 seems to have permitted it and its occupants to "fall away" from inward collapsing structure and to be thrown out into the open as the cabin tore free. Both occupants survived, with multiple bruises and lacerations over most of their bodies and second degree burns from the flash fires that broke out in scattered areas of the wreckage.

The three remaining seats on the right side of the cabin were forced into the aisle by inward flexion of the sidewall along with collapse of the ceiling structure; the aisle seat anchorages failed. The buffet just ahead of the entrance door—on the left side of the cabin—tore free and struck the seat ahead (18-18A); failure of the aisle anchorages permitted the right-hand seats, with the exception of 21A-21, to pull free from the wall structure and hurtle onto the ground—with their occupants—as the cabin broke away from the center section. Two of the people in these seats on the right were fatally injured. One of the six survivors had dangerous head injuries. Five sustained non-dangerous injuries; the occupants of the rearmost seat had only a few lacerations, contusions and bruises.

Apparently none of the three double seats on the *left* side of the cabin—between the buffet and the center section—tore free during the initial phase of the principal ground impact. However, the attachments of Seat 14-14A probably were damaged when adjacent floor structure failed during jackknifing of the fuselage; this seat, with its

* 9A-9 through 12-12A.

occupants, was thrown into the main wreckage debris. One of the occupants was killed. The adjacent passenger had dangerous, but not fatal, head injuries.

The anchorages on Seat 18—18A seem to have been damaged when the seat was struck by the buffet; the seat subsequently tore loose when the rear cabin struck a tree broadside—after it had broken away from the center section. The people in this seat had dangerous injuries consisting of multiple fractures, lacerations and bruises—injuries which may have been sustained by prior involvement with downwardly collapsing ceiling and wall structures, as well as when the seat tore free.

Seat 16-16A, less than six feet from the center section break, was undamaged . . . ; its anchorages were intact and the seat remained in place. Its occupants sustained only non-dangerous injuries. One person remembers finding himself hanging upside down, unlatching his belt, crawling out of the cabin and then helping other people out of the wreckage.

The extensive collapse of the right sidewall and ceiling in this area, as well as the acute flexion of the cabin, as denoted by the complete fragmentation of the coat closet structure behind Seat 21A-21, suggests that most of the survivors in this part of the cabin would have been more severely injured—and probably killed—if the buffet unit had not prevented complete collapse, or "flattening," of the cabin.

Aft Cabin Area (Excluding Lounge): During the principal ground impact (in which the forward half of the airplane disintegrated, killing nineteen people) the seven forward-facing passenger seats in the rear cabin area remained in place and the fourteen occupants sustained no injury at this time.

However, after jackknifing and tearing free from the center section, the rear half of the fuselage spun on its own vertical CG and struck a large tree trunk broadside; simultaneously, heavy up and side forces—from the right—were imposed on the cabin structure, the seats, seat attachments and the occupants. A moment later, the cabin "wrapped" itself around the tree as the trunk forced its way partly through the fuselage, causing injury and death to nine of the fourteen passengers.

Seat 27A-27—on the right side—was directly in the path of the tree trunk; the seat was crushed and the occupants killed.

As the cabin collapsed around the tree, the entire floor structure (with the exception of a small portion under Seat 22-22A) disintegrated under "explosive" tension loads. As a result, all of the seat attachments, with the exception of those on 22-22A, failed, throwing the seats and occupants into a pile inside the cabin shell.

Of the fourteen passengers in the rear cabin area, five died—primarily of crushing injuries of the head. These five were in seats whose location roughly approximated a triangle with its center line parallel and adjacent to the tree trunk. Undoubtedly, the crushing injuries sustained by these five passengers were caused by inward displacement and failure of the cabin wall and ceiling and, in some cases, actual—forceful—contact with the tree trunk itself.

Three of the nine surviving passengers had non-dangerous injuries. Five had minor or no injuries—although they were no more than two seats away from persons who were killed.

Only one of the surviving passengers had dangerous injuries—to the head—which were caused by downward displacement of overhead cabin and hatrack structure.

The stewardess was seated facing aft in a folding jump seat attached to the rear side of the buffet. She was uninjured except for a glancing blow on the head which she probably received from a hand fire extinguisher when it tore loose from its attachment clip and hurtled laterally across the cabin; she was reported to have been unconscious for only a few moments.

As can be seen from Fig. 7, clockwise rotation of the cabin (around its longitudinal axis) during impact with the tree trunk tended to pull the right-hand seats "downward" and away from the tree—prior to failure of the floor structure. This may

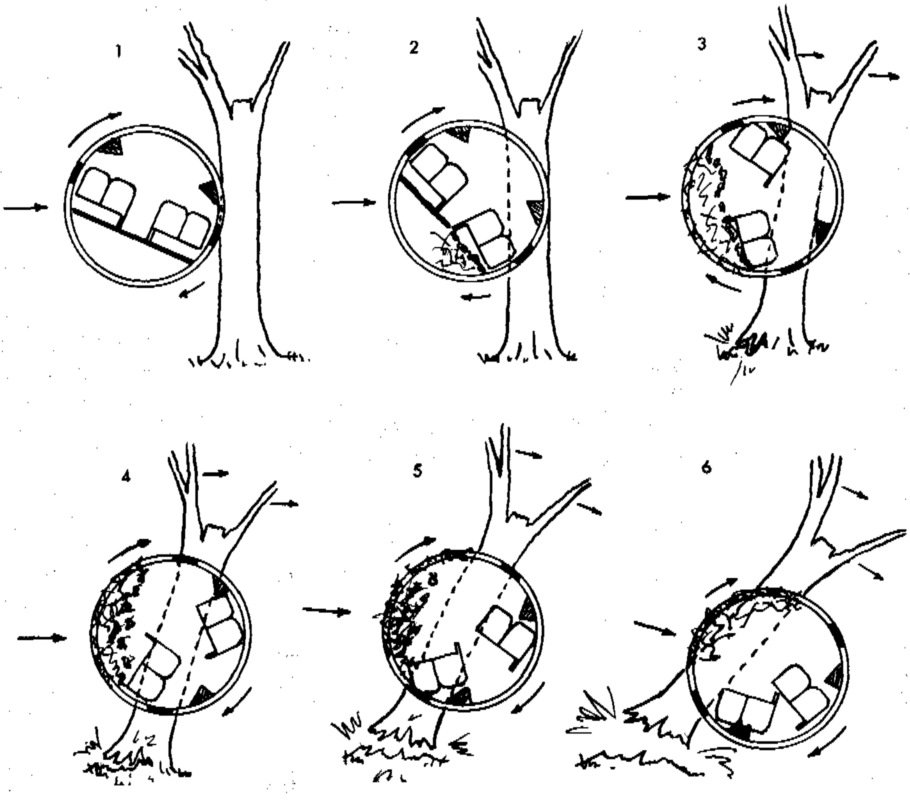


FIG. 7. View (through section A-A of FIG. 8 [omitted]) looking forward through rear cabin area during impact with tree. (*1*) Revolving to the right on its longitudinal axis, the cabin strikes large tree at seat 27. (*2*) Cabin continues revolving as tree penetrates ceiling and wall structure. Flooring begins to break up. (*3*) Entire floor structure disintegrates and belly structure starts to break apart under tension loads as cabin begins to "U" around tree. Seats break free and start tumbling inside cabin. (*4*) Cabin continues revolving as it breaks around tree. Six sets of 2-person seats tumble around inside cabin shell. (*5*) Cabin breaks apart into two separate pieces as belly and wall structures fail completely; seats tumble; tree breaks near ground. (*6*) Two pieces of cabin strike ground and come to rest partially inverted and "U-ed" around tree. Seats —with their occupants—intermingled in a jumbled mass. No fire ensued.

have had a marked effect in causing the seats—due to inertia—to initially "fall away" from the ceiling and tree as they came free from the disintegrating floor.

It is noteworthy—from the point of view of seat-back *height* design requirements—that the occupant of Seat 22 received only a minor laceration of the forehead although she was sitting only a few inches from a person who suffered fatal crushing injuries of the head; this survivor was a small child whose head was well *below* the top of the seat-back and thus was somewhat protected from downward crushing roof structure.

Had the rear cabin not been involved with such an "immovable object" as the large tree that it struck, there is every indication that all of the fourteen passengers in this area would have survived, with minor or, at the worst, non-dangerous injuries.

Actually, the people in the rear cabin endured two accidents; the first—involving disintegration of the forward portion of the airplane and fatal injury to many persons in the front cabin—caused *no serious injury to the occupants of the rear cabin.* The "second accident," however—involving an abrupt deceleration against the tree with inward crushing of structure—caused the serious and fatal injuries which were sustained in the aft area of the cabin.

The Lounge Area: While nineteen people were being fatally injured in the forward part of the DC-6 as it struck the ground, the six passengers in the lounge felt no appreciable crash force—nor were they injured. However, when the rear half of the cabin struck a large tree broadside, the lounge occupants were thrown heavily against their safety belts, the seats and, in some cases, the center lounge table.

As shown in Fig. 8 [omitted], the six lounge seats—with low seat backs—were arranged in a semi-circle. Under the directional conditions of crash force which existed during impact with the tree, the passengers in the left-hand seats (L1, L2) were subjected to "forward facing" conditions and the upper attachments of their seats failed under tension loads, permitting the seats to pull partially away from the sidewall structure; however, the two passengers were uninjured. Those in the center seats (CL, CR) were subjected to "side-facing" loads; the passenger in CL had only minor injuries. The one in CR, however, was thrown heavily sideways against the unyielding armrest and sustained an injury of the lower spine.

The passengers in the right-hand seats (R1, R2) were, in effect, seated facing "aft." The person in R2, *who was short in stature,* suffered non-dangerous but painful lacerations of the face and head as well as a fractured facial bone and mild concussion. The lacerations of the head and face apparently were caused by flying fragments of nearby plastic partitions which shattered during the tree impact. The fractured facial bone may have resulted from the passenger "rebounding" and striking the table top. The occupant of R1 (a *tall* man) is reported to have suffered a non-dangerous back injury; this may have resulted from his "flexing" backward over the low seat back with which the lounge seats were equipped.

From the point of view of injury potential in relation to seat design, and direction of crash force application, it is interesting to note that the two people who, in effect, were seated facing forward (L1 and L2) sustained no injuries whatsoever, while one of those facing "aft" in a low-backed seat (R2) did sustain a spinal injury although it was of a non-dangerous degree. On the other hand, the most serious injury (to the spine) was sustained under a "side-facing" condition (CR).

Injuries

The injuries sustained by the 59 passengers varied widely in seriousness—from multiple, crushing, fatal injuries to minor bruises and lacerations, or no injuries whatsoever.

Twenty-seven of the fifty-nine passengers were killed; eight suffered dangerous* injuries; fifteen sustained non-dangerous** injuries, and the remaining nine had minor or no injuries.

Sixty-four percent of the passengers received blows to the head of sufficient force to cause skull fracture and/or concussion, and/or death from brain lesions.

The injuries sustained by each person with respect to seat location are detailed in . . . Appendix [3].

Fatal Injuries: Eighty-eight percent of the twenty-seven persons killed in the accident had fractures of the skull and/or of the ribs; eight of these had a combination of fractures of the skull *and* ribs *and* one or more of the extremities (arms or legs). Another five had fractures of the skull and ribs without fractures of the extremities. Nine of the twenty-seven dead had fractures only of the skull.

* Dangerous: Injuries threatening life even under prompt medical care.
** Non-dangerous: Injuries which *normally* do not threaten life.

There was one case in which internal injuries were definitely reported; however, these internal injuries were associated with fractures of the ribs. Two other persons were reported as possibly having internal injuries—one of these passengers also had a fracture of the skull; the other had injuries of the chest. None of the three cases of reported and "possible" internal injuries was attributed to the safety belts.

Only one passenger sustained eviscerating injuries of the abdomen.

In summary, of the 27 passengers killed in this accident:

- 48% sustained fractures of *both* the head and ribs.
- 33% sustained fractures of the head alone.
- 7.4% sustained fractures of the ribs alone.
- 3.7% were reported to have had internal injuries.

Dangerous Injuries: Eight survivors sustained dangerous injuries. Two of these eight had a combination of dangerous fractures of the skull *and* ribs; a third had a skull fracture, and a fourth suffered fractures of the ribs.

Seven of the eight had concussion.

Only one of the two persons who sustained a combination of fractures of the skull and ribs had internal injuries of the chest. Another, who sustained fractures of the ribs only, was reported to have had *possible* abdominal injuries; the "possible" and reported internal injuries were *not* attributable to the safety belts.

Three of the eight dangerously injured survivors sustained fractures of one or more of the extremities.

In summary, of the eight passengers who suffered dangerous injury:

- 25% had fractures of *both* the skull and ribs.
- 12½% had fractures of the skull alone.
- 12½% had fractures of the ribs alone, and
- 87½% had some "degree" of concussion.

Non-dangerous Injuries: Fifteen of the passengers sustained non-dangerous injuries; *none* had fractures of the skull. However, three sustained fractures of the ribs, and two received fractures of one or more of the extremities.

Two of these fifteen persons were reported to have had sprains of the back, and one a non-dangerous injury of the lower spine. One passenger had a fracture of the clavicle (collar bone), and one had a contusion of the chest wall.

None were reported to have had internal injuries.

Eight of the fifteen exhibited "degrees" of concussion which were not regarded as normally dangerous.

In summary, of the fifteen passengers who sustained non-dangerous injuries:

- None had fractures of the skull, although
- 53.5% sustained concussion.
- 2% sustained fractures of the ribs, and
- None had internal injuries.

Minor or No Injuries: The remaining nine passengers—and the stewardess—sustained minor or no injuries. The minor injuries consisted, in most cases, of nothing more than bruises, contusions and/or lacerations. Four of the nine reportedly sustained no injuries whatsoever; two of these are said to have taken a taxi to the airport immediately after the accident and boarded another airplane to their intended destination.

Burns: Of the fifty-nine passengers involved in the accident, a total of thirteen received various degrees of burns as a result of being involved in the post-crash fire which developed on and around the left-wing and center section wreckage. The following is a breakdown of the number of persons who received burns with reference to their injury category:

	Number burned
Fatals	4
Dangerously injured	3
Non-dangerously injured	5
Minor or none	1
Total	13

FATAL INJURY IN RELATION TO CABIN DEMOLITION

Forward Cabin: As stated earlier in this report, the forward half of the fuselage—ahead of the rear wing spar disintegrated during the principal ground impact. Nineteen of the twenty-seven fatally injured passengers were in this disintegrated area. These twenty-two dead represented 76% of the total number of passengers seated in the forward cabin.

Fatal injuries in this area resulted from the people being crushed, or by their striking or being struck by wreckage. In most cases, they sustained multiple and fatal crushing injuries of both the head and chest, accompanied by fractures of the arms or legs.

There were, however, six persons in the front cabin who survived the crash. Four of the six were seated on the extreme lefthand side—furthest away from the "heavy impact" region. Two were on the right side; one was in the most forward row of seats and the other in the second row. The survival of these two can be attributed to nothing more than luck, in that they missed being crushed or hit by heavy structures as the cabin disintegrated around them.

Center Cabin: The center cabin—immediately aft but adjacent to the prime disintegration "zone"—was damaged to a severe degree and in danger of complete collapse; however, basic cabin structures held together sufficiently to protect many of the occupants, for eleven of the fourteen passengers survived. Sixty-three percent of these sustained *non*-dangerous injuries consisting, in some cases, of nothing more than bruises and lacerations.

Generally, the injuries sustained in the center cabin area were caused by (a) inward displacement of structure, and/or (b) the passengers being thrown—in their seats—against intact but rigid cabin components and against wreckage of basic aircraft structure. Even when seats tore free, the semi-intact cabin shell apparently prevented many of the seats (and people) from being thrown against or under solid structures—such as the engines and center section wreckage—and crushed.

Rear Cabin: Causes of injury in the rear cabin and causes of survival followed the same pattern as that in the forward cabin area. The passengers killed in the rear cabin mostly sustained crushing injuries of their heads and chests, and fractures of the extremities. This was due, again, to complete collapse and disintegration of part of the cabin structure (just ahead of the lounge) when the fuselage struck, and broke around, a large tree trunk.

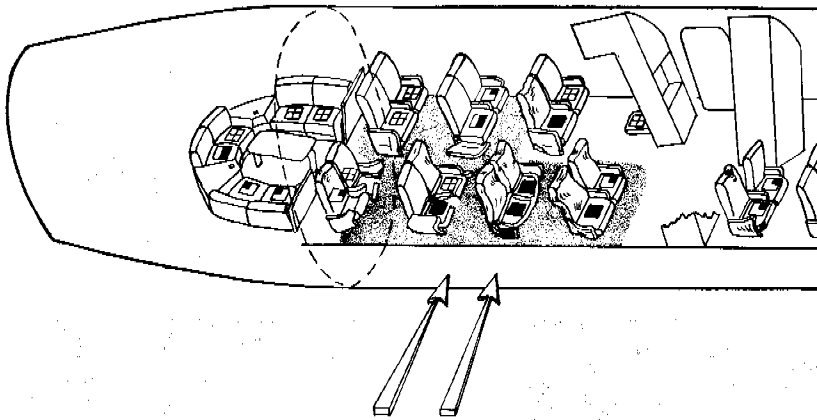
Five of the passengers (or 36% of the fourteen passengers) in the rear cabin were killed—mostly as a result of being struck by inward crushing cabin structure and, in several cases, from being hit directly by the tree as it tore through the interior of the cabin.

An equal number of passengers (5) in this same general area sustained minor or no injuries, indicating that (a) the demolition area (with resulting fatal injuries) was sharply defined, and (b) that crash force, in itself, was not primarily a direct cause of injury.

As evidence of the above, two people, seated within a few inches of persons fatally injured, sustained nothing more than a few bruises and lacerations. In another instance, the occupant of a window seat sustained non-dangerous injuries, while his companion in the adjoining aisle seat received dangerous head injuries when the hatrack structure crushed downward—his head was *above* the top of the seat back; the seat back was relatively undamaged.

The Lounge: The lounge structure (in the rear of the airplane) was substantially damaged and on the verge of collapse. However, there was little inward "flexion" or crushing of structure during the crash, and the damaged "shell" protected the occupants. All six occupants of the lounge were thrown heavily against their safety belts and seats but they were held in place; no fatalities occurred. Three of the passengers sustained injuries classed as minor or none; two had no injuries at all. Only one lounge passenger

FIG. 11. National Airlines DC-6 February 11, 1952, Elizabeth, N. J. crash. Reconstruction drawing showing areas of floor demolition and "degree" of injuries sustained by passengers in relation to damage and location of their seats in the aircraft at the time of the crash.



suffered a "dangerous" injury (to the lower spine) which probably resulted from sideward flexion against a rigid bookrack which served partly as an "armrest."

INJURY IN RELATION TO SEAT DAMAGE

In areas where cabin structure was *demolished*, fatal and dangerous injury generally coincided with severe damage to the seats. Twelve 2-person seats were located in the forward section of the cabin—which disintegrated during impact with the ground. Six were on the left side of the cabin, and six on the right. The first set on each side was aft-facing; the rest were forward-facing. Eleven of the twelve sets of seats were severely damaged and, in some cases, disintegrated. This damage resulted from disintegration and inward crushing of the cabin ceiling, walls and floor. Nineteen of the twenty-four people (and one baby) sitting in these seats, which were severely damaged, were killed. In most cases, they sustained multiple, fatal crushing injuries of the head and chest, accompanied by multiple fractures of one or more of the extremities.

Seven 2-person seats were in the rear cabin—a major portion of which was demolished on impact with the tree. Four of the seats sustained severe damage; five of the fourteen passengers were killed.

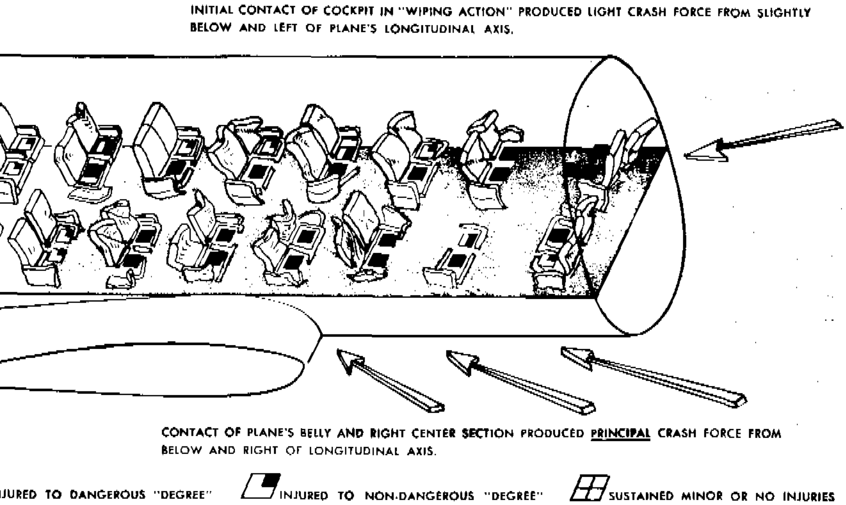
In other portions of the cabin which sustained severe damage but *were not demolished*, fatal and serious injury was *not* necessarily associated with severe seat damage. For example, although three of the seven sets of seats in the center cabin were severely damaged, only one person in the severely damaged seats was killed. The two others who were killed occupied seats which sustained little damage; their fatal injuries apparently were caused by small portions of rigid structure striking their chests and faces.

Eleven passengers survived in this center cabin area, five of whom were sitting in seats which sustained severe damage.

The lounge—relatively intact—contained three sets of seats, all of which were damaged to a minor degree; all six occupants survived.

GENERAL DETAILS OF SEAT DAMAGE IN RELATION TO INJURY

Front Cabin: The first five rows of seats on the left side of the forward cabin and the first six rows on the right side were severely



damaged; some were practically disintegrated. . . . *Since these eleven sets of 2-person seats were located in the forward portion of the airplane that disintegrated during principal impact, the degree of demolition of the seats is not unusual.* The bottoms of the first four rows of lefthand seats were torn apart and practically disintegrated . . . ; the rear main cross tube of the first, second and fourth row seats were broken, destroying, to a great extent, the integrity of the seats and any protection which the seats might have provided the occupants.

As shown in Fig. 11, the seat backs on all eleven sets of seats were damaged to a severe degree. The type of damage indicates that the seats were subjected, in most cases, to heavy crushing loads; these loads also were responsible for the crushing injuries sustained by the nineteen fatally injured persons.

The second and third rows of seats on the right side were also damaged by fire after impact. However, one occupant of these seats survived with critical injuries; evidently he was thrown clear of the seat when the safety belt end-attachments failed.

A number of the seats had deep vertical V-type dents in the tops of the seat-backs...; it is indicated that this was caused by impingement of rigid hatrack structure on the tops of the seat-backs as the cabin roof and floor collapsed toward each other.

Center Cabin: In the center cabin area, three of the seven 2-person seats were severely damaged; three occupants of the damaged seats sustained dangerous injuries; a fourth was killed.

Two of these three seats were apparently thrown out into the burning wreckage area when the cabin broke away from the center section. The people in Seat 15A-15 suffered non-dangerous injuries but received burns on their faces and extremities, as well as multiple bruises and lacerations.

The four remaining sets of seats in the center cabin area were damaged to a minor degree. Five of the occupants had non-dangerous injuries, one had dangerous injuries, and two were killed. The dangerous and fatal injuries sustained in "intact" seats were probably caused by "small" pieces of wreckage striking the peoples' heads and chests as the seats broke free.

Rear Cabin: In the rear cabin, the four rows of seats on the right side were generally damaged to a severe degree due to (a) inward crushing of cabin wall and roof structure, and/or (b) forcible contact with the tree trunk as it broke into the interior of the cabin.

Four of the people in these severely damaged seats were killed; a fifth had dangerous injuries. The remaining three sustained minor injuries only.

The three sets of seats on the left side of the rear cabin were damaged slightly. Three of the occupants had minor or no injuries, a fourth suffered non-dangerous injuries, a fifth had dangerous injuries, and the remaining passenger was killed. Both the fatally and dangerously injured passengers in these seats apparently were struck by downward crushing roof and hatrack structures.

The Lounge: The three sets of 2-person seats in the lounge sustained only minor damage. Three of the occupants had minor or no injuries, two had non-dangerous injuries; the sixth occupant sustained a lower back injury, probably due to sideward flexion against the book rack structure forming the armrest at the side of the seat.

To summarize:

Eighty-eight percent of the fatally injured passengers and 62% of the dangerously injured persons occupied seats that sustained severe damage.

On the other hand, *60% of the non-dangerously injured passengers and 77% of the passengers with minor or no injuries occupied seats that were virtually intact.*

As noted before, all but three sets of seats—excluding those in the lounge and the stewardess's seat—were torn free sometime during the accident. Many of these seats and their occupants were crushed by heavy wreckage. However, other seats, although free to plummet against structure, provided some degree of protection for their occupants. It appears, therefore, that seats can be designed to give protection for passengers who are not directly involved with demolition of heavy aircraft structures.

* * *

APPENDIX 2

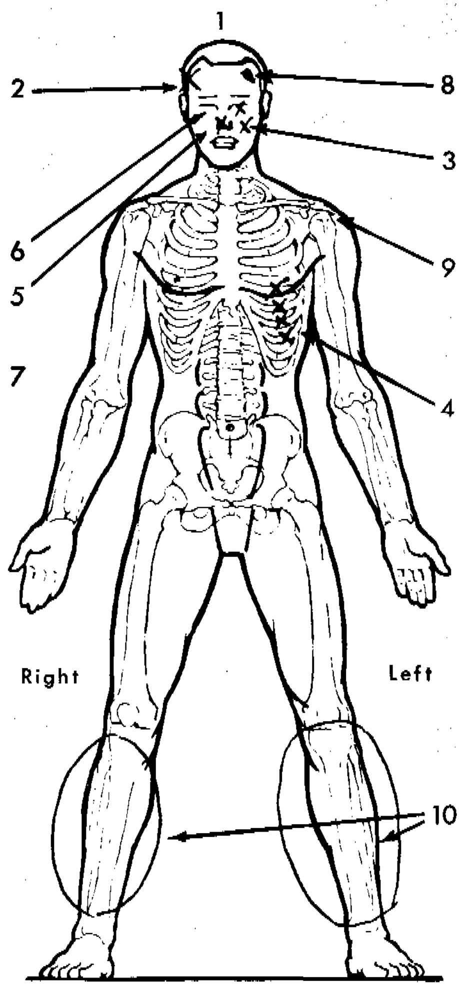
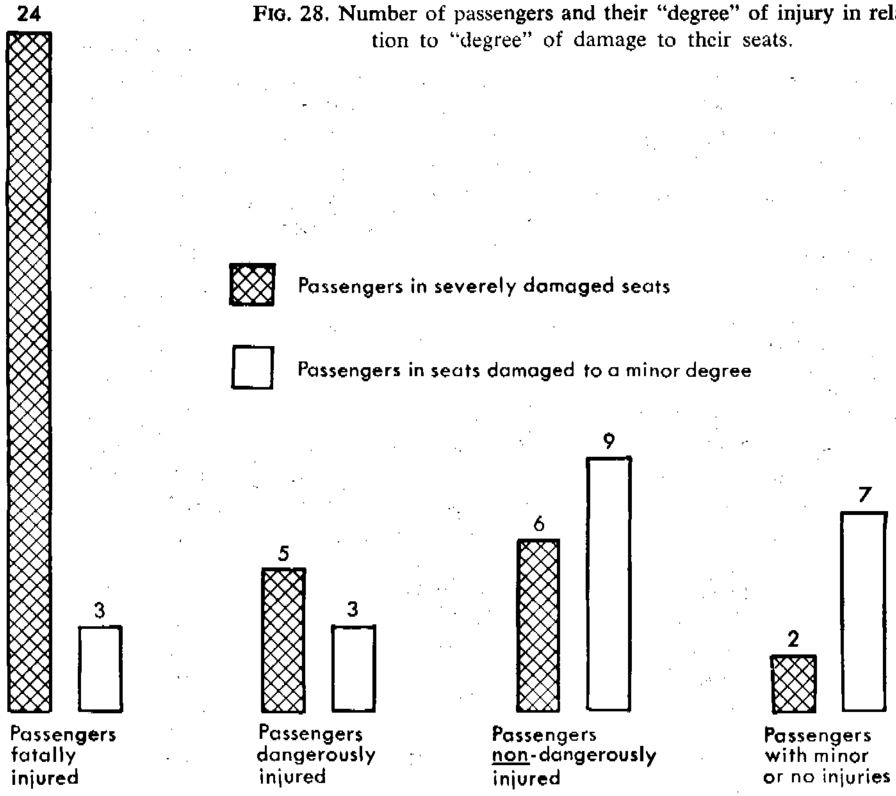


FIG. 27. Diagram showing injuries sustained by a survivor in the transport accident covered in this report. Injury classification: *Dangerous.* (*1*) Cerebral concussion: shock. (*2*) Skull fracture: right parietal. (*3*) Fracture zygoma and orbit. (*4*) Fracture 5th, 6th, 7th, 8th ribs with separation. (*5*) Fracture and dislocation of nose. (*6*) Severe laceration about both eyes. (*7*) Multiple body bruises. (*8*) 2½″ × 2″ laceration on forehead. (*9*) Slight acromioclavicular separation. (*10*) 2nd degree burns lower extremities (sustained after crash).

APPENDIX 3

FIG. 28. Number of passengers and their "degree" of injury in relation to "degree" of damage to their seats.



We mentioned in connection with Stapp's work the difficulty of adequately determining under *non*experimental conditions all the pertinent force configurations. For this reason, workers concerned with understanding and ameliorating the factors that result in injuries to occupants of passenger vehicles have produced carefully planned and instrumented crashes. These experiments have substantially advanced our understanding of accident phenomena of this type.

AUTOMOBILE-BARRIER IMPACTS, SERIES II†

—D. M. Severy, J. H. Mathewson

By now the reader should be quite aware that the variables pertinent to the production of injury, whether unexpected or not, are different from those which have

† The issue of *Clinical Orthopaedics* from which this selection is reprinted contains other reports of interest, notably a discussion by the late Edward A. Dye of the results of his pioneering work with respect to the kinematics of the body motion under crash conditions. In addition, an example of the instrumented crash of an aircraft with dummy occupants has been reported by Turnbow.[10]

usually been considered by research workers concerned with accident causation. For this reason, particularly in Chapter 3, we have repeatedly made a somewhat artificial but useful distinction between research concerned with the factors leading up to accidents and research concerned with the factors that determine the resultant injury. However, the strangeness of these more physical parameters should not frighten away those with backgrounds in other fields, since it is quite possible for them to glean at least principles from the relatively technical material presented here. Because of this objective, and to indicate the considerable complexity and sophistication of this field, we have retained much of the detail presented by Severy and Mathewson in their original report.

Among the many points which should be noted in this report is the remarkable brevity of the impacts and interactions described. Similarly short intervals are the rule rather than the exception in the production of unexpected injury. As a result, the observer or participant unaided by appropriate devices often cannot provide reliable information as to the details of accidents that occur before his eyes. This also often holds for the immediately preceding events, although this is frequently overlooked in legal and other attempts to determine the details of accidents that seem to have been adequately witnessed. This brevity may also explain the late development of crash injury research, since the detailed phenomena involved were not easily recognized.

BARRIER CRASHES conducted in 1953 and 1954 furnished the first detailed information of the deceleration rates and patterns associated with ground vehicular crashes. This type of experiment is easy to conduct relative to one involving two moving objects, since the impact parameters for the exacting purposes of research may be predetermined with reasonable accuracy. The rate of deceleration for the barrier crash generally exceeds that for other types of impacts at comparable velocities. Hence, the barrier impact provides a rigorous test having decelerations of the same direction and of comparable magnitudes and patterns as those which are encountered most frequently in collision-type accidents. Therefore, valuable basic data may be derived from experiments on restraining harnesses and similar safety devices under these conditions while simultaneously collecting much information on the collapse characteristics of the automobile. Because this type of impact eliminates the variables of (1) type of structure of opposing car, (2) mass of opposing car, (3) velocity of opposing car, (4) direction of impact and (5) point of impact, the barrier provides an excellent medium for testing the shock absorption effectiveness of force-moderating innovations and safety restraining-devices, all designed with the purpose of reducing the crash injury potential of the vehicular accident. These basic reasons indicate why the auto-barrier crash was selected as the first type of fully instrumented collision experiment to be undertaken by ITTE. [Institute of Transportation and Traffic Engineering, University of California, Los Angeles.]

EQUIPMENT AND FACILITIES

A barrier was constructed near the end of a 1,000-ft. dirt road (Fig. 1). This barrier, 8 ft. tall and 14 ft. wide, was made of large-diameter electric-utility poles sunk to a depth of 8 ft. in the ground and backed by suitable cross-members and braces to provide a rigid structure.

Cars of the same make, model and age

[Reprinted, with permission, from *Clinical Orthopaedics*, *8*:275-300, 1956. The final portion of the text, 16 figures, and 7 tables have been omitted.]

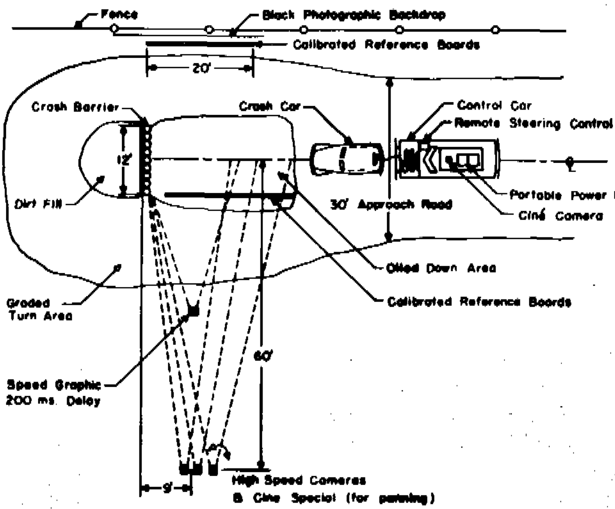


FIG. 1. The experimental site.

were selected for these barrier collisions. Appropriate calibration markers were secured to the car. . . .

A movie camera (modified G.S.A.P. 16-mm camera operated at 64 frames/sec.) was mounted on the rear shelf of the crash car and directed forward for the purpose of photographing the movements of the dummies during collision. Specially devised indicators were welded at 6-inch increments to the frame of the car from its forward end (left side) back to below the firewall. The target indicators of these devices were grouped behind the left-front wheel. . . . These devices provide data concerning the deceleration pattern for each 6-in. increment of the front section of the car frame. Accurate precrash and postcrash measurements were made of the frame, forward of the firewall, to provide permanent deformation data. The electrical leads from safety belt tensiometers, electric accelerometers, remote-control steering and braking devices, and other special equipment within the test car were joined to a cable which was secured to an 8-ft. boom extending out from the rear of the car. This boom supported the cable during the crash, tending to prevent the cable from being thrown under the wheels of the car as the car rebounded from the barrier. This 100-ft. cable was connected to the push-truck which carried the recording oscillograph, the remote steering and braking controls, the portable power units and accessory equipment.

EXPERIMENTAL PROCEDURE

The test car was brought up to the barrier to permit the photographic equipment to be focused and directed at the vehicle. Following this, the vehicle was removed to a point approximately 1,000 ft. from the barrier. Then the instrument truck was used to push the test vehicle up to a steady speed of approximately 30 mph until a predetermined point in front of the barrier was reached. At this point the instrument truck was braked to a quick stop. The test vehicle coasted on into the barrier at an impact speed of 25 mph. . . . Throughout, the crash car was guided by remote control by an operator seated in front of the right section of the instrument truck windshield. . . . During the time the car took to coast this interval of 100 ft., the instrument truck was decelerated to a stop so that it was motionless, and the recording oscillograph was started before the car struck the barrier. Thus, the mobile recording station had become stationary in time to record the crash data without having the interference problems possible with mobile recording units.

INSTRUMENTATION

Photography: Two Eastman high-speed cameras (0-3,000 frames/sec.) were used as a precaution against possible loss of valuable data due to power failure, film processing accidents, etc. Reference targets were painted on the principal points of interest of the car and on the dummies to provide a means, by high-speed photography, for recording data leading to the determination of velocity, acceleration, deformation and similar information. The G.S.A.P. camera mounted on the shelf above the rear seat provided an inside-the-car record of the dummies' reactions to impact. A Ciné Special movie camera was used for panning the car as it proceeded into the barrier. A second Ciné Special camera was mounted on the top of the instrument truck to provide a record of the collision in the direction of the motion of the colliding vehicle. Table 1 [omitted] presents the photographic data related to these tests.

Camera-Oscillograph Synchronization: In order to provide a common time basis for relating the physical observations of the crash recorded by the camera to the physical factors recorded by the oscillograph, a means of synchronizing these two variable speed-recording functions was introduced. This comprised feeding the signal from a magnetic pickup on the drive wheel of the camera to one channel of the oscillograph via a line from the camera to the instrument truck and dragged by the truck. The camera film speed was identified by a 60-cycle per second timing light marking on the edge of the film. The photographic paper speed of the Hathaway Recording Oscillograph was identified by the transverse line applied each 100th second.

The common time origin for these two recording systems was selected as the instant the front bumper of the car came into contact with the barrier. A probe was mounted so that it extended through the radiator flush with the front bumper. A slight axial movement of this probe actuated a switch which was connected to one channel of the oscillograph. The broad end of the probe was clearly visible from the high-speed camera position so that the instant of contact also could be determined photographically.

Accelerometers: Eight electrical accelerometers were used, of which 6 were Hathaway units and 2 Statham. In addition, 5 Gross mechanical accelerometers were used. The characteristics of these devices are given in Table 2 [omitted], while the placement and the axis orientation for these experiments are given in Table 3 [omitted].

Experience has shown that aircraft, the automobile and vehicles such as the linear decelerator sled used by Stapp developed vibrations within their structural components during collision decelerations which, although comprising seemingly negligible displacements, nevertheless may represent large accelerations. In such cases, the vibration of the structural member at its natural frequency may mask completely the total structure acceleration.

Table 4 [omitted] presents the vibratory frequencies during the first $4\,{}^{1}/_{10}$ second intervals following the crash. The average of these values provides an estimate of the natural frequency of the structure on which the accelerometer unit was mounted. It appears that for the cars used in this crash, and for the structures instrumented, the natural frequency of these structures varied between 60 and 90 cps.

In many experimental studies, it is desirable to have detector units with as high a frequency response as is technically possible. However, in the problem of measuring decelerations of impacting structures, consideration must be given to the differentiation between oscillations and accelerations. Therefore, it is important to select a frequency response sufficiently high to reproduce adequately the impact decelerations without having the response so high that the unwanted vibrations (so-called "buzzes" of the structure) are included to confuse or even mask the basic data.

It has been estimated, using a triangular pulse as a simplification of the deceleration pulse encountered during collisions, that with an undamped natural frequency for an accelerometer of 50 cycles per second and a damping ratio of 0.7 or less, an accelerometer error of not more than 5 per cent results. . . . the natural frequency of the Hathaway accelerometers is 230 to 260 cps, and for the Statham, 120 cps. This relatively high frequency response appears to account for the 60 to 90 cps "hash" present in the deceleration curves produced from these units.

Hathaway Oscillograph: The signals from the various detector units mounted in the experimental car were fed to the 24-channel Hathaway Oscillograph Type S 8-C via its associated power supply units and its Strain Gage Control Unit, Type MRC-15... A sample of the data from this oscillograph is given in Figure 8.

Frame Deceleration Indicators: The mechanism of collapse of a structure during collision is of interest to the engineer. A knowledge of the order and the magnitude of deformation of each section of the structure provides a basis for evaluating the total structure in terms of its efficiency for attenuating the collision forces and, therefore, the decelerations of the intact portions of the vehicle.

A system has been developed by ITTE for instrumenting each 6-inch section of the front of the car frame back to a point about opposite the rear edge of the front wheel. This system was necessary for the provision of accurate photographic instrumentation to a point on the structure obscured from view by the front wheel. This was accomplished by welding $1/4$-in. steel drill rods to the frame at these points in such a manner that they were nearly flat against the frame and pointed toward the rear of the car. A checkered target was painted onto the $3^1/_4$ x $3^1/_4$ x $^1/_{16}$ in. plate welded to the unsecured end of the rod. . . .

The movement of these targets as the car frame decelerates and deforms was photographed by high-speed cameras. The results obtained from this system of frame deceleration measurements is presented in a later section.

Frame Deformation Indicators: One method of obtaining useful engineering information from a collision is to measure specific car frame positions before and after impact in order to evaluate the location and the magnitude of collision deformations.

Positions on each side of the car frame were marked with metal screws at points approximately 1, 2, 3, 4, 5 and 7 feet back from the front edge of the bumper. The distances between these points were measured by projecting them onto a horizontal plane both before and following the collision. . . . The results of these analyses are presented under *Frame Deceleration and Deformation* in a later section.

Tensiometers: Electrical accelerometers, high-speed photography, dummy-damage diagnosis and safety-belt tensiometers provided the instrumentation applied to the dummies. The belt tensiometers provided a force-time history of the loading to which the safety belts were subjected. Four tensiometers were constructed for this purpose. . . . The belt is threaded between the 3 bolts connecting the 2 links. Application of tension to the bolt bends the links sufficiently to permit the pair of SR-4 (Type A-5) strain gages bonded to each link to register the deformation. The tensiometers were calibrated statically, using a 60,000-pound Baldwin Universal Testing Machine. This calibration provided the basis for interpreting deflection of the recording oscillograph, connected to a belt tensiometer, in terms of pounds load. Tensiometers were used in pairs, one near each anchorage of the belt, in order to detect differential loadings to which the belt was subjected during collision. The records taken by these devices are presented in a later section.

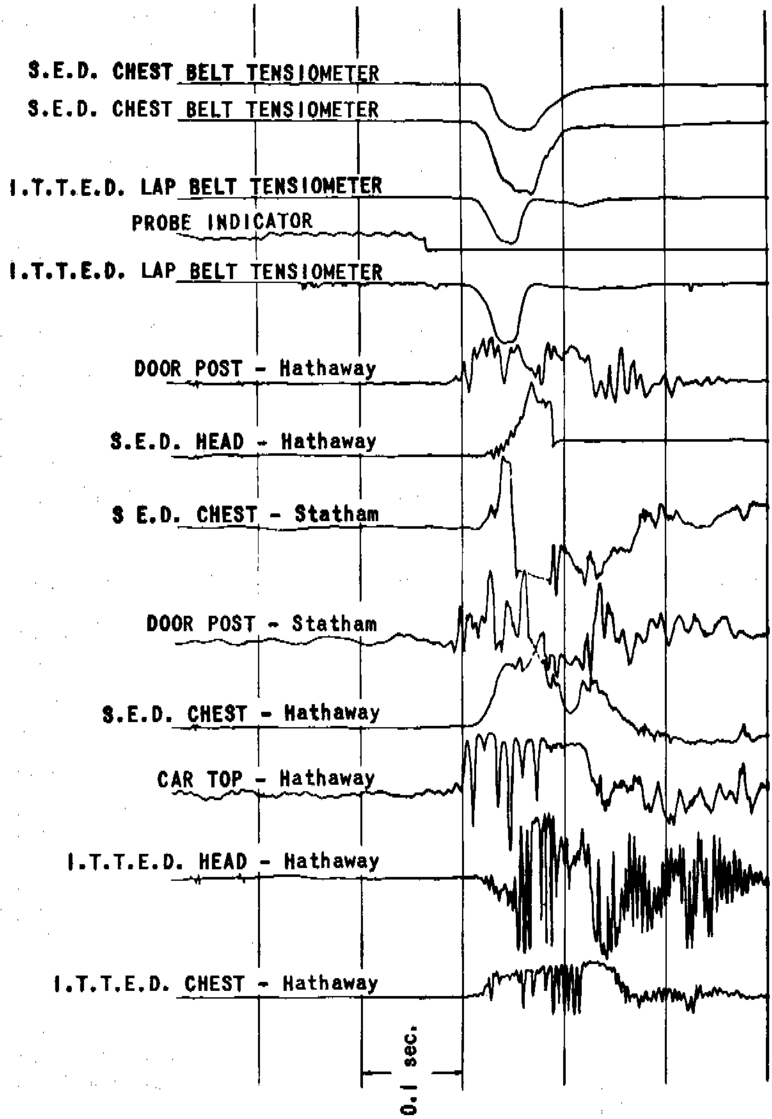


FIG. 8. Oscillograph record of collision with fixed barrier at 29 mph.

Physiologic Instrumentation: Instrumented anthropometric dummies provide the most practical means of determining the injury potential to vehicle occupants under specific collision conditions. The data recorded during impact permits the determination of the force system applied to the motorist during collision and from this, the type, the nature and the severity of injuries likely to be encountered. An explanation of this system, together with the results obtained, is given in a later section.

The dummy* built by the Institute is referred to as ITTED, the abbreviation for Institute of Transportation and Traffic Engineering Dummy. The second dummy is called SED, after its manufacturer, Sierra Engineering (Company) Dummy. The Model 120 Anthropometric Dummy (SED) is described in detail by the manufacturer's brochure.

In general, the more severe the collision conditions, the more closely the anthropometric dummy duplicates human responses, because the small differences between the dummy and the human relative to joint fixation, flesh compressibility and similar factors become negligible during collisions where the body may be loaded by 1 or 2 tons crash force.

Experimental Findings

Human Body Dynamics with Changes in Belt Configurations: The dynamics of the human body during a collision were determined for 5 conditions of restraint. Four restraints were evaluated by experimental collisions with a fixed barrier, using anthropometric dummies, while the fifth restraint was used by a human subject in a collision with a stationary car at 20 mph. The results of this latter experiment have been used as a basis for estimating the performance for that restraint in a collision with a fixed object at 25 mph.

The effect of varying the belt configuration for a 25-mph collision with a fixed object is given in Figure 10. The performance of the belts used for the first 4 examples is discussed in connection with Figures 11, 12 and Table 5. The inferred injuries developed during the first 4 test conditions are presented in Table 6. The human subject using the combination restraint (lap and shoulder-loop belts) for a 20-mph collision with a stationary car provided the basis for estimating the body dynamics given by the example at the bottom of Figure 10. . . .

Belt Tensiometer Results: Belt tensiometers provide a force-time history of the loading to which the safety belts were subjected. Tensiometers were used in pairs, one near each anchorage of the belt (Figs. 11 and 12). For the shoulder-restraining device, 2 tensiometers were placed in series adjacent to each other in order to provide the evaluation of reproducibility of the tensiometer. Referring to Figure 11, the curves show the close reproducibility of information. An important characteristic of the shoulder-loop belt is the fact that the rate of onset and subsequent reduction of the force is relatively gradual. *The belt restrains the body against significant forces over a comparatively long period of time.* These features of the curves suggest that the belt commenced restraining the body more quickly following the onset of collision so that large differential velocities could not develop between the car body and the human body.

Figure 12 presents tensiometer curves for the lap belt and the chest belt. The tensiometers on the left side for both (front seat) dummies gave lower readings than those on the right side, indicating that frame failure on the left preceded the right side. This condition was unexpected, considering the fact that the collision was a direct (approximately perpendicular to the barrier) impact. The car was undergoing a very shallow turn to the right to correct its course toward the center of the barrier when it struck the barrier. Although the impact appeared to be perpendicular, the front side of the car frame may have been slightly leading the right side. Also, it is possible that irregularities in the barrier or the basic car frame structure may have accounted for this uneven application of forces.

The integral of the Figures 11 and 12 provides a basis for comparing the relative effectiveness of restraining configurations for the same collision conditions. Table 5 presents the results of this comparison.

* Anthropometric dummy. Sometimes referred to as anthropomorphic dummy. A mannequinlike structure having measurements, component weights, centers of gravities and similar dynamic parameters which correspond closely to those of the human body. The behavior of such a device during a crash or similar dynamic event corresponds closely to the kinematic behavior of the human body under similar conditions.

TABLE 5.—PERFORMANCE OF 3 BELT CONFIGURATIONS

Restraint configuration	*Peak force lbs.*	*Belt stress duration in seconds*	*Force time units*	*Relative restraining effectiveness* *
Chest	1,735	0.105	2,300	100
The chest belt dissipates a greater amount of body crash energy than the other (see below) 2 units without increasing the peak stress to the body. Physiologic considerations are discussed elsewhere.				
Lap	1,725	0.057	1,500†	77
The lap belt is a somewhat less efficient restraining device for front-seat occupancy and for the front-end impact situation. It does not prevent the head and the upper torso from striking the forward surfaces of car interior. Energy is then absorbed from the most vital parts of the anatomy by injury-producing mechanisms.				
Shoulder loop	1,735	0.143	1,550	68
The shoulder belt dissipates the least amount of body crash energy. However, it maximizes (for a single restraint) the protection of the most vital parts of the anatomy, the head and the trunk.				

* The area under the force-time curves (Figs. 10, 11 and 12) given in "units" by this table provides an index of the relative restraining effectiveness of each configuration. For ease of comparison, these values are divided by a constant to make the most efficient equal to 100. Consideration was given to the fact that lap- and chest-belt tensiometers were arranged in parallel so that their force-time values were additive, while the shoulder-belt tensiometers were arranged in series so that their values were averaged.
† This value must be corrected by the factor 200/170 to account for weight differences of dummies before determining the relative restraining effectiveness of the lap-belt.

The fact that peak forces for all 3 belt configurations were approximately the same must be regarded as coincidental, even though the cars were crashed under comparable conditions. This becomes evident when one considers the fact that this load is developed as a result of 2 contributions: the effective mass being restrained at the instant of maximum deceleration and the maximum deceleration to which this effective mass is subjected. Both of these factors will vary for the same impact event with variations in the restraining configuration so that the fact that the 3 configurations developed the same peak force under a condition involving a double variable must be regarded as coincidental rather than significant. This is further pointed out by an examination of the curves for each belt which show slight variations in rates of onset and marked variations in durations of force.

Each belt configuration, per se, is capable of restraining effectively the body against the decelerative forces of this collision. However, particularly with respect to the front-seat installation, the effectiveness of each belt configuration is also dependent on the extent to which it prevents forceful striking of human body components against the car's interior during the collision event. To the extent that human body components dissipate their energy by striking the car interior surfaces, the belt tensiometers record correspondingly lower force values. Consequently, the excessive flailing of arms, the relatively smaller forces transmitted by the legs and the extremely destructive forces applied to the head and the chest during collision by the front-seat dummy secured by a seat belt account for the relatively small number of force-time units restrained by this belt configuration (Fig. 12).

If another column were added to Table 5 which included the potentialities of each belt configuration for reducing the severity of injury, then the shoulder belt and the chest belt would be upgraded considerably, relative to the lap belt, because of their performance of providing restraint to the vital portions of the anatomy (head and trunk). No attempt was made to include this factor in Table 5 because experiments were not

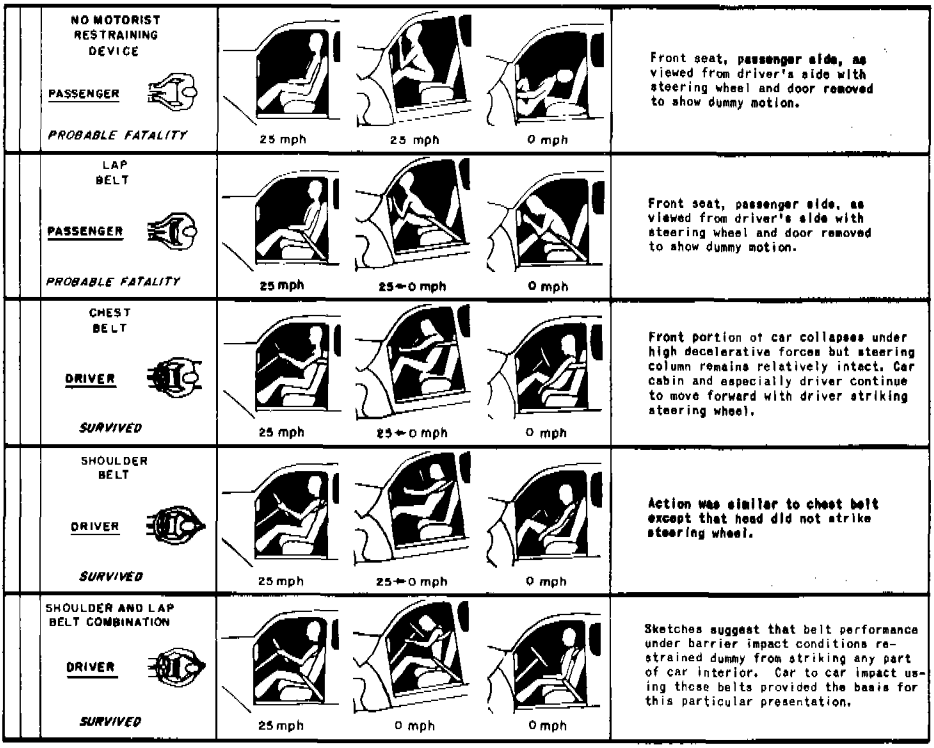


FIG. 10. Effect of varying safety-belt configuration for 25-mph collision with fixed barrier. All sketches . . . are reasonably faithful reproductions from high-speed motion pictures of actual collisions.

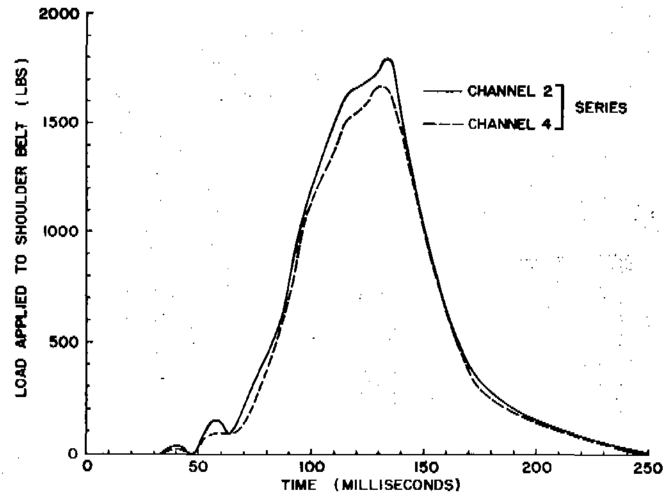


FIG. 11. Shoulder force—time history, S.E.D., car No. 2 (26-mph barrier impact).

conducted to determine the relative limitations of these configurations above which the belts themselves introduce injury.

Anatomic Pathologic Diagnosis: It is recognized that a medical authority cannot be expected to translate, without qualification, structural damage occurring to an anthropometric dummy into injuries which the human counterpart would have been subjected. It is also impractical for an engineer to attempt to evaluate precisely the structural failures and other more subtle indications of abuse to which an anthropometric dummy is subjected during collision in terms of human injury data. Until more basic data are procured concerning the average strength and resistance to injury of the various components of the human body, the combined judgment of the medical and engineering researcher appears to be the most practical approach to applying this type of instrumentation to the experimentally crashed car.... These combined evaluations or interpretations of the physical consequences of dummy damage in terms of physiologic consequences of the inferred body injury are presented in Table 6.

On the basis of the observations presented in Table 6, some conclusions are indicated. The reader is cautioned against regarding these findings as generalized or even specifically final in nature. A presentation of the inferred physiologic consequences of this particular type of collision has been made. While less exacting than most systems of instrumentation, it is believed that certain useful information is provided. However, it should be recognized that a change in any one of the many variables of collision may alter the injury pattern appreciably. Nevertheless, results of these tests do suggest the following:

1. For direct front-end impacts of the more serious type, the lap belt versus no belt for the front-seat passenger appears to offer little significant protection from injuries received by contact with the forward surfaces of the car. It should be pointed out, however, that the lap belt will prevent the body from being thrown out of the car or from being hurled about within the car in those rather prevalent collisions where spin-type forces are present. The serious consequences of such accidents suggest that the use of lap

TABLE 6.—CRASH INJURY FINDINGS: AUTO BARRIER IMPACT *
(Classes of Injuries: Minor, Moderate, Severe, Serious, Critical)

				INFERRED INJURIES †
Car	*Dummy*	*Forces on safety belt (lbs.)*‡	*Deceleration of dummy*	*Head*
No. 2 26 mph	ITTED Front seat passenger (wearing no belt) Probable fatality	(No belt)	Head: Calculated mean deceleration in excess of 200 G	*Critical* Scattered abrasions; contusions around mouth, frontal skull and over occiput. Probable concussion. Fractured and lacerated nose. Combined injuries probably fatal.
	SED Driver (wearing shoulder loop belt) Survival	1,735	§	*Minor* Multiple abrasions. Minor contusions around nose, right eyebrow, around left earlobe, and chin. Other multiple small abrasions about head.

*** We have reproduced only the first portion of this table. [Eds.]**
† Mean value of tensiometer peak readings for each belt taken from Figs. 11 and 12.
‡ Based on the examination and evaluations of Wendell Severy, M.D., Beverly Hills, Calif.
§ The authors chose to delete these data because their accuracy could not be established. Structural buzzes confounded the basic data in the manner described in connection with Table 4.

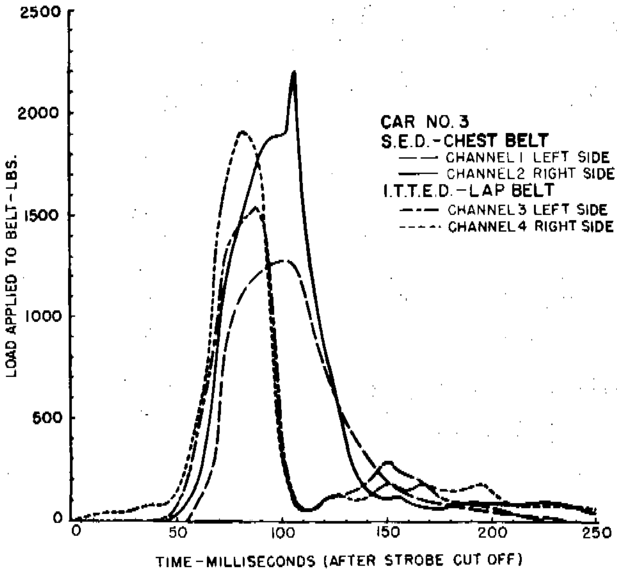


Fig. 12. Barrier impact at 29 mph.

belts is extremely important. If it can be made acceptable to the motoring public, an upper torso restraining device should be developed.

2. The horizontal chest belt configuration continues to give experimental results which indicate satisfactory protection from serious impact injuries. This belt does permit the hips and the legs to shift forward in the seat so that the knees strike the instrument panel. However, this action is considered to be less serious than the action of the lap belt which allows the head and the chest to strike the forward surfaces of the car's interior. Before the use of this belt can be recommended, it is essential that the physiologic consequences, if any, of the pressures applied to the chest be investigated. This can be accomplished by conducting tests on live ape subjects. The use of cadavers is not recommended because some of the potential injuries of concern involve trauma observable only in live animals.

3. The shoulder-loop belt has proved to be the most promising single-unit restraining device evaluated to date. This experimental unit was developed by ITTE for the purpose of motorist protection by the use of a single-unit restraining device. Certain anatomic components of the human body are essential to life, while others are convenient accessories to the function of living. Protecting the limbs, or at least the legs, from impact injuries by the use of a lap belt may compromise under some circumstances the chances of survival by exposing the vital parts of the anatomy—the head and the trunk—to destructive impact. The shoulder belt restrains the trunk and the head at the shoulder level, permitting abdominal and pelvic regions to shift forward. This exposure of the lower trunk to possible injuries by the steering wheel, while undesirable, appears to be a more satisfactory compromise than the exposure of the head and the upper trunk because of their relative importance to survival. With the feet against the floor, the legs are better able to restrain forward motion of the hips than the less strong arms, holding the weak rim of a

TABLE 7.—COMPARISON OF DECELERATION CURVES OF FIGURE 15 [OMITTED] FOR 3 COLLISIONS WITH A FIXED BARRIER

1	2	3	4	5	6
Car No.	*Velocity mph*	*Area under G-t curves Square Units**	*Velocity-area correlation column 3 : 2*	*Rate of onset G/sec.*	*Peak G*
1	24.9	100	4.02	810	18.7
2	25.9	102	3.94	685	14.3
3	29.3	118	4.03	560	17.0

* Each square unit represents 1 G for 10 milliseconds.

steering wheel, are able to restrain the head and the chest. As the body shifts forward, the knees strike the instrument panel, thus loading the femur in compression, which affords additional restraint to forward travel of the hips. The undesirable shift of the hips could be prevented if both lap and shoulder-loop belts were used, but this more complicated restraining system for the present appears to be out of the question for the motorist.*

As a conclusion to these remarks, it may be stated that:

1. In severe accidents the motorist is almost certain to receive critical injuries unless he is restrained to decelerate with the car, thereby shifting the abuses of impact from the human to the car structure.

2. The effectiveness of the lap belt as a single restraining device has been evaluated only for one accident type. This device prevents the motorist from being hurled destructively about within the car or ejected from the car. The driver remains behind the wheel where, by retaining or regaining control, he may prevent the occurrence of secondary impacts that actually may prove to be more injury-producing than the initial collision. These experimental studies point out that users of the lap-type belt should be cautioned against regarding this device as providing protection against injuries for all types of impacts. The observations of researchers at ITTE suggest that the lap belt will prevent fatal injuries from occurring for some types of impacts.

3. The experimental performance of the horizontal chest belt has been very good. It is nearly as simple to operate and provides a more positive restraint than the lap belt. It may not be as comfortable to wear, particularly for women motorists, and *the physiologic consequences of its force system as a result of collision still must be evaluated before its use can be recommended.*

4. Without the need for introducing a more complicated restraining system, the shoulder-loop belt shows promise of overcoming both possible injury-producing consequences of the chest belt and the need for upper torso restraint not provided by the lap-type belt. Nevertheless, this belt is still regarded as an experimental model, even though with the use of dummies it has been tested in 3 collisions with impact velocities ranging up to 50 mph, and with the use of human subjects, in 8 collisions to 25 mph.

Head Movement during Impact: Analysis of high-speed motion picture film revealed that the head of both the human and the dummy passed through a 1.5 cycle oscillation. For both the human and the dummy restrained at the upper torso, the head appeared to be forced as far forward as the neck would flex during the first phase of the impact. After the car had decelerated nearly to zero velocity, the restitutional forces of the neck exceeded the now small deceleration forces of the head, applied through the neck, and the head was thrown back into an acute dorsiflexion position. Next, with the velocity of the car now at zero, the restitutional forces which had developed in the collapsed portion of the car accelerated it from the barrier in the reversed direction. This acceleration from

* However, it should be pointed out that this combination of restraining devices was chosen as the means for protecting human subjects in a recent series of automobile collision tests conducted at ITTE. . . .

zero velocity to 5 feet per second in combination with the forces of elasticity of the neck, in the case of the 25-mph collision, forced the head all the way forward again, though less abruptly than in the case of the initial forward movement. The resilient properties of the neck brought about the return of the head to an approximately erect position. Thus, the possibilities of whiplash injuries of the neck appeared to exist for the motorist who is restrained against a more violent trauma.

While making the car considerably safer for rear-end collision exposure, this problem could be alleviated simultaneously if the seat backs were extended to provide head support in the vicinity of the seat where the head needs support against acute dorsiflexion.

* * *

When limited to artificial "subjects," experiments can usually yield little or no reliable information as to the injury *thresholds* of man and other animals. Even where anthropomorphic dummies and similar devices have been devised to duplicate known human thresholds, their own thresholds may not be appropriate except within those ranges for which data derived from man or other animals are already available.[10] This has also proved a problem in connection with attempts to duplicate in the articulations of such dummies the muscular and other soft-tissue support present in man. However, it is relatively easy to duplicate in these devices the mass distributions of living organisms and for this reason they can be used in experiments of the type under discussion in the foregoing report.

PENETRATING WOUNDS OF SKULL DUE TO METAL AXLE OF COLLAPSIBLE TOY CARS

—*William H. Mosberg, M.D., John O. Sharrett, M.D.*

The pertinence of the concepts presented in this chapter is not limited to transport accidents, as De Haven's work and this selection well demonstrate. The latter reports injuries that resulted from falls onto toy cars with rigid steel axles. In each case, the presence in the child's impact area of a spikelike axle vertically positioned converted what would otherwise have been a minor mishap into a potentially serious accident. In other words, the characteristics of what De Haven has referred to as the structural environment rather than their antecedent causes were the prime determinant of the results of these accidental falls. Further, the pertinent characteristic of that environment was, as Hippocrates in effect first noted, a surface which so localized the dissipation of the energy of impact that the local soft tissue and bone injury thresholds were exceeded.

It is inappropriate to consider such toys, or their axles, as causes of accidents in the same sense as the space heaters described in Chapter 4. The explosion of the latter in normal use initiated the accidents in which they were involved. In contrast, the presence and characteristics of these toys determined only the results of falls probably initiated by quite unrelated events.‡ This again illustrates the fundamental point that it is the manner in which energy is dissipated that determines the results of mishaps, not the antecedent causes, whatever they might be. This has been overlooked in most accident prevention and research.

This report pertains to three children whose skulls were penetrated by the metal axle of rubber or plastic toy cars. In each instance the toy car was lying on its side with the metal axle perpendicular to the floor. When the child fell and his head struck the toy, the rubber or plastic chassis of the car held the axle in an upright position so that the metal axle penetrated the skull as the chassis collapsed or crumbled (fig. 1). In two of the three cases, a flange on the axle prevented a penetration of more than a few millimeters through the skull. It is believed that this type of accident would be less likely to occur if toys were made in such a way that the chassis would not crumble or collapse any more readily than the axle or if each wheel were mounted on a small pin rather than an axle traversing the width of the vehicle. It is therefore hoped that the report of these cases will stimulate the reporting of any similar cases so that toy manufacturers may have the benefit of the statistical incidence of this type of accident.

Report of Cases

Case 1.—A 21-month-old boy, referred by Drs. Theodore Kaiser and William Brendle, was admitted to the Harford Memorial Hospital on May 14, 1959. He had fallen on a rubber tractor lying on its side, and the metal axle had penetrated his skull just above the right mastoid. Attempts by the family to extract the toy from his head were unsuccessful, so the rubber chassis was cut away from the axle and the boy was brought to the hospital with the tip of the axle imbedded in his skull just above the right mastoid.... He was taken to the operating room, where, after he had been put under general anesthesia, a trephine was made just above the foreign body, the bone adjacent to it was moved with a rongeur, and the axle was removed. The dura mater was not perforated. Prophylactic chemotherapy was administered, recovery was uneventful, and neurological examination showed normal results throughout.

Case 2.—An 8-month-old boy, referred by Dr. Donald E. Fisher, was admitted to University Hospital on Jan. 29, 1959. He had fallen on a toy tractor, the chassis of which was made of rubber, and the metal axle penetrated his skull in the right side of the occipital region. About 3 mm. of the axle remained impacted in the skull until it was forcibly extracted, after which he was brought to the hospital. Physical examination showed normal results except for a small puncture wound of the right side of the occipital region. Roentgenograms of the skull showed a small puncture wound

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‡ Some of the problems and possibilities of removing such environmental hazards are illustrated by the subsequent history of cars of this type. After this report had been noted in a widely distributed consumer magazine, a toy industry organ reported that one manufacturer was dispensing with such axles in favor of wheels which snap into place.[11] (This incidentally may have been a poor substitute since buttonlike objects can become lodged in children's respiratory passages, sometimes with fatal results.) Nonetheless, more than a year later a large toy manufacturer teamed up with the maker of a major brand of peanut butter to distribute such steel-axled plastic cars to children nationwide, as a sales premium. The *British Medical Journal* has also called attention to the hazards to children from poor toy design.[12]

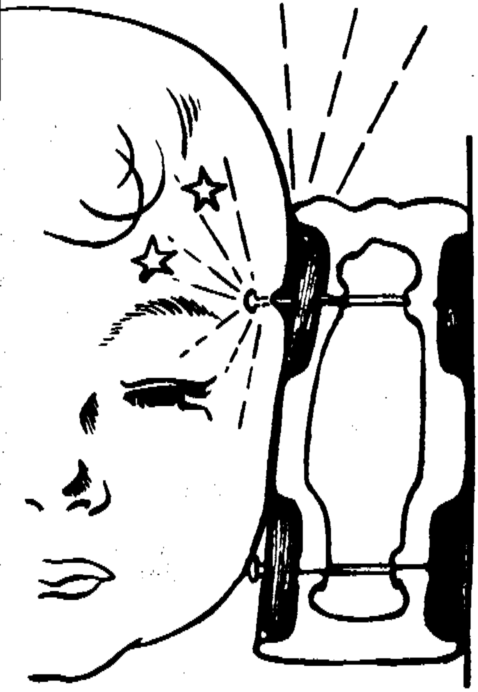

FIG. 1. How metal axle with chassis made of rubber or plastic enters child's head.

of the right side of the occipital bone but showed no evidence of depressed fragments of bone. Prophylactic chemotherapy was administered, his hospital course was uneventful, and he was discharged on Feb. 7, 1959. He was last seen on March 2, 1959, at which time he was asymptomatic. Neurological examination showed normal results throughout.

CASE 3.—An 11-month-old girl, referred by Dr. Julius Chepko, was admitted to University Hospital on Nov. 26, 1959. She had fallen on a toy truck, the chassis of which was made of plastic, and the metal axle penetrated her skull just posterior to the left side of the mastoid. As the axle penetrated the skull, the wheel on that side was displaced until it came to lie against the other wheel, which was held in place by the flange on the opposite side of the truck. All of the axle but the flange on the opposite side and the width of the two wheels penetrated the skull. After considerable force had been applied, the axle was withdrawn, and only minimal bleeding occurred. Prophylactic chemotherapy was administered, recovery was uneventful, and the child was discharged from the hospital on Dec. 2, 1959. Neurological examination showed normal results throughout.

COMMENT

The surgical management of these patients requires no further comment. Fortunately each of the three children recovered, and it does not appear that any of them will suffer any permanent disability. If two associates working in the same office have encountered three such cases within one year there must be other clinicians who have had similar experiences.

TIC-TAC-TOE BURNS—THE HAZARD OF EXPOSED FLOOR-TYPE ROOM HEATERS

—Julian A. Waller, M.D.

This selection also reports a series of childhood injuries resulting from falls, but in this case the energy dissipated in over-threshold amounts was thermal rather than mechanical. Again the injury-producing device probably had little to do with the initiation of the falls per se, but its characteristics determined the results. This demonstrates once more the broad pertinence of the principles we are discussing here. It also illustrates, as does the preceding report, that the pertinent interactions may in at least some cases be identified without sophisticated scrutiny. It is also worth noting that the primacy of the characteristics of the impacted surfaces in determining the results of these falls, and the difficulty of preventing falls among children (*cf.* Chap. 3), suggest that the removal of such environmental hazards may usually be

the easiest way to prevent the injuries. Finally, it is curious that although the removal of poisons from the reach of children has seemed obvious to many, the corresponding removal of hazardous impact surfaces, especially in and around homes and in play areas, has frequently escaped attention. This holds also for the environment provided for adults, especially the elderly.[1]

THIS PAPER will call attention to a vehicle for childhood trauma that has taken a high toll of minor and major injuries but has as yet eluded notoriety. During a one-year period from 1958 to 1959, I conducted a child-health conference with a case load of about 50 children under two years of age for the Contra Costa County Health Department in California. Within this period 9 children suffered burns on 13 separate occasions from falls onto the grating of room heaters set just below floor level. A summary of these injuries is presented in Table 1.

The danger of these heaters again became apparent when I discussed such injuries with numerous residents in the Atlanta, Georgia, area. Fully 75 per cent of the people queried could recall burns to their own children or to those of friends or neighbors. Many of these children retain permanent scars, usually of a tic-tac-toe pattern—the brand of the floor grating.

The floor-type heater consists of a gas furnace set immediately below floor level and covered with a floor-level grating. Many of these are so situated that it is impossible to avoid stepping onto them when one is going from one room to another. In such cases the family is sometimes forced to turn off the heat while the children are awake, or to restrict them by gates or other means. Where the heater is out of the direct line of traffic, a fenestrated brick wall or other structure can be inexpensively constructed around it. It will be noted that 11 of the 13 injuries listed in Table 1 occurred in 3 families. Obviously, the opportunity for preventive counseling by the physician is unlimited.

The best solution to the floor-heater problem is the substitution of a different type of heating system that avoids the exposure of children to extremely hot surfaces. Such construction is available in many of the more expensive houses, but is not too common in low-cost housing.

TABLE 1.—SUMMARY OF BURNS CAUSED BY CONTACT WITH FLOOR-TYPE ROOM HEATERS

Family	*Patient*	*Site of injury*	*Mechanism*
1	C.B.	Legs (permanent scars)	Crawled onto grate
		Fingers	Touched grate
		Buttocks	Sat on grate
	S.B.	Hands & feet	Walked onto grate
		Buttocks	Sat on grate
2	L.F.	Buttocks	Sat on grate
	D.F.	Hands	Unknown
	D.F.	Knees	Unknown
3	L.S.	Knee & foot (permanent scars)	Crawled onto grate
		Foot	Walked onto grate
	G.S.	Thigh	Fell on grate
4	M.M.	Arm (permanent scar)	Pushed onto grate by sibling
5	R.S.	Hand	Unknown

If floor heaters must be used, the vent grating should be located at a level or in a place where children cannot easily fall against it. Another alternative is the use of a grating material that dissipates heat so slowly that it does not become excessively hot to touch. The heater manufacturers are attempting to develop such a material, but they have been unsuccessful to date. Until

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the existing floor heaters can be modified, the physician will have to bear this hazard in mind when speaking with expectant parents or with those who currently have young children.

SUMMARY

The danger of injury to children from falls onto the exposed grating of floor-type room heaters is discussed. Nine cases are reviewed.

We pointed out in Chapter 3 that the use of given grades of injury to define accidents is a source of bias when susceptibility to injury varies with such parameters as age and sex, which are also being studied from the standpoint of their role in causation. That such variation in susceptibility is often of major importance in influencing accident distributions has been conclusively demonstrated by Haddon *et al.* (Chap. 4), Alffram and Bauer,[13] and others,[1] and by the work reported in the next selection. Less formally, it is also well known that falls and other mishaps that result in no injury in the young commonly result in fatal or serious lesions in the aged.* Nonetheless, the possible pertinence of such threshold differences has been almost totally overlooked in studies of the types with which we have been concerned in this chapter. Although this has not always been a major problem in investigations of gross variations in injury in relation to causes of energy dissipation, it will require careful attention in the design of studies of the more subtle variations in injuries. This is excellently illustrated by the sex differences in injury susceptibility reported in the next selection and by the age difference reported in a related paper.[8]

SKIING INJURIES: EPIDEMIOLOGIC STUDY

—*William Haddon, Jr., M.D., M.P.H., Arthur E. Ellison, M.D., Robert E. Carroll, M.D.*

In studies of the causation of injuries, irrelevant types of lesions must be excluded from specific structure-injury comparisons. In this work, for example, the efficacy of release bindings was evaluated chiefly in relation to the injuries (musculoskeletal lesions of the lower extremities) whose incidence they would be expected to influence. This has also been carefully considered in the reports elsewhere in this chapter. It is easy, however, to overlook this point, and failure to make such segregations in the data obtained results in the dilution of case series with irrelevant material which can obscure associations that would otherwise be found. This is the equivalent in injury causation of the inclusion in more classical accident causation data of individuals—for example, pedestrians hit by runaway cars—not responsible for their own involvement, a problem discussed in Chapter 3.

In addition, this report demonstrates the feasibility of controlled investigations of recreational accidents and, especially, the practicality of using research designs

* The elderly are thus in triple jeopardy: their increased susceptibility to falls and other mishaps (*cf.* Sheldon and Haddon *et al.*, Chap. 4); their lowered injury thresholds (*cf.* Haddon *et al.*, *ibid.*);[1, 13] and their increased incidence of post-accident complications (Haddon *et al.*, *ibid.*) all contribute to heightened accident morbidity and mortality.

which at the same time yield: (1) accident rates; (2) data as to the factors of importance in accident initiation; and (3) highly specific information as to injury causation per se. Aside from the difficulties of isolating these three linked portions of accident sequences, it is often far more efficient and productive to study them together than separately. However, accident research has not yet generally reached this level of design and execution, and in this respect this report is unique.

It is also unique in its concern with the possible presence of associations between the use of given types of equipment and likelihood of accident involvement. This problem, which we have noted previously (Chap. 4), is one that will have to be increasingly considered as accident research deals with more subtle distinctions than those with which it has generally been concerned. Finally, this work illustrates the evaluation of an injury-prevention device and some of the practical problems, such as variations in the way it is used, which this can involve.

THE FUNDAMENTAL QUESTION in searches for the etiology of accidents, as well as other causes of morbidity, is how do persons affected differ from those who are not. Despite this, there has heretofore been no scientifically adequate attempt to investigate this question with respect to any type of recreational accident.

This report records the methods, findings, and implications of a controlled epidemiologic investigation of skiing accidents. The study was undertaken as a result of a suggestion by one of the authors (Ellison) who provides emergency care of skiing injuries at a large ski resort. The accompanying report presents a clinical analysis of skiing injuries and their variation with age, sex, and skiing ability. The epidemiologic report carries the investigation back to the population from which the injured were derived and records the characteristics of the skiers and their equipment which were associated with increased risk of injury.

Methods

The study was conducted at Mount Snow, Vt., a ski resort owned by the Mount Snow Development Corp. The study population was composed of all persons purchasing tickets to ski on the four consecutive Saturdays and Sundays from January 28 through February 19, 1961. The case-subjects were those members of this population who were injured while skiing and who came to the resort's medical facility on the day of injury. It is estimated that at least 95 percent of those injured at the resort who received medical care anywhere on the day of injury were in this group, and that virtually all those seriously injured were included. Members of the resort's ski patrol were excluded from both the case and the control groups, as were those whose tickets entitled them to only single rides on the lifts.

The population at risk was sampled by interviewing every 50th person obtaining a ski ticket at either of the resort's two ticket booths. Immediately after the ticket was stapled to the skier's clothing, those selected were asked to step aside for the "ski census." For each person who refused, the next 25th person was interviewed. Of 451 persons so selected, only 5 refused, leaving a sample of 446.

The interview included questions on the following: residence, age, marital status, occupation or school year, age when he or she first skied, frequency of skiing,

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previous skiing at Mount Snow, types of turns performed, history of previous injury, height, weight, hours of sleep during each of the previous 2 nights, ski club membership, self-rating as a skier, ownership of equipment in use, and time and place of last binding adjustment. In addition, the skis were measured, and the type of binding used was recorded.

The injured, on arrival at the resort's medical facility, were asked the same questions by either physicians or medical students. The nature of the injuries, in full clinical detail, was also recorded. Since the skis in use by those injured were sometimes not brought to the medical facility, the majority of the accident sites were visited before the injured were removed. At the site, full particulars of the accident were obtained, the skis were measured, and the binding type was noted. The visits were made by expert skiers who worked with the ski patrol and also circulated continuously on the trails where accidents most often occurred.

Because this research design did not control for possible variations in the amounts and types of skiing by skiers of different characteristics, use of a second design was explored. For 1 day each person interviewed was asked to wear a prominently numbered canvas racing bib of the vest type used for identification of participants in ski races. Bands of intense color painted on these made them visible up to 700 feet. Only 8 percent of those requested to wear the bibs refused, but study of the skiing population late the same afternoon showed that significant numbers must have taken them off. Hence, these bibs were not used further during the investigation. The intention was to have the research workers visiting the accident sites record the numbers of the first bibbed non-accident-involved skiers passing the accident scenes. These skiers would have been used as a site- and time-matched control group for those injured. Similar tagging has long been used in studies of animal populations. In addition, such site- and time-matched controls have proved exceptionally useful in the study of motor vehicle accidents. This approach should be explored further in studies of recreational accidents because it makes possible comparison of cases and controls equally exposed to risk.

Virtually all the types of weather commonly occurring during skiing were encountered. The temperature ranged from $-10°$ to $67°$ F. Sleet, rain, and heavy snow fell, but population sampling and case collection continued without interruption.

All the data were analyzed in terms of four variables suspected to be of fundamental importance: age, sex, skiing ability, and type of binding used. The turns which each person said he or she could perform were used as the best measure of skiing ability available in this study. On this basis the skiers were divided into the following three turn groups: snowplow only; snowplow and stem christie only; and snowplow, stem christie, and parallel and wedeln turns. Parallel and wedeln turns were grouped together because of the small number of skiers who could perform these. In the population studied this was almost invariably the sequence in which turns were learned. The skier's turn group could therefore be used as a measure of expertise. However, since some are now learning the turns in a different order, use of turn groups may not be practical in future studies.

In this study it would also have been possible to use the skier's self-ratings (beginner, novice, intermediate, or expert), since these were highly correlated with the turn group ratings. Self-ratings were not used because we thought it possible that skiers would not give the same assessment of their ability immediately after an accident as they would otherwise.

Multiple injuries were classified in the same manner as in the clinical study, with musculoskeletal injuries given precedence over lesser injuries also present.

Bindings were classified by inspection into release and nonrelease types. A release binding is so designed that it is supposed to disengage from the ski boot under forces

TABLE 1.—INJURY RATES FOR MALE AND FEMALE SKIERS, BY TURN GROUP AND AGE, MOUNT SNOW, VT., 1961

Turn group and age [1]	MALES			FEMALES			BOTH SEXES		
	Cases	*Controls*	*Injury rate* [2]	*Cases*	*Controls*	*Injury rate* [2]	*Cases*	*Controls*	*Injury rate* [2]
Snow plow:									
Under 20 years	13	11	23.6	14	18	15.6	27	29	18.6
20-29 years	17	14	24.3	18	19	18.9	35	33	21.2
30 years and over	5	11	9.1	5	18	5.6	10	29	6.9
Stem christie:									
Under 20 years	6	22	5.5	4	22	3.6	10	44	4.5
20-29 years	6	26	4.6	6	14	8.6	12	40	6.0
30 years and over	3	35	1.7	3	22	2.7	6	57	2.1
Parallel and wedeln:									
Under 20 years	5	39	2.6	2	9	4.4	7	48	2.9
20-29 years	7	65	2.2	6	19	6.3	13	84	3.1
30 years and over	7	61	2.3	3	13	4.6	10	74	2.7
Total, all ages	69[3]	284[4]	4.9	61	154	7.9	130[3]	438[4,5]	5.9

1 Turn group assignment was based on the most difficult turn each skier stated he could perform.
2 Per 1,000 ski-man-days. Since the controls are a 2 percent systematic sample, injury rate = cases × 20 ÷ controls.
3 1 male case was omitted because his turn group was not recorded.
4 1 male control was omitted for the same reason.
5 7 controls were omitted because their sex was not recorded.

exceeding those customarily encountered, thus presumably reducing the likelihood of injury.

RESULTS

Injury rates by sex, age, and turn group observed in the population studied are presented in table 1 and figure 1. Although considerable variation in rate with these characteristics was noted, variations in the type of binding used associated with age and expertise were also found (table 2).

Because of these variations and the stated belief of many persons familiar with skiing that the use of release bindings substantially reduces the risk of accidental injury, a matched case-control group was established in order to determine whether users of release bindings actually did have different injury rates from otherwise similar skiers. This group consisted of 121 case-control pairs matched by sex, age (within 3 years), and turn group; 104 were matched within 1 year of age.

In the matched case-control group a statistically significant association ($P<0.01$) between the occurrence of injury and the use of nonrelease bindings was found among the males (table 3). However, no such association ($P>0.3$) was found among the females.

Since the use of release bindings might be expected to have little or no influence on the incidence of injuries other than musculoskeletal injuries of the lower extremities unless those using such bindings skied differently from those who did not, the matched case-control pairs were next separated by type of injury sustained into three categories (table 4 and fig. 2). Group A included all single-site musculoskeletal lesions not affecting the lower extremities, together with lacerations and contusions

TABLE 2.—USE OF RELEASE BINDINGS BY SKIERS IN RELATION TO TURN GROUP AND AGE, MOUNT SNOW, VT., 1961 [1]

Turn group and age	*Number using release bindings*	*Number not using release bindings*	*Percent using release bindings*
Snow plow:			
Under 20 years	20	9	69
20-29 years	22	11	67
30 years and over	21	7	75
Stem christie:			
Under 20 years	34	12	74
20-29 years	29	10	74
30 years and over	46	10	82
Parallel and wedeln:			
Under 20 years	44	7	86
20-29 years	78	7	92
30 years and over	69	5	93
Total, all ages	363	78	82

1 Based on a 2-percent systematic sample of those obtaining tickets to ski on the 4 consecutive Saturdays and Sundays of the investigation.

TABLE 3.—USE OF RELEASE BINDINGS AMONG MALES AND FEMALES IN THE MATCHED CASE-CONTROL GROUP,[1] MOUNT SNOW, VT., 1961

Sex	*Release bindings*	*Non-release bindings*	*Binding type unknown*	*Total*
Males				
Cases	31	24	8	63
Controls	50	13	0	63
Total	81	37	8	126
Females				
Cases	36	22	0	58
Controls	40	18	0	58
Total	76	40	0	116

[1] Each pair was matched by sex, age, and turn group.
NOTE: For males, $P<0.01$; for females, $P>0.3$, calculated using Cochran's method for comparison of matched samples, pairs containing unknowns omitted.

of all sites. Group B, which is of principal interest here, included all single-site musculoskeletal injuries of the lower extremities, and group C, all multiple-site musculoskeletal injuries.

No statistically significant differences in the use of release bindings were found between the case and control distributions for either sex with respect to injuries in groups A and C. In the lower extremity-musculoskeletal group B, however, there was a significant ($P=0.03$) difference in the use of such bindings among males, but no significant difference ($P>0.5$) among the females.

There was also a substantial difference in the proportions of males and females in each injury group. While 64 percent (38/59) of the males in groups A and B sustained group B injuries, the corresponding figure for females was 86 percent (44/51).

No significant association ($P>0.3$) between the occurrence of ankle sprains as opposed to fractures and the type of binding was found among members of the entire case series (table 5). Actually, the ratio of fractures to sprains was greater among those with release bindings (14/11) than among those with nonrelease bindings (9/13).

Many additional analyses were performed, using chiefly variance analysis and the chi-square test. Without exception no statistically significant or suggestive differences were found between cases and controls with respect to any of the following variables: weight, height, ski length (none of the skis were the very short ones now becoming popular), amount of skiing during the present and previous seasons, previous skiing at the same resort, ski club membership, use of own as opposed to rented or borrowed skis, interval since binding adjustment, distance traveled to the resort, years of skiing experience and age when person first skied, marital status, and history of previous skiing injury. The comparisons with respect to marital status and previous injury shown in tables 6 and 7 illustrate the typically negative findings obtained in these analyses.

DISCUSSION

One of the fascinations of epidemiology is

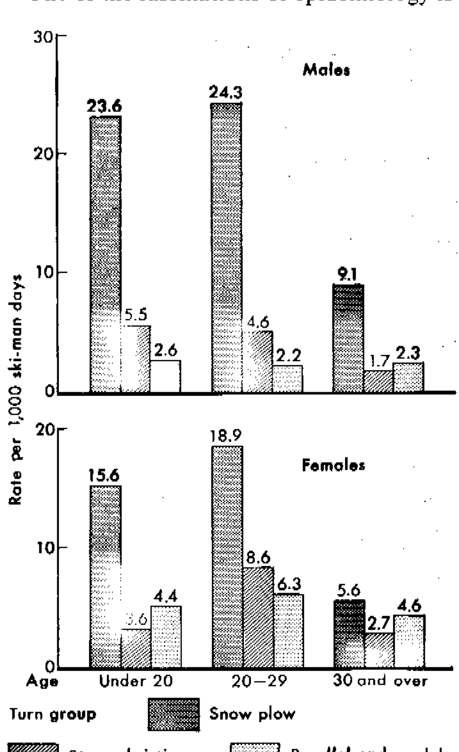

FIG. 1. Injury rates of skiers by sex, age, and turn group, Mt. Snow, Vt., 1961.

TABLE 4.—TYPE OF INJURY IN RELATION TO SEX AND USE OF RELEASE BINDINGS, MATCHED CASE-CONTROL GROUP, MOUNT SNOW, VT., 1961

Sex	INJURY GROUP A[1]				B[2]				C[3]			
	Release bindings	*Nonrelease bindings*	*Binding type unknown*	*Total*	*Release bindings*	*Nonrelease bindings*	*Binding type unknown*	*Total*	*Release bindings*	*Nonrelease bindings*	*Binding type unknown*	*Total*
Males[4]												
Cases	15	4	2	21	15	17	6	38	0	3	0	3
Controls	17	4	0	21	30	8	0	38	2	1	0	3
Total	32	8	2	42	45	25	6	76	2	4	0	6
Females[4]												
Cases	6	1	0	7	28	16	0	44	2	4	0	6
Controls	5	2	0	7	30	14	0	44	4	2	0	6
Total	11	3	0	14	58	30	0	88	6	6	0	12

1 All single-site musculoskeletal injuries not affecting the lower extremities and lacerations and contusions of all sites.
2 All single-site musculoskeletal injuries of the lower extremities.
3 All multiple-site musculoskeletal injuries. All of these were the syndrome described in the accompanying report, knee sprain associated with sprained or fractured ankle.
4 One male case and his matched control and one female case and her control were omitted because their injuries were not adequately described.
NOTE: For males, group A, $P > 0.9$, group B, $P = 0.03$; for females, group A, $P > 0.5$, group B, $P > 0.5$, calculated using Cochran's method for comparison of matched samples, pairs containing unknowns omitted. Group C data were not tested because of the small numbers.

that the afflictions of man show characteristic ecologic patterns, and skiing injuries are no exception. The gross distribution of such injuries, however, unlike those of certain chronic diseases now under investigation, is easily predicted. These injuries reflect the times and places in which the sport is practiced, and, as a result, they occur largely in discrete foci in mountainous areas. They also vary in time, as is well known, with the availability of snow, and at least in New England increase in incidence on weekends and holidays with the increase in the numbers of persons skiing.

Skiing accidents have also increased during recent years as the number of skiers has grown. In the United States skiing has progressed rapidly since the 1932 Winter Olympics at Lake Placid, and the techniques and the equipment used are still evolving. This is reflected in the considerable variety of equipment seen in this investigation and in the youthfulness of most of the skiers. For example, 26 was both the median and the mean age of the population studied. In addition, 94 percent (421/446) were between 10 and 45 years of age.

It is likely that skiing populations will tend to become older as the sport reaches and passes its period of most rapid growth. When this happens, the injury pattern may be expected to shift to include relatively more of the lesions which tend to occur among older skiers. . . . An association between age and type of injury has been noted also by Boder, who reported that all of the femoral fractures in his series occurred in persons over 60 years of age. This age group was not found in the population described here; the oldest person in the case and control groups was 53 years of age. In this context it should be borne in mind that the present findings, particularly as they relate to the efficacy of release bindings, should not be indiscriminately extrapolated to substantially older, or

TABLE 5.—RELATIONSHIP BETWEEN SPRAINS AND FRACTURES OF THE ANKLE AND USE OF RELEASE BINDINGS, MOUNT SNOW, VT., 1961 [1]

Injury	*Release bindings*	*Nonrelease bindings*	*Total*
Sprains	11	13	24
Fractures	14	9	23
Total	25	22	47

1 Of 51 such ankle injuries in the entire case series, 2 fractures and 2 sprains were omitted here because the bindings type was unknown.
NOTE: $P > 0.3$, by chi-square test.

younger, populations, since injury thresholds probably shift substantially with age, as has been documented for adult pedestrians struck by motor vehicles.

The over-all injury rate in the population at Mount Snow was 5.9 per 1,000 ski-man-days. This is consistent with the recent statement of Earle and co-workers, based on their experience at Sun Valley, Idaho, that "it seems likely that the over-all ski-accident rate approaches 1 percent per day." Although such crude rates are useful for estimating caseloads, they obscure the major variations in rates with age, sex, and skiing ability revealed by more detailed analyses.

As shown in table 1 and figure 1, the snowplow turn group, composed largely of beginners, had the highest injury rate. Although they constituted only 21 percent of those skiing, members of this group contributed 55 percent of the injuries. Their injury rate was 16.0 per 1,000 ski-man-days, compared with rates of 4.1 and 2.9 in the stem christie and parallel and wedeln groups. Females also contributed a disproportionate share of the injuries. Although only 35 percent of those skiing

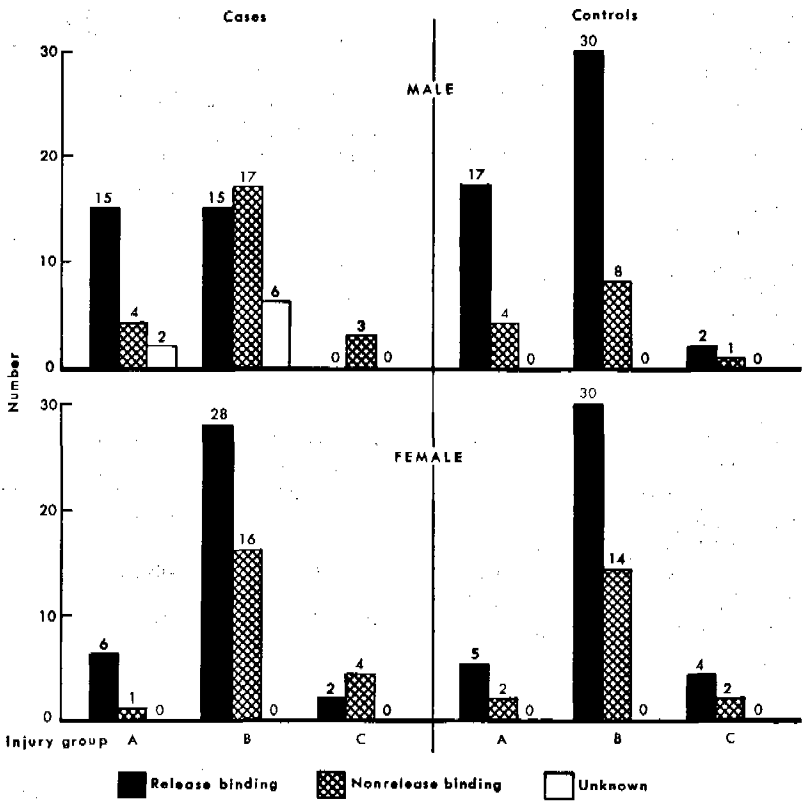

FIG. 2. Type of injury in relation to use of release bindings among males and females, matched case-control group, Mt. Snow, Vt., 1961.

TABLE 6.—MARITAL STATUS OF MALES AND FEMALES IN THE MATCHED CASE-CONTROL GROUP, MOUNT SNOW, VT., 1961

Sex	*Married*	*Widowed*	*Separated*	*Divorced*	*Never married*	*Marital status unknown*	*Total*
Males							
Cases	13	1	0	0	48	1	63
Controls	8	1	0	1	52	1	63
Total	21	2	0	1	100	2	126
Females							
Cases	18	1	0	0	39	0	58
Controls	16	0	0	1	39	2	58
Total	34	1	0	1	78	2	116

were females, they accounted for 47 percent of those injured. The injury rate for females was 7.9 per 1,000 ski-man-days in comparison with a male rate of 4.9. The markedly higher injury rates of these two groups suggest that preventive measures should be directed particularly toward them.

It would be easy to jump to conclusions concerning the reasons for the age-, sex-, and experience-associated differences in these rates. For example, it might be postulated that they result from inexperience, poorer neuromuscular coordination, poorer physical condition, lower injury thresholds, or inappropriate equipment. They might also result from beginners' slopes of too great difficulty or use of advanced slopes by the unqualified. Remarkable speeds can be reached on relatively gentle slopes (see Technical Note). In view of these, perhaps at least beginners' slopes should be made less steep since this group has the highest injury rate. Another possibility is that attrition from the skiing population of beginners with high accident rates results in lower rates among those progressing to the stem christie and parallel and wedeln groups.

Investigations concerned with these and similar variables will require considerable sophistication of design and data analysis. Although this is the rule in controlled studies, it is particularly necessary here because the various characteristics of skiers tend to be statistically highly associated. For example, use of release bindings among skiers at Mount Snow increased with age and expertise (table 2). The investigation of the efficacy of release bindings was therefore approached through the use of a case-control group matched by age, sex, and turn classification, which made possible the comparison of the injury experience of otherwise similar skiers.

This comparison revealed significantly fewer injuries among males using such bindings but not among females so equipped (table 3). Without further analyses these findings could have been considered with at least two hypotheses:

1. That the release bindings per se were significantly effective for the males, but not for the females; or

2. That the release bindings per se were not significantly effective, but that there were pertinent differences in the ways in which males using them skied.

Because of the central importance of this point, the equivalent of questions raised in connection with smoking and lung cancer, for example, analyses were made to determine whether the reduction in injury occurrence with the use of release bindings was specifically related to the injuries which they were purportedly designed to prevent, or whether there was also a similar reduction in

TABLE 7.—HISTORY OF PREVIOUS INJURY AMONG MALES AND FEMALES OF THE MATCHED CASE-CONTROL GROUP, MOUNT SNOW, VT., 1961

Sex	*Previous injury*	*Fracture*		*No previous injury*	*History unknown*	*Total*
		Yes	*No*			
Males						
Cases	7	1	6	56	0	63
Controls	4	1	3	59	0	63
Total	11	2	9	115	0	126
Females						
Cases	6	4	2	52	0	58
Controls	7	0	7	50	1	58
Total	13	4	9	102	1	116

other types of injuries (table 4 and fig. 2). Finding of the latter would have strongly supported the second hypothesis.

The data, particularly as presented in figure 2, show for each injury group and its matched controls the number of skiers with release as opposed to nonrelease bindings. Among females no difference in any of the injury groups was found in the proportions of cases and controls using each type of binding. However, among males there was a large and statistically significant case-control difference in the use of nonrelease bindings among those sustaining lower extremity musculoskeletal injuries (B), but not among those with other types of injuries (A and C). In other words, the decrease in injury rates among males using release bindings (or, conversely, the increase in injuries with the use of nonrelease bindings) was specifically limited to those injuries which would be expected to be influenced.

These findings indicate that release bindings, as adjusted and used by the population studied, are a specific preventive device, significantly effective in the partial prevention of injuries among males, but not among females. The most reasonable interpretation of this difference is that the forces required to disengage ski boots from these bindings tended to exceed the injury thresholds of females, but not those of males. This is consistent with the lighter musculoskeletal structure of females and with the fact well known to those concerned with skiing injuries that such bindings often fail to disengage before injury is sustained. However, although we favor the attribution of this sex-associated difference in efficacy to lower female injury thresholds, it is also possible that it was the result of pertinent sex differences in the adjustment of the bindings themselves or in the specific types of release bindings employed.

Whichever interpretation is correct, these results do not suggest that release bindings should not be used by females or that they may not occasionally be of value. Rather, they indicate that an attempt should be made through the lowering of the binding release thresholds to extend to females at least the partial protection they now afford males. In addition, a similar attempt should be made to improve their efficacy for males. These attempts must consider the highly varied musculoskeletal characteristics of skiers within each age, sex, and experience group. While release bindings as a whole have been shown to be of some value, it is likely that among these highly varied devices there is considerable variation in release thresholds and efficacy, both of which should be investigated in future research. When this is done, it would be desirable to study release bindings in relation to each of the many types of injuries in the B group. This was not possible here because of the relatively small number of cases.

We do not know, except in gross terms, the nature or magnitude of the forces to which the ski-binding-boot-foot-leg-thigh-torso linkage is subjected in either normal skiing or under injury-producing conditions, and this information is needed for better design of safety equipment. Some of this missing information could come from laboratory research, for example, the instrumentation of the several portions of this linkage while subjected to various force conditions. However, results of such work would tend to be of indeterminate relevance to the prevention of skiing accidents unless buttressed substantially with data from studies conducted under actual skiing conditions. In addition, while either laboratory or field experiments might lead to understanding of the forces produced under non-injury-producing circumstances, they would not be likely to lead to determination of those which result in injury, since injuries cannot be deliberately induced in human subjects. Lower animals could not be used because of the differences in the structure of their lower extremities. For these reasons, progress in the understanding of skiing accidents will depend largely on further epidemiologic study of the natural experiments posed by skiers engaged in their sport.

Serious consideration should also be given to the study of ways in which group A injuries might be prevented, since the release bindings appear to contribute little to their prevention. Some of these, for example, injuries to the head and shins, might be reduced through the use of protective devices, but whether this will prove practical remains to be determined.

We had expected to find a decrease in the fracture-to-sprain ratio associated with the use of release bindings on the theory that such bindings in comparison with nonrelease types might disengage before the forces applied reached fracture thresholds even after those for sprains had been exceeded. No such decrease was found (table 5), but in view of the small numbers available for this comparison and the inclusion of 26 females, the results are not conclusive. This point should be studied further, particularly since a reduction in severity of injury should be one of the objectives of preventive measures.

It was also not possible to settle the question of whether or not there was a shift in accident rate with age—binding type, turn group, and sex being held constant. No statistically significant shift was found, but again the numbers available for analysis precluded a firm conclusion. This point should also be explored further.

Many skiers feel that preseason conditioning, that is, some form of preparatory exercise, contributes greatly to their safety. For this reason, those interviewed were asked whether they had engaged in any such activity, but responses were so varied and vague as to be unsuitable for analysis. What constituted "conditioning" to one did not to another. If physical condition is studied in the future in relation to skiing or other recreational accidents, it is suggested that ergometric and other objective measurements be used rather than interviews alone.

Other variables analyzed in this study failed to discriminate between cases and controls. Marital status was included not only as a common social parameter, but also because the unmarried have recently been shown to be significantly more often involved in fatal motor vehicle accidents than the married similarly exposed. Our data show that skiing, at least at Mount Snow, is overwhelmingly a sport of the unmarried, as were, as a result, the injuries (table 6). In addition, while there was no difference between cases and controls in the amount of sleep obtained during each of the previous nights, among adults of each sex the married had had considerably more sleep than the unmarried.

The negative findings with respect to previous injury were of particular interest (table 7). Though the small numbers of such injuries may have obscured case-control differences, the important point is that a history of prior injury was absent in 89 percent (108/121) of the cases and 90 percent (109/121) of the controls. Therefore, whether or not there is an increased risk with such history, its rarity indicates it to be of no importance in the causation of the overwhelming majority of such injuries.

Many additional variables, not among those formally considered, deserve attention. For example, surface and weather conditions are undoubtedly important. Increased numbers of accidents seemed to occur, for example, with the sudden freezing of wet slopes. Fatigue has often been mentioned, chiefly because accidents in some series have increased in numbers in the afternoon. Evidence has not yet been presented, however, that the numbers of persons skiing do not show parallel increases, and the point consequently remains undecided. Alcohol might be expected, from its effects and its demonstrated importance in accidents of other types, to play a role in at least occasional skiing accidents, but this appeared likely in only two accidents known to us. No firm conclusions about alcohol could be reached, since no objective determination of its presence—through the use, for example, of the breath and blood tests employed in other accident research—was made.

The characteristics of ski boots should also be studied. Except for their ownership (rented, borrowed, or owned), which correlated highly with that of the skis and which was not associated with risk of injury, no characteristics of the boots were studied. Since the dynamic relationships between foot and ski must be mediated through the boot, it is extremely likely that its characteristics, including the tightness of the straps and laces, influence injury rates.

Finally, it is appropriate to consider four strategies which may be employed in reducing the occurrence of skiing injuries and mitigating their consequences. These have close parallels in the prevention of motor vehicle accidents and correspond in general to the levels of prevention long discussed by public health workers. They also correspond to interference at four levels in the causal sequence, the end results of which are of concern here. These four strategies are: (*a*) prevention of skiing accidents per se, for example, through better training and use of gentler slopes by the unqualified; (*b*) prevention of skiing injuries per se, for example, through development of more effective release bindings and other protective devices; (*c*) amelioration of the immediate effects of injuries through provision of the best possible emergency orthopedic and general medical care; and (*d*) provision of the best possible follow-up medical care and rehabilitation. It is hoped that recognition of these strategies and the work reported here will favor development of the knowledge and means by which the incidence of these injuries will be greatly reduced or perhaps even eventually eliminated.

Summary

This report describes the first adequately controlled investigation of any type of recreational accident. The population at risk, those skiing at a large New England resort on four consecutive weekends, was sampled by interviewing and inspecting the equipment of every 50th person obtaining a ticket to ski. The case series consisted of the injured from the same population.

The over-all injury rate was 5.9 per 1,000 ski-man-days, but major variations in rates with age, sex, and skiing ability were found. There was a significant association between the occurrence of injury and the use of nonrelease bindings among males. That this was true only for musculoskeletal injuries of the lower extremities suggests that the differences resulted from the bindings per se, rather than from associated differences in skiing. Among females no significant differences in any of the injury groups were found in relation to the use of release bindings. The most reasonable interpretation of this sex difference is that the forces required to disengage ski boots from these bindings tended to exceed the injury thresholds of females, but not those of males. This suggests that an attempt should be made through the lowering of release-binding thresholds to extend to females at least the partial protection such bindings now afford males. In addition, a similar attempt should be made to improve their efficacy for males.

No differences were found between cases and controls with respect to a number of other variables, including age when person first skied, history of previous injury, height, weight, ski length, sleep during each of the previous 2 nights, and marital status.

The directions which further research might take are discussed, and strategies for prevention are outlined.

Technical Note: Physical forces applied to the body in skiing are the immediate and necessary cause of the injuries sustained. These in turn result from forces secondary to the characteristics of (*a*) the skier and his actions, (*b*) his equipment, and (*c*) the environment in which he skis. While this has long been recognized informally, it is only very recently that Sprague has treated the physical parameters of these three aspects of the system analytically. On the basis of this work, he has derived the following equation for the velocities which can be reached on given slopes. These agree closely with velocities observed under racing conditions (personal communication).

$$v = K\left(\frac{W(\sin\theta - K_s\cos\theta)}{A \times K_w}\right)^{1/2}$$

v = maximum attainable velocity (the "terminal velocity" at equilibrium, i.e., the speed at which wind resistance and friction of the skis balance the force of gravity), in miles per hour.
K = 0.68 (with this term = 1.0 the equation gives v in feet per second).
W = weight of skier, in pounds.
θ = slope angle in degrees.
K_s = coefficient of friction.
A = frontal area of skier, in square feet.
K_w = coefficient of wind resistance.

According to Sprague, for a 190-pound skier in a medium crouch ($A = 5.6$ ft.^{2}), with well-waxed skis and under optimum skiing conditions, $K_s = 0.02$ and $K_w = 0.0009$. v then varies with θ as follows:

Slope angle (degrees)	*Velocity (mph)*
3	24
5	34
10	52
20	75
30	92
45	110

Intrinsic and Acquired Resistance to Injury

Injury thresholds are the sum of two subthresholds, one intrinsic and the other acquired. The structure and substance of the human body per se provide intrinsically a certain degree of resistance to the forces to which it may be subjected. It acquires additional resistance through exposure to such forces. The combination results in the injury thresholds which determine whether or not forces of given magnitude, localization, and rate of application will result in injury. Among the many evidences of such acquired resistance are the callusing of the skin with work, the tanning of the skin with exposure to sunlight, the increased tolerance to arsenic and other chemical agents with repeated exposure, and the decreased susceptibility to injury which has long been one of the objectives of athletic practice and training.

Such intrinsic and acquired resistance to external insults are remarkably parallel to the phenomena long described under such terms as "natural" and "acquired" immunity to infection. Although we cannot fully develop this parallelism here, it should be noted in addition that both immunity to infection and resistance to injury may be overwhelmed by massive insults. The recognition of these parallels should prove useful to those who are shifting their attention from the more classical sources of pathology to accident research and control problems.[1,14]

Therapeutic Approaches to Accident Prevention

Research involving a therapeutic approach is of two general types: the first attempts to prevent the events that lead to accidents and the second attempts to raise injury thresholds through various forms of therapy. The former is illustrated by research concerned with such diverse matters as the development of: (1) drugs that prevent epileptic, coronary, hypoglycemic, and other types of acute medical episodes and thus the injuries in which they can result; (2) drugs that maintain alertness under prolonged stress, as used, for example, in certain military applications such as long bomber missions; and (3) means for the surgical amelioration or correction of some orthopedic, visual (*e.g.*, cataracts), and other conditions that can lead to increased rates of accident involvement. However, it is the second type of research—that concerned with the increasing of injury thresholds—that is of interest here.

This also falls into two categories. The first deals with measures to increase pathologically low injury thresholds, and the second with means for increasing normal thresholds to higher levels. In the untreated hemophiliac, for example, mishaps which for a normal person result in only minor bruises and cuts can become major and even fatal accidents because of the substantial inability of the blood to clot. However, as the result of research directed at this problem, whole blood or an appropriate one of its fractions is now routinely administered to many hemophiliacs, thus raising their injury thresholds toward those of the normal population. Similarly, much research has been directed at the development of therapeutic approaches to osteoporosis—with its great weakening of the bones—which among other complications appears to contribute heavily to the frequently fatal results of falls among the elderly. As an additional example, research is needed to devise means for the treatment of osteogenesis imperfecta (brittle bones), another condition that illustrates how the presence of pathologically low injury thresholds can convert minor mishaps involving small amounts of energy into gravely serious accidents.

As an example of research concerned with raising *normal* injury thresholds, there has of late been much effort to find drugs that will increase the resistance of normal individuals to ionizing radiation.† Although conducted chiefly with military applications in mind, this research also has pertinence for the routine protection of scientists and others who may be accidentally exposed because of reactor accidents and the spillage of radioactive materials.‡ Additional examples may be found if it should be demonstrated that fracture rates are lowered by the ingestion of fluoride or other minerals.[16]

Factors which Determine the Subsequent Effects of Accidents

Factors other than the pattern of energy exchange determine the subsequent results of accidents, and these are very susceptible to research. Once injury is sustained, for example, the outcome may be substantially influenced by the quality and quantity of the available first aid, emergency transportation, and medical care. Many persons die or carry needlessly the marks of accidents because such care is as yet very poorly planned and implemented in most areas.[1] In addition, much of the literature dealing with emergency care is based on opinion rather than on adequately designed research. Nonetheless, improvements are taking place, and this is reflected in the slowly increasing attention being given to such matters in the medical and, especially, the surgical literature. There continues, however, to be a major discrepancy between the relatively efficient organization of such care under some military as opposed to most civilian conditions, and the improvement of this situation should be the subject of much research and planning by interested individuals and groups.

Additional levels at which accident morbidity can be modified involve, as emphasized in the foregoing selection, the provision of follow-up medical care and

† For example, one recent report lists 930 organic compounds screened for this purpose,[15] and much additional work is believed to be under way. The function of such drugs would be parallel to that of γ-globulin or hyperimmune serum used where protection against an infectious agent is needed because of a possible future or recent exposure to it.

‡ Although by no means always publicized, a number of such spillages, some in urban areas, have occurred during recent years in connection with the industrial, clinical, and laboratory use and shipment of radioactive materials.

rehabilitation.[1] Here, too, research is needed, since many preventable residuals continue to add to our accident burdens. Although the considerable progress in these areas during recent years is also documented throughout the medical literature, physicians in a wide range of medical specialties are quite aware of accident cases poorly handled, sometimes with the most tragic results. More research is needed not only to determine the most effective methods for dealing with the early and late results of trauma but also to develop the means for measuring continually the extent to which we are failing to apply such care. The latter will require the evolution and use of increasingly specific and sophisticated methods of quality control, a development still in its infancy.

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