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.

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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