Human Tolerance to Impact Conditions as Related to Motor Vehicle Design-SAE J885

SAE Handbook Supplement
issued 1964

HUMAN TOLERANCE TO IMPACT CONDITIONS AS RELATED TO MOTOR VEHICLE DESIGN - SAE J885

SAE Information Report

Report of Body Engineering and Automotive Safety Committees approved March 1964.

1. SCOPE

This SAE Information Report provides data regarding human tolerance to impact conditions. It is intended that this information will aid those having to do with the planning or designing of motor vehicles in which people may experience high forces, to so design various components to reduce the likelihood or severity of injury.

This information is based on currently available knowledge and experience in the biomechanical field. However, in utilizing the information set forth, it must be recognized that both experience and data in the field of biomechanics are extremely limited and, in some cases, unrefined.

It is intended that all portions of the paper be subjected to continuing review and that it be revised as additional knowledge and experience would warrant.

2. HUMAN TOLERANCE TO IMPACT

2.1 INTRODUCTION - Impact will expose the human body to force, acceleration, or pressure versus time histories. Not all kinds of injury can be precisely defined by any one of these terms alone. The reader is therefore cautioned against using them interchangeably or out of technical context.

Tests using human subjects riding accelerators are providing data on voluntary tolerance to impact. Obviously, such data are at a subinjury level and there is no accurate means of extrapolating these data to the threshold of injury. Similarly, there is no way of accurately correlating animal studies to human tolerance. However, responsible investigations of injury producing highway accidents and human free-fall accidents can provide data concerning both survivable and fatal impulse levels. Additional data, particularly on skeletal tolerance, are being obtained by engineering tests and analysis on both intact cadavers and cadaver parts.

In many cases, interpretation of acceleration readings obtained from instruments mounted to humans or animals is difficult because the components of the body are not rigid in the usual engineering sense. Thus, the measured acceleration cannot be directly converted to a force by the F = ma equation, as the actual force at the point of impact may be substantially different than would be indicated by an acceleration measured some distance from the impact point.

The term "acceleration" denotes both positive and negative acceleration (deceleration).

Evaluation of the degree of injury is complicated by the many types of injuries that can occur. Medically, these run from minor bruises, lacerations and bone fractures to serious fractures, injuries to the brain and other vital organs. Also, it is difficult to evaluate functional impairment of various organs since the impairment may not be evident for several days and may then be masked by other injuries.

Finally, it must be remembered that the tolerance of individual humans to injury will vary; it must be expected that some humans will sustain injuries when exposed to impulses well below the tolerance level of the average human.

Experience and data regarding human tolerance to impact conditions and the mechanism of injury causation in motor vehicle accidents is extremely limited. Nevertheless, the information to date is sufficiently reliable to justify the combining of preliminary human tolerance data and general engineering design principles in a practical, common sense endeavor to reduce the likelihood of occupant injury during accidents. In applying the following data and principles, it must be recognized that optimum occupant safety is but one requirement of overall vehicle design. Compatibility with other essential requirements, including those relating to overall driving safety, must be considered in applying this data.

2.2 FACTORS AFFECTING IMPACT TOLERANCE -

2.2.1 Location of Measurement (Forcing Function versus Response Function) - Due to the dynamic characteristics of the materials involved in impact situations, the forcing function will, in general, differ from the response in both magnitude and time duration (see paragraph 2.2.8). When injury criteria are given, it is practically always as the response function and not as the forcing function.

2.2.2 Direction of Impact - Most regions of the body can withstand more severe impacts in one direction than can be withstood in another direction. For example, a well distributed impulse applied to the vetebral column of a person in a transverse direction is not nearly as likely to cause injury as one along the axis of the column. With complete body and head support, an acceleration of about 20 g's for 100 msec at high jerk applied parallel to the vertebral column is likely to injure a lumbar vertebra, whereas 60 g's for 100 msec applied aft-to-fore through a seat back should cause little or no injury.

2.2.3 Location of Impact - Certain portions of the body are more susceptible to impact injury than others. For instance, head injury is probably most serious, considering both the severity and frequency of occurrence during accidents. However, severe impacts to the chest, abdomen, and lower extremities can cause death or prolonged disability. Therefore, no portion of the body should be neglected in designing for safety.

2.2.4 Area of Contact - The degree of injury is an inverse function of the area of the body contact, up to a maximum impact tolerance level for the particular region contacted. A blow from a sharp pointed object, such as a knife blade or an icepick, can cause severe injury with little impulse to the body. On the other hand, large impulses with no injury can occur when a large area of the body is contacted such as occurs when an individual falls into water.

2.2.5 Time Duration of the Impact - High forces, pressures or accelerations can be tolerated for very short time periods while lower values of these quantities can be tolerated for longer periods of time. Fig. 1 shows this relationship for forehead impacts where acceleration has been used as the injury criterion.

2.2.6 Kinetic Energy - All other variables of the impact situation remaining the same, the degree of injury to a particular body area is a function of the kinetic energy absorbed by that body area during the impact. The energy absorbed by a body area is dependent upon the crush characteristics of the object impacted.

2.2.7 Maximum Force, Pressure, or Acceleration - The peak values of such quantities can serve as criteria of damage only for a theoretically brittle material, but are of limited use as indices of bodily injury because they take no account of time exposure to loading.

2.2.8 Dynamic Response - In a mechanical sense, the human body is a complex nonlinear, damped, multimass system. As such, it is subject to dynamic response behavior in any of its many modes of vibration. This means that the response, or actual acceleration-time history experienced by the body, or a portion thereof, may differ markedly from the acceleration-time input to the body applied at the point of impact. The response of a single degree of freedom, linear mechanical system, to an acceleration-time input, is a function of the overall waveform of the input, but for a known system and simple input shapes, can often be approximated by the use of the three basic waveform characteristics:

1. Time required to reach peak amplitude or average jerk.
2. Peak amplitude.
3. Overall time duration of the waveform.

For any pulse duration less than about one-sixth the natural period of a given vibratory mode, the maximum amplitude of response of a single degree of freedom, linear system, will be less than that of the input pulse and will be proportional to the area of the pulse waveform. For greater pulse durations, depending upon the nature of the waveform, the maximum amplitude of response can exceed that of the input by as much as 2 to 1 for a linear single degree of freedom system and by greater amounts for more complex systems.

2.3 DISCUSSION - Human tolerance to impact conditions of the type normally experienced in vehicle accidents, has been more fully studied with respect to head, chest, and facial injuries, than with respect to injuries to other areas of the body. Thus, the following information with regard to such injuries should be given special consideration.

Much of the data regarding tolerance of the head to impact have been obtained from forehead impacts. There is evidence that the difference in energy necessary to produce skull fracture, when various areas of the head are impacted against a standardized target, is within the variance in fracture tolerance between individuals. There is considerable attentuation of acceleration in deforming soft tissue such as the scalp. To illustrate, a skull with the soft tissue removed will fracture at about 25 in.-lb of energy if it strikes a flat, unyielding surface, whereas, with the soft tissue intact, 400-700 in.-lb are required under the same test conditions.

Voluntary chest accelerations as measured by Stapp and others, have reached the tolerance level since minor injury did occur in a few cases. In those tests, the load was spread over a large portion of the chest wall as opposed to a load concentrated on the sternum (breastbone).

Facial injuries are prevalent during accidents and can occur at low impulse levels, even when the load is not concentrated. Although many of these injuries may be classed as minor, they may be disfiguring and have serious psychological effects on the individual. Also, such injuries may involve impairment of the eyes, ears, nose, and mouth. Therefore, it is essential that avoidance or reduction of such disfiguring facial injuries be carefully considered.

Trauma to the knee-thigh-hip complex can have serious, lifelong crippling effects on the patient. Fracture of the patella (kneecap) and/or injury to the knee joint results from even slow to moderate speed knee impact to a hard surface or small protuberance. A more severe impact to a

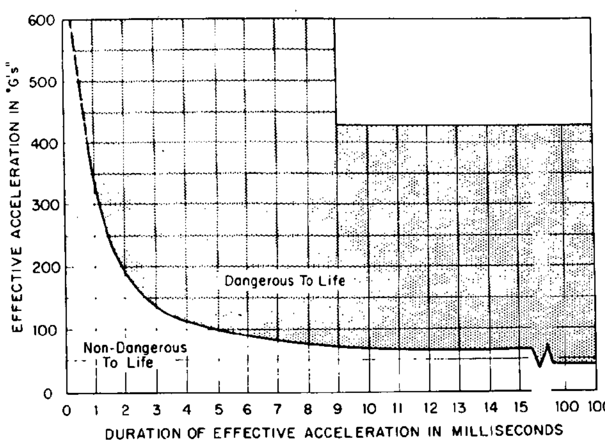

Fig. 1 - Impact acceleration - time tolerance for the human brain in forehead impacts against plane, unyielding surfaces

somewhat yielding or conforming surface might not seriously injure the knee area, but may result in fracture of the neck of the femur (thigh bone), dislocation of the hip joint or damage to the hip joint. These injuries sometimes require a hip prosthesis and, in some instances, fusing the joint. The long convalescence and permanent crippling effect of these injuries make their reduction or elimination of major importance.

2.4 TOLERANCE LEVELS - Appraisal of the injury potential of an impact, as it is affected by pulse wave shape, may be estimated by the two following criteria:

2.4.1 Weighted Impulse Criterion - Weighted impulse criterion recognizes the importance of both the magnitude and the time duration of the impulse, which contribute to tissue damage by an amount which is dependent upon the viscoelasticity of the injured tissue. Published data indicate that a weighting factor should place relatively greater weight upon the ordinate (force, acceleration, or pressure) than upon time duration. This is particularly true of the failure of skeletal components, which are less viscoelastic than soft tissue. For the more viscoelastic materials, the weighting factor should be lower.

Under this criterion, injury potential is proportional to

$$\int a^n dt$$

where

a = acceleration (force or pressure)
n = weighting factor greater than 1
t = time

The exponent n has a value between 2 and 3 for the head tolerance curve of Fig. 1.

2.4.2 Impulse Area Criterion - Area under the acceleration-time curve, pressure-time curve, or force-time curve may sometimes provide a useful approximation to its injury potential. This assumes equal importance of the ordinate and its time duration in their contribution to tissue damage.

Under this criterion, the area under very sharp spikes of the acceleration-time wave is generally negligible and is therefore ignored. The problem is to find the effective acceleration magnitude, which, when multiplied by the total time duration, will give the area under the curve. Therefore, the following guides should aid in arriving at an effective value for acceleration.

(a) If the acceleration-time trace has an essentially flat

Table 1 - Experimentally Determined Levels of Impact Producing Moderate Injury[a]
(Response Functions)

Body Area Impacted	Assumed Effective Weight of Body Area, lb	Effective Accel, g	Accel Duration, msec	Injury Expected at Tolerance Limit	Conditions Used to Obtain Impact Data
Face[b]	20	40	30	Soft tissue damage with possibility of some facial bone fracture.	Hard flat surface impacted with the accelerometer mounted on bone opposite to the point, and colinear with the direction of the impact.
Knee (each)[c]	50	20	30	Knee cap fracture.	
Head (skull)[d]	20	100	4	Minimum to moderate concussion.	
		75	8		
		50	30		
Chest[e]	90	60	100	Reversible injury to organs of the thorax.	Accelerometer mounted to sternum.

[a] See Section 3, paragraph 3.1.

[b] H. R. Lissner and L. M. Patrick, Wayne State University Biomechanics Department Cadaver Impact Studies, 1963.

[c] Jacob Kulowski, M. D.

[d] H. R. Lissner and L. M. Patrick, Wayne State University Biomechanics Department Cadaver Impact Studies, 1959-1963.

[e] John Stapp, Air Force Sled Deceleration Studies.