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ABSTRACT

A common misconception formulated is that the amount of vehicle crash damage due to a collision, offers a direct correlation to the degree of occupant injury. This paper explores this concept and explains why it is false reasoning. Explanations with supporting data are set forth to show how minor vehicle damage can relate or even be the major contributing factor to occupant injury. Mathematical equations and models also support these findings.

INTRODUCTION

A common concept formulated is that the amount of motor vehicle crash damage offers a direct correlation to the degree of occupant injury. This paper explores this concept and explains why it is false reasoning. This false reasoning is often applied by insurance adjusters, attorneys and physicians and frequently results in costly unjustified litigation. Due to this litigation process, the injured parties often are not compensated, resulting in unjustified hardship to the party who has already been injured.

The object of this paper is to present a clear understanding of vehicle body performance when it is subjected to crash dynamics and the relationship to occupant dynamic responses and resulting injury.

THEORY

One of the major factors relating to occupant injury due to a collision is the G force to which the occupant is subjected. [1][2] Even with seat belts air bags and other measures, severe injury and fatality occurs when a vehicle is subject to a collision. [3][4][5][6] This is a rather complex subject to answer in a single paper, but fundamentally even when seat belts are used, the G force sustained by the vehicle beyond the crush zone or arresting distance is transferred to the occupant.

Galileo Galilei formulated an equation that can be used to demonstrate the G force an occupant will receive, assuming a "fixed" seated position. If an object starts from rest, Galilei's equation states: [1]

$$V = \sqrt{2as} \qquad (1)$$

where V = Velocity of object
a = acceleration rate
s = distance moved by object.

Rearranging Equation 1 to get deceleration, we have:

$$a = \frac{V^2}{2s} \qquad (2)$$

where s = arresting or crush distance
V = Velocity at time of impact
a = deceleration

Applying this formula (2) to the scenario of a pole vaulter. If a pole vaulter jumps 6.5 meters (20 feet), his speed when reaching a 1.5-meter (5-foot) safety mat can be calculated thus, using Equation 1:

$$V = \sqrt{2as} \qquad (1)$$

where s = 6.5 - 1.5 = 5 meters
a = 9.81 m/sec^2

hence: V = 11.29 m/sec or 40 km/hr (25 mph)

The resulting G force to which the pole vaulter is exposed can be calculated to be as follows, using Equation 2:

$$a = \frac{V^2}{2s} \qquad (2)$$

where V = 11.29 m/sec
s = 1.5 - 0.5 = 1 meter

hence: a = 63.7 m/ sec^2 (6.5 Gs)

If the vaulter impacted a concrete surface, the results would be clearly different. It is the amount of crush in the safety padding that prevents injury to the pole vaulter.

Applying the formula to vehicles which impact a solid brick wall:

First Scenario: Vehicle Green is traveling at a velocity of 12 meters/second (25 mph) and crushes 1 meter (3.1 feet) while impacting a solid brick wall. Using equation (2) above, then V = 8 m/sec (25 mph), s = 1 m (3.1 feet) and deceleration is:

$$a = \frac{12^2}{2} = 72m/\sec^2 = 7G$$

Second Scenario: Vehicle Red undertakes same velocity as Vehicle Green but crushes only 0.2 meters while impacting the solid brick wall. Deceleration is:

$$a = \frac{12^2}{0.2} = 360m/sec^2 = 37G$$

The results show that the greater the crush distance of the vehicle, the less the G force received by the occupant.

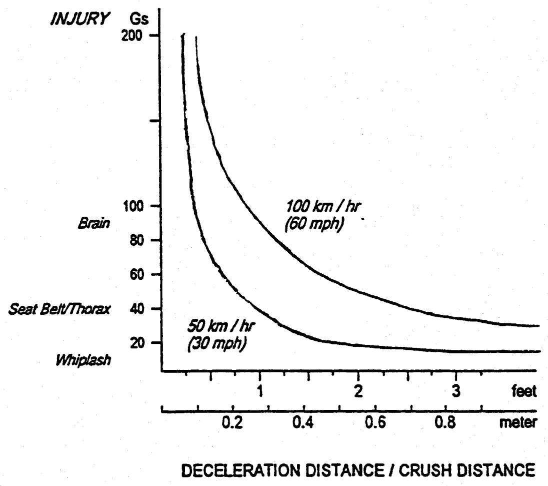

Figure 1

The graph shown in Figure 1 demonstrates the effect a vehicle's crushing distance has on the G force with a fixed collision speed.

DISCUSSION

The average force an occupant of a motor vehicle experiences with normal driving is in the range of 0.2 to 0.5 G. Under these conditions motor vehicle occupants can readily change direction or speed with the vehicle. Some braking will impose a resulting force of 0.9 G, which may cause unrestrained occupants to be thrown forward in the occupant area. The limiting factor is the amount of coefficient of friction available between tire and road for braking and steering. Injury has been known to result due to severe braking, typically when occupants did not have time to brace themselves and were restrained.

If a motor vehicle impacts an object, loads on occupants can rise to very high values. When this takes place, the unrestrained occupant cannot keep pace with the vehicle's change in speed or direction. Hence the unrestrained occupant continues to move within the interior passenger compartment, colliding with the compartment surfaces such as steering wheel, windshield or dashboard. The introduction of seat belts is an attempt to keep the occupant restrained and moving along with vehicle speed and direction. Air bags and padded interior surfaces are provided to cushion the occupant's limbs and head, which contact with occupant interior surfaces.

While the amount of crush a vehicle sustains does not relate to occupant injury, provided no penetration occurs to the occupant compartment, the amount of crush does relate to the impact velocity or speed in the event of a collision with another vehicle or object. In fact, evaluation of occupant injury when related to vehicle damage can only be made when several factors are taken into account. Some of these factors are the following:

Dynamics of force applied to occupant.
- Velocity of vehicle or objects on impact.
- Crushing or arresting distance of vehicle or object. [7][8]
- Ability of vehicle or objects to dissipate the energy of the impact.
- Combination of above factors will establish the dynamics of force applied to occupant.
- Initial positioning of occupant in relation to safety devices such as seat belts or air bags.

Physical condition of occupant.
- Degree of muscular stimulation at the time of impact, i.e., was impact anticipated by occupant?
- Structural strength of occupant, i.e., sex, age, bone mineral content and joint strength. [9]
- Geometric dimensions, i.e., height, weight.

One main factor for determining the dynamics of occupant injury due to a motor vehicle collision is the amount of crush or arresting distance, known as value "s" and previously discussed. This value can vary a great deal from vehicle to vehicle and its location on the vehicle. If we examine a soft drink extruded aluminum can and liken it to a motor vehicle body, several observations can be made:
- Firstly, force applied on the top of the can downwards meets a greater resistance than a force applied to the sides. Clearly the type of structure of the can plays a major part in the deformation resistance.
- Secondly, if a force is applied to the top, a relative great deal of resistance is initially met, then slowly, as the can is crushed, the amount of resistance deteriorates and the can yields.

Likewise, on a vehicle with a chassis, no serious visual deformation may occur even though it is subjected to relatively high speeds of impact. Classically, we see this in the case of pickup trucks or all-terrain vehicles that are traditionally fitted with a solid bumper-to-bumper chassis. Many of these types of vehicles are subjected to relatively severe impacts with little or no resulting damage to their bodies and bumpers. The classic whiplash injury associated with a great deal of litigation is most likely founded on the reasoning that if there was little or no vehicle damage, no injury can result. Motor vehicle bodies or bumper-to-bumper chassis offer little or no crushing effect on arresting obstacles when impacted; thus, relatively high G forces can be experienced by occupants when rear-ended, resulting in whiplash injury. The use of stiff motor vehicle bodies and chassis will also produce a spiked G force loading to occupants, even if little damage occurs to vehicle body or chassis.

Spike loading is a result of a non-linear yielding of a vehicle body, as previously discussed in the scenario of the tin can. In actual practice, deceleration rates during an automobile collision are rarely uniform, especially when chassis, drive trains and mounting panels are involved in the collision.

It is not uncommon to see a motor vehicle that has experienced mass destruction and damage, yet the occupants sustained little or no injuries. This is often a prime example of a situation in which the vehicle or vehicles have absorbed the dissipating kinetic energy of the collision. The occupants are thus not subjected to severe G forces. It is for this very reason that racing cars, when seen in a collision, appear to almost shed their body structure. Wheels are seen detaching and the body structure is seen to dissipate and crush almost in every direction. High-performance racing cars as seen on the Grand Prix circuit are designed with state-of-the-art crash engineering. The main outside structure of these racing cars is designed to allow for crushing and to dissipate energy in the event of a collision. The driver is protected by a rigid enclosure and is also very effectively restrained. These design factors in high-performance crash engineering account for the low driver-injury rates, even though the collisions involve very high speeds. So here we see heavy vehicle-body damage and relatively low occupant injury rates. i.e., the body of the racing car is sacrificed to prevent driver injury or death.

SUMMARY

The amount of crush or damage received by a motor vehicle in a collision is an indication of velocities involved when the stiffness of the motor vehicle and object or objects is known. However, the crush damage does not relate to the expected occupant injury, i.e., the more vehicle damage, the more chance that the occupant is injured, is not a conclusion that can be made. In fact, it is more likely the reverse. If the occupant is decelerated over a greater time/distance due to a large crush/arresting distance, then the likelihood of injury is reduced.

This conclusion has been demonstrated by both mathematical expression and practical examples. The first example is that of the pole vaulter who survives his 5-meter (16-foot) drop by the crush of the padding or mat. It is this crush which breaks the vaulter's fall and hence allows for increased stopping distance and time. The second practical example is that of the high-performance racing car which makes use of a rigid driver compartment for protection. However, the compartment is surrounded by a body which is designed to allow for crush or deformation due to a collision. The result is a reduced number of injuries or fatalities.

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Malcolm C. Robbin's training and education began with a formal engineering apprenticeship in the UK. His qualifications include City and Guilds in Manufacturing and Mechanical Engineering and a B.Sc. degree in Production Engineering. He is a member of the American Society of Safety Engineers and the Institution of Production Engineers and Industrial Managers in the UK.

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