CHAPTER 11

Safer Vehicle Design

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ABSTRACT

This chapter presents some basic principles used in the design of safer vehicles. There are two distinct segments at risk. There are people in the vehicle, and people outside of the vehicle. Research over the last 40 years has lead to the evolution of seat belts, air bags and crush zones which are able to protect the users of four wheel vehicles fairly effectively. The state of the art is to use finite element simulations in conjunction with crash testing to design vehicles.

Key Words: Kinetic energy; seat-belts; air-bags; crush-zones; Finite Element Simulation

11.1 INTRODUCTION

A typical modern lathe machine has a five horsepower motor and stores a kinetic energy of about 1 kiloJoules. The operators of these machines wear helmets, wear eyeglasses, and undergo three years of fulltime training, and their skills are constantly upgraded by retraining programs. In contrast, a modern vehicle is a 100 to 600 horsepower machine weighing 800 to 4000 kg without load. When travelling at 40 km per hour it stores kinetic energy of the order of 100 kiloJoules. The operators of these machines are mostly untrained at their jobs, operating them part time for maybe 1 hr a day. Acceptance of these facts, and engineering for safety is the first step towards a safer vehicle design.

There are two distinct segments at risk. There are people in the vehicle and people outside of the vehicle. Research over the last 40 years has lead to the evolution of seat belts, air bags and crush zones which are able to protect the users of four wheel vehicles fairly effectively. In our environment, there is a large segment of people outside of the vehicle who are exposed catastrophically to 100 kJ of energy over durations as short as 10 ms. Users of two-wheeled vehicles are also ineffectively protected in spite of the helmet laws. Here the aim is to elucidate some basic principles used in the design of safer vehicle designs. To the end, we will have a look at some of the latest tools being used at IIT Delhi for the design of safer vehicles.

11.1.1 Safety must be engineered

One of the questions often asked is if safety has to be engineered or if it can be done actively by the operators or passengers. Let us start by computing the time we have on hand. We can convert a typical speed of 40 km/h to 11 m/s. If the dashboard is 1m away (any closer and you will not be able to open the glove compartment) and the car comes to a dead halt, if unobstructed, you will cover the distance in 1/11 sec. This is about the time taken for the flick of an eyelash. It is known that the time taken for one human synapse is about 1/30 sec. Three synapse cycles is too little a time for the human brain to take any cognitive action. So any preventive measures have to be based on reflex action.

Now that seatbelts are compulsory in India, I often see parents sitting strapped in holding on to their children. The 5 kg baby has a kinetic energy of $\frac{mv^2}{2}$ or $\frac{5\times 11^2}{2}$ $\cong$ 302 Joules. To dissipate the energy, and to bring the baby to rest, the effort required is equivalent to lifting a 60 kg mass by half a meter in a tenth of a second, which is beyond the capacity of humans. Parental instinct in case of a crash will just not be backed by parental muscle power.

Even worse is the case of the parent who is not strapped in. After the child hits the dashboard and dissipates 302 Joules, the parent will hit the child. If the parent weighs 50 kg (ten times), an additional 3000 Joules of energy will crush the child against the dashboard. Clearly, safety has to be engineered and cannot be the result of conscious or reflexive evasive action.

11.1.2 Newton's means of safety

With a little poetic license, I aim to demonstrate how the basic issues of safety can be assessed by the 400 year old formulae of Issac Newton. The simple understanding of the nature of impact is to derive an equivalence of impact when travelling in a vehicle at 40 km/h or approximately 11 m/s. Recounting our high school physics, realize that this is the velocity attained by a body under free fall from a height of $\frac{v^2}{2g}$ or $\frac{11^2}{2\times 9.8}$ $\cong$ 6.2 m which is a height of two floors, very close to the vaulting record of Sergei Bubka. As a kid, I (some of you as well) jumped down from one floor height and I am still healthy, but not from two floors. Mr. Bubka however, vaults this height and survives because of the cushioning. So the obvious solution that comes to mind is to provide cushioning. For Mr. Bubka, the International Olympic Committee recommends a cushioning of 1 m depth! This is one of the best possible safety devices. The problem is that most car users would not like to strap one on the moment they sit inside vehicles. It is however, used in the expensive cars; the cushion appears only when there is an impact, is an air cushion and is called an airbag! The requirement of rapid deployment and providing cushioning requires a sophisticated system design involving accelerometers, ignitors, jets and an intricately folded membrane structure.

What are the other options? Bungee jumping allows people to drop the height of a few stories and still survive. The bungee rope is specially designed to limit the load experienced by the human to tolerable levels. This is the most popular measure for car safety, and it is called a 'seat belt'. It is important to understand that as one cannot buy rope off the street and go bungee jumping, the same is true of seat belts. Any belt used to strap in the rider cannot provide safety. A device called a centrifugal clutch is used to allow the belt to extend when the motion is slow. This allows the user to adjust the belt. For rapid movement, of the type of 1 m in 1/11 of a second, the clutch locks up, and restrains the user. That is not all. If the belt were

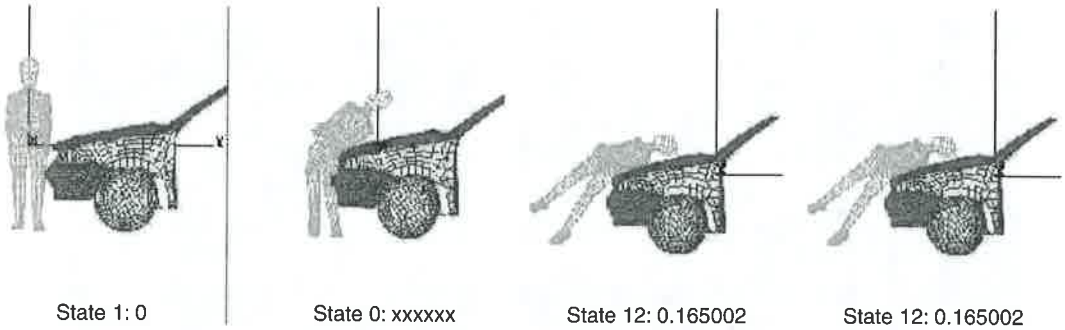

Figure 11.1 Simulation of pedestrian impact.

rigid, there would be no bungee jumping, but a hanging. It would be as good as hitting the dashboard. The belt is a result of precision engineering that brings the occupant to rest not with zero travel, but only after a travel of maybe half a meter. This ensures that we do not have lacerated necks and completely crushed ribs. Needless to say, for the seat belt to save lives, it has to be a precision-engineered system.

11.1.3 Slow it down

Slowing down is a good safety principle. For example, if the vehicle speed is 20 km/h, the energy which varies as a square of the velocity, becomes a fourth. So the survival height becomes 1.5 m in place of 6 m, a drop that many of us expect to survive. However, this is a social solution. An engineered crushing mechanism can provide an equivalent slowdown. The bonnet of a car typically has a length of over a metre. If the design of the vehicle allows the bonnet to compress on impact, then the dashboard of the vehicle does not stop instantaneously but travels forward. This gives additional space to the designer of the airbag and seatbelt to bring the rider to rest with less damage. It does not, however, help the rider who is not strapped in, or in the absence of an airbag. It is not sufficient to have a crush zone. The crushing must be supported by appropriate seat belt design to save lives.

11.1.4 Design for VRU

There are many more people outside the vehicle than inside the vehicle in developing countries. The riders of vehicles are reasonably safe due to the effort of engineers in the US, Europe, and Japan. The principles used in protecting the riders are applicable in protecting the road user as well. One design would be to mandate a crush boundary layer of half a meter. Bonnets that fold on impact, rounding of the front profile, and sinking the hard pivots of the windscreen wiper below the bonnet, are some of the measures that have been taken. However the present-day bumpers and bonnets with small clearance to engine are not VRU friendly designs. Similarly, bus and truck front designs can be improved to make them more pedestrian and two-wheeler friendly. Figure 11.1 shows simulations being conducted on pedestrian impact.

11.2 ADVANCED METHODOLOGIES

The basic principles of the common safety design methods have been discussed. In reality, very sophisticated experimental and simulation tools are used to achieve the goals in the earlier sections. The snapshots below show a car-motorcycle crash test carried out, and Finite Element Simulations.

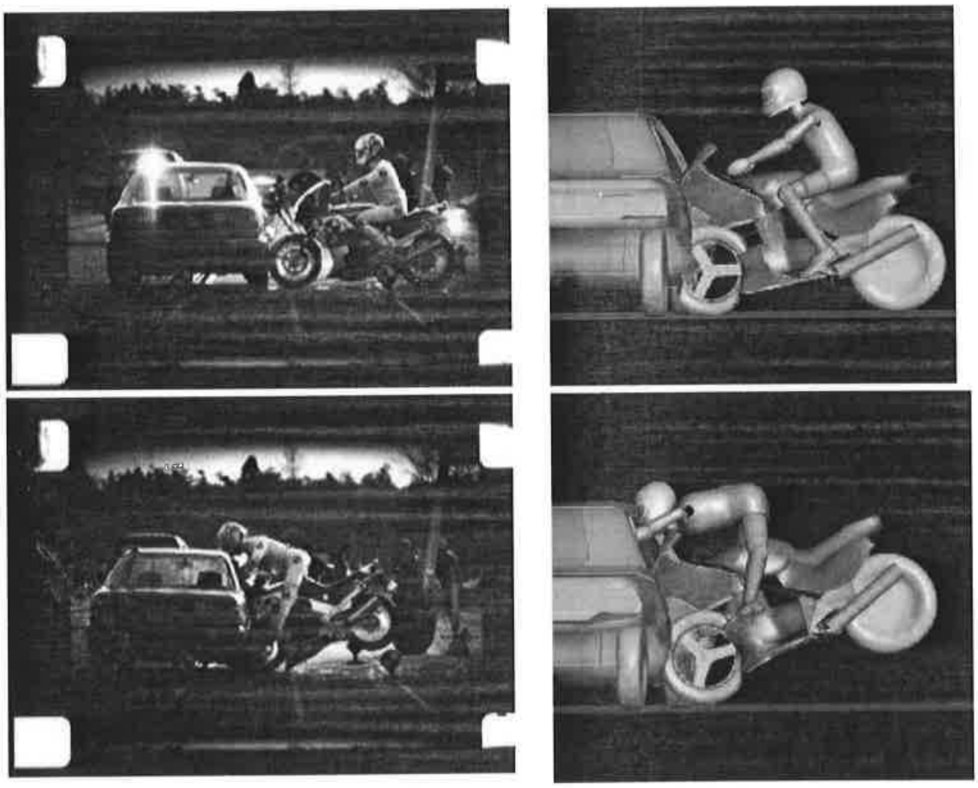

Figure 11.2 Car-motorcycle crash test and simulation.

Figure 11.3 Crushing of honeycomb, test and simulation.

Honeycomb materials are often used to design crush zones as they have good energy absorption characteristics. They can be designed to fit stress corridors on demand and are lightweight structural materials. Figure 11.3 above shows a crushed honeycomb and the simulated crush.

Airbag deployment has to meet stringent requirements, as the bag has to be fully deployed within 5 ms to avoid 'slapping' the rider. The airbag mass is about 200 gm. and moves at a peak speed of around $0.5\,\text{m}/.005\,\text{s} = 100\,\text{m/s}$! Energy content is about 1000 Joules! The slap can be strong enough to break the rider's jaw, following which it has to deflate as the rider impacts the surface to minimize the injury to the rider.

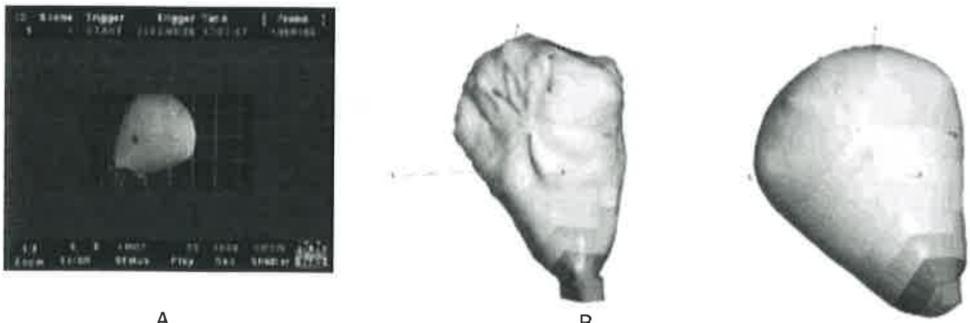

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Figure 11.4 Airbags a) Experiment, b) Intermediate simulation and c) Full blown simulation.

Figure 11.4 above shows simulation of the airbag inflation process that is used to study the inflation and iterate on the design of airbags. Needless to say, the driver side and passenger side airbags are of completely different designs because of the space availability.

11.3 CONCLUSIONS

Basic issues in design for vehicle safety have been discussed. The state of the art is to use finite element simulations in conjunction with crash testing to design vehicles. Both these activities need substantial infrastructure and skilled manpower to execute.

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