TERRIBLE COMPARIBLE COLLISIONS

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Introduction and Background

Evaluating car safety is a rapidly growing field which is gaining new interest each generation. More than ever car industries, insurance companies and consumer groups want to know which vehicle will provide the best means of safety. This field has rapidly grown over the past few decades due to the technology that is now available. Today a car collision may be viewed from several different angles and monitored in a variety of different ways before a car even "hits" the market. Being able to simply view the results of a collision in this fashion has instigated a greater interest in this data throughout the general populous (highwaysafety.org).

According to Insurance Institute for Highway Safety, one way of testing car safety that supplements the technology is to evaluate forces using physics. Safety is not only dependent on the force received by the vehicle during the collision but more importantly the force received by the person. The most prevalent concept to work with is momentum. Momentum is often referred to as "mass in motion." More precisely it is a relationship between mass and velocity that defines momentum (Halliday et al 2005). Because the net force on an object is related to the momentum, one may see why momentum plays a major role in evaluating car collisions.

Currently the incoming generation of consumers has taken great interest in this topic. Knowing which vehicle will keep us safe, along with those we love, will never be more necessary than now. Since this generation is quickly approaching parenting age it is important to understand, and thus prevent, the dangers of driving. In fact, in 2001 70% of unintentional injury deaths in young people from 5-19 years of age were due to motor vehicle accidents (cdc.gov). This project will provide a deeper understanding of momentum, forces, and a necessary understanding of automobile safety.

The goal of this project is to discover exactly which forces are acting on a crash test dummy during an auto insurance crash test video. Achieving this goal will require the calculation of force exerted on a crash test dummy in a 40 mph car collision with a stationary object, which simulates the force a human would experience in a similar situation. In order to accomplish this goal, an investigation into the forces acting on the vehicle and the variance of these forces acting on the dummy is crucial. It is proposed that these forces will differ for each specific type of vehicle involved in an accident and will lead to a better understanding of car safety. Thus, the question arises as to whether or not mass and cost are major factors in automobile safety.

Questions concerning safety will be answered by measuring the collision forces on the dummy with an airbag in different styles of automobiles. The conditions in these experiments will be constant since the videos used were provided by an insurance company. These videos portray various automobiles in exactly the same situations. All automobiles have the same velocity before the collision and are acting in the same environment when the collision occurs.

This experiment requires minimal starting assumptions, which are as follows: air resistance is negligible on the car and on the dummy inside the car, the dummy used in each of the crash videos is the same dummy and therefore has the same mass in each video clip and the amount of gasoline in the tank of each car is unknown and is therefore not included in the final mass of the car. Lastly, is assumed that the center of mass will move with any one point on the car before and after the collision.

The objectives will be accomplished by transferring the videos of automobiles undergoing a collision into VideoPoint and using the software to find the momentum of the vehicle and dummy before and after the collision. Discovering momentum will provide a means to calculate the forces on both vehicle and dummy. Information regarding the masses of the vehicles and dummies were provided by Progressive Auto Insurance and the Insurance Institute for Highway Safety. From this information the force will be calculated for the dummy when it hits the airbag and the automobile when it hits the collision barrier.

The four vehicles being analyzed are a mini-van 2002 Kia Sedona (Figure 1), a luxury model Cadillac CTS 2003 (Figure 2), a 2002 sports utility vehicle Ford Explorer (Figure 3), and a 2003 family mid-size sedan Honda Accord (Figure 4) (iihs.org).

Figure 1 Kia Sedona

Figure 2 Cadillac CTS

Figure 3 Ford Explorer

Figure 4 Honda Accord

Each of these vehicles was tested at 17.88m/s (40mph) in a head on off-set collision with a steel reinforced concrete barrier (Figure 5).

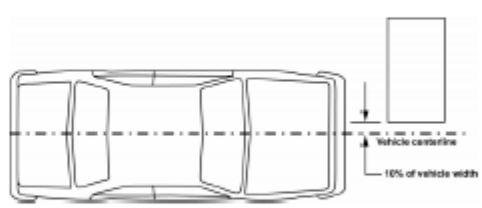

Figure 5 Offset collision

Our goal will be accomplished by obtaining the physical measurement information of each car, provided by the Insurance Institute for Highway Safety, and use the scaling ability of VideoPoint to analyze the information. This will provide the ever so important feature of distance which is required to find out the fashion in which the crash test dummy and the car move.

According to present perception of these types of vehicles, it is likely that the Cadillac CTS's occupant will receive the least amount of force followed by the Ford Explorer, then the Honda Accord and lastly, the Kia Sedona's occupant will undergo the largest force during collision. This perception comes from the assumption that safety is incorporated into the cost of the vehicle due to the fact that most luxury models go through more rigorous safety tests. Also, imbedded in this perception is that mass will provide safety for it's occupants.

Methods

Mass of vehicles (iihs.org):

2002 Explorer: 2050 kg

2002 Kia Sedona: 2120 kg

2003 Honda Accord: 1448 kg

2004 Cadillac CTS: 1648 kg

Figure 6   Male Hybrid III dummy

Figure 7   Hybrid III family

Mass of occupant, Hybrid III Dummy seen in Figure 6 and 7 (iihs.org): 77.3 kg

Mass of occupant head (Melkerson 2004): 4.5 kg

Composition of the barrier that each vehicle collided with consisted of laminated steel and reinforced concrete with a total mass of 145,150 kg (highwaysafety.org). Figure 8 shows a top/side view of the collision barrier (highwaysafety.org).

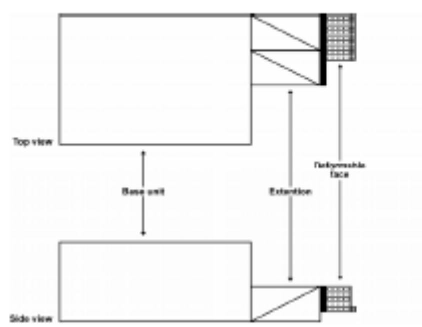

Figure 8   Deformable barrier (top and side view)

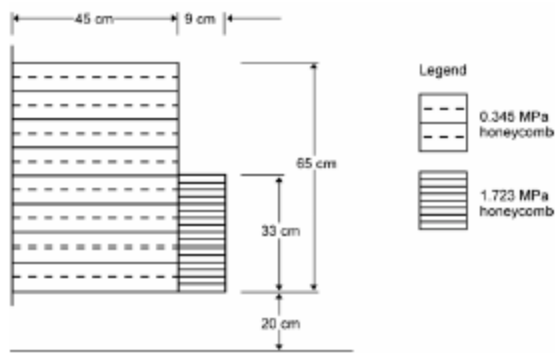

Figure 9 Deformable barrier (composition)

Figure 9 shows the honey comb portion which is the deformable face composed of aluminum and plywood (highwaysafety.org). This portion collapses upon impact in order to simulate the body of another car.

The crash test videos were obtained from the Progressive Auto Insurance website and were then transferred into VideoPoint 2.1.2. To be able to use the videos they needed to be converted from an .mpeg format to a .mov format. This was accomplished by using iMovie software provided by Dr. Chris Cline and Apple Computer.

Dimension values (Figure 10) for each video were obtained from the Insurance Institute for Highway Safety. These values were then used to scale the videos by using the "inch tape" located on the top of each of the vehicles as shown in Figure 10 below (highwaysafety.org).

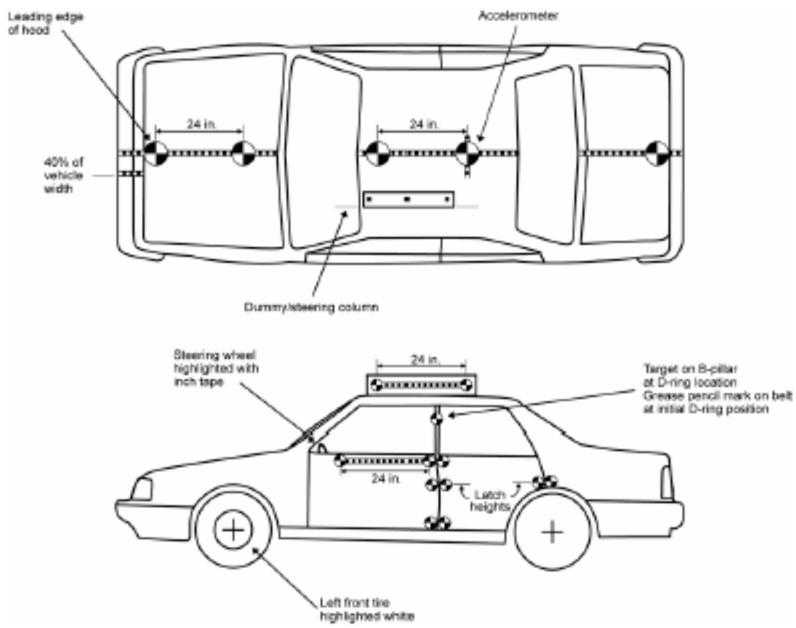

Figure 10 Vehicle dimensions (used for scale)

The 24 in. bar located on the top of each of the vehicles was used to scale the video in meters.

Data collection was accomplished by using VideoPoint software to trace the paths of each vehicle before, during, and after each collision. The focal points for each video were the front tire and the head of the Hybrid III male dummy (Figure 11). Overall, two sets of position data were collected for each video in the (x) direction. In order to calculate force and impulse on the object data was only collected in the (x) direction. The (y) direction was ignored due to the fact that the forces of gravity F_g and the normal force F_n were independent of determining force and impulse on the object in the (x) direction.

Figure 11 VideoPoint frame capture (Cadillac CTS 2003)

Data collected in VideoPoint was transferred into Excel for analysis which included position along the *x*-axis and time.

Using the graphing function in Excel the data was plotted as position vs. time (Figures 12-19). Overall, the graphs are a depiction of the change in motion before, during and after the collision. Through these position vs. time graphs, velocity was calculated before and after the collision for both the tire and the dummy's head.

The given time in each frame presented by VideoPoint was incorrect because they were in slow motion; therefore adjustments were necessary. In order to overcome this obstacle we created a ratio of "false values" to "real values." These values included velocity and time per frame. The ratio was set up as seen in equation 1 and proved to be the best means for accomplishing our task.

$$\frac{t_r}{t_f} = \frac{\vec{v}_r}{\vec{v}_f}$$
$$t_r = \frac{\vec{v}_r}{\vec{v}_f} * t_f \tag{1}$$

Where: t_r = time real, t_f = time false, $\vec{v}_r$ = velocity real, and $\vec{v}_f$ = velocity false.

Impulse was calculated by finding the change in momentum for both the tire and the dummy. These values were then used to compare car model safety.

$$m\vec{v}_2 - m\vec{v}_1 = \Delta\vec{p} \tag{2}$$

Where m = mass (kg), v = velocity (m/s), Δp = change in momentum in kg*m/s

$$\int F_{NET}\,dt = \Delta\vec{p} \tag{3}$$

F_{NET} = net force (N), dt = change in time (s)

$$K = \frac{1}{2}mv^2 \tag{4}$$

K = kinetic energy in Joules (J)

$$W_{NET} = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 \tag{5}$$

W_{NET} = Net Work in Joules (J)

$$W_{NET} = \frac{1}{2}\Delta t * F_{MAX} \tag{6}$$

All of the above equations were obtained from the text (Halliday 2005) and also validated from previous experiments conducted in the classroom. Equation 6 was derived from the fact that the area under the bell curve, similar to a triangle, defines net work.

Results:

Using the methods outlined above, results were gathered for time and position for each vehicle.

With the gathered data, graphs (Figures 12-19) were made depicting each vehicle and dummy head position with respect to time. For better analysis the graphs were split into before, during and after the collision.

Kia Sedona:

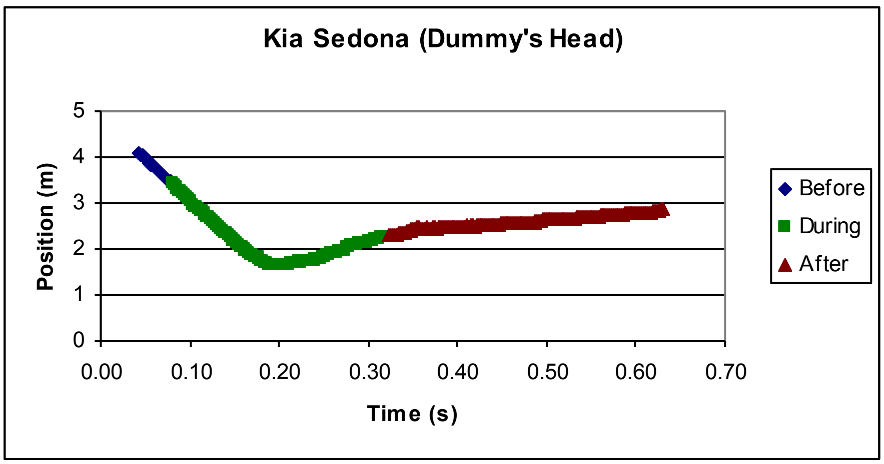

Figure 12 Position of head vs. time

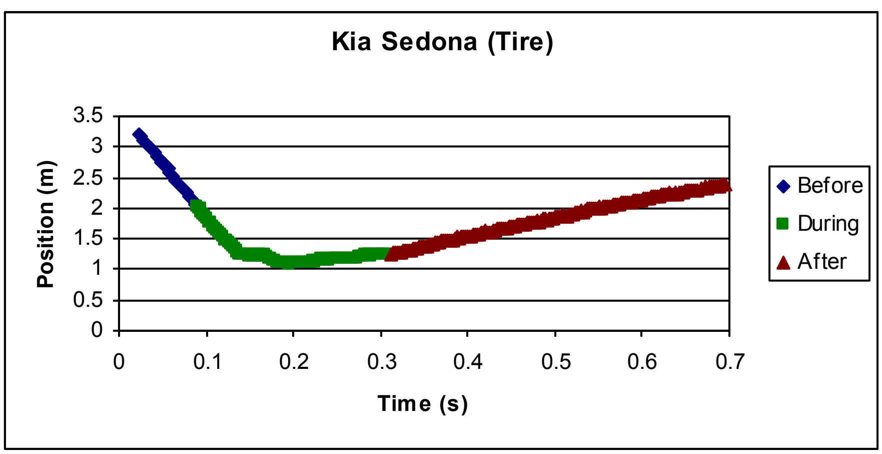

Figure 13 Position of tire vs. time

Cadillac CTS:

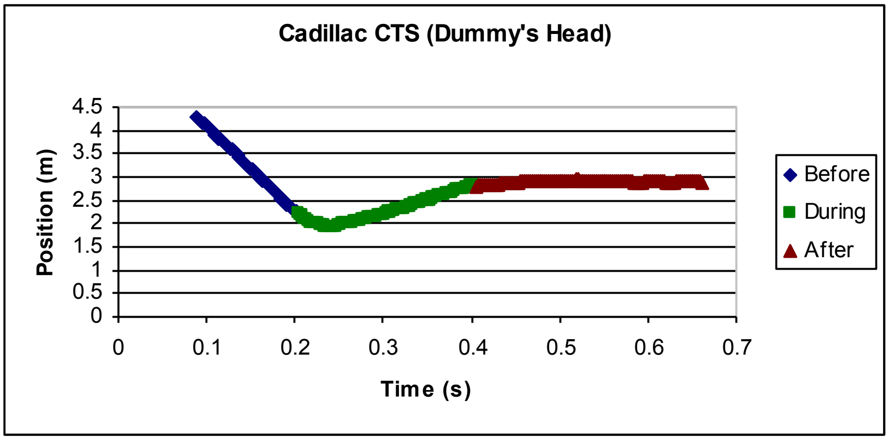

Figure 14 Position of head vs. time

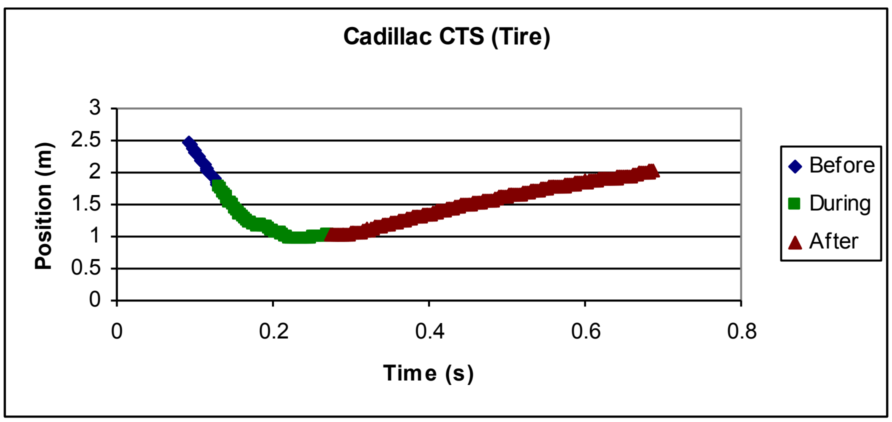

Figure 15 Position of tire vs. time

Ford Explorer:

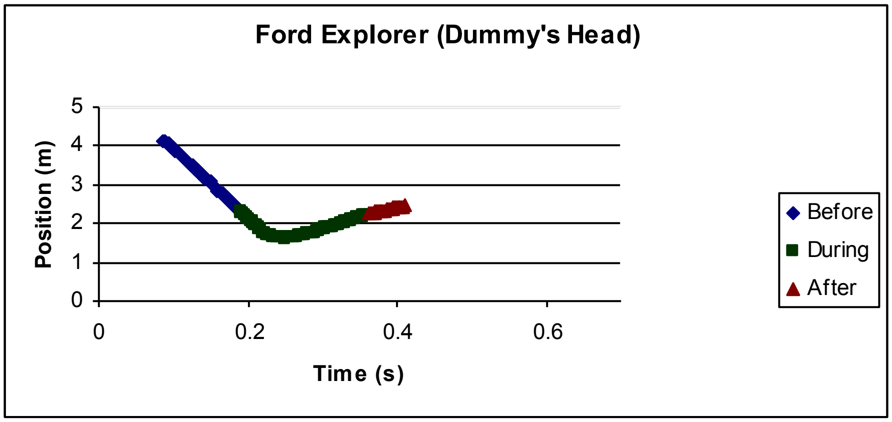

Figure 16 Position of head vs. time

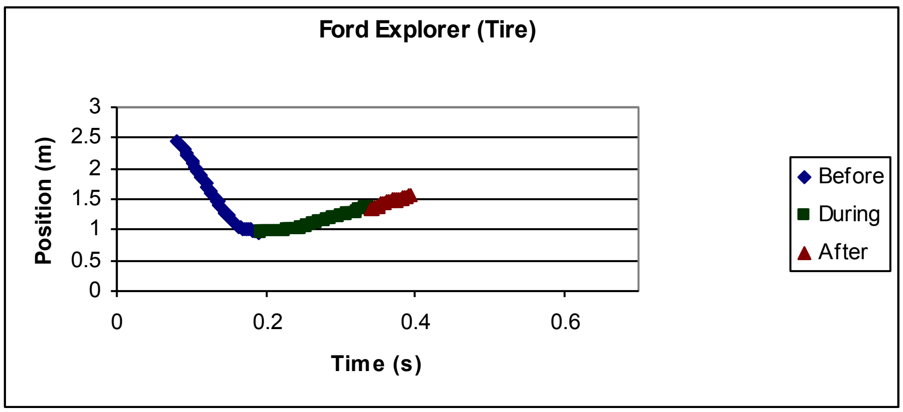

Figure 17 Position of tire vs. time

Honda Accord:

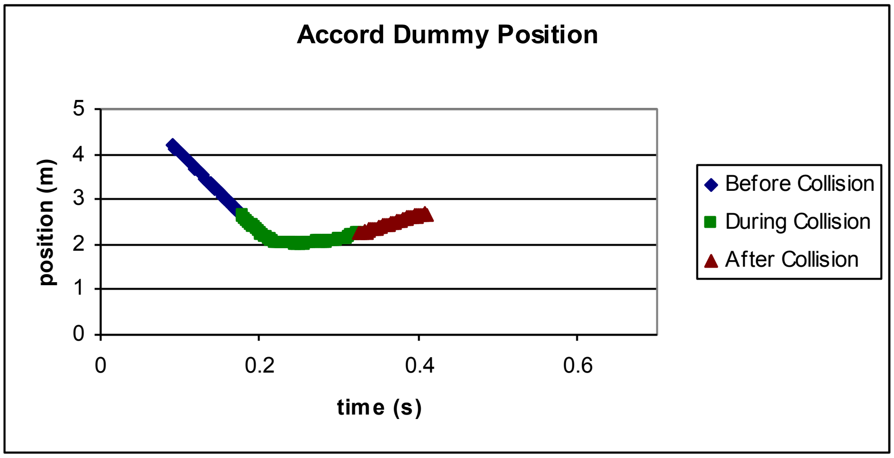

Figure 18 Position of head vs. time

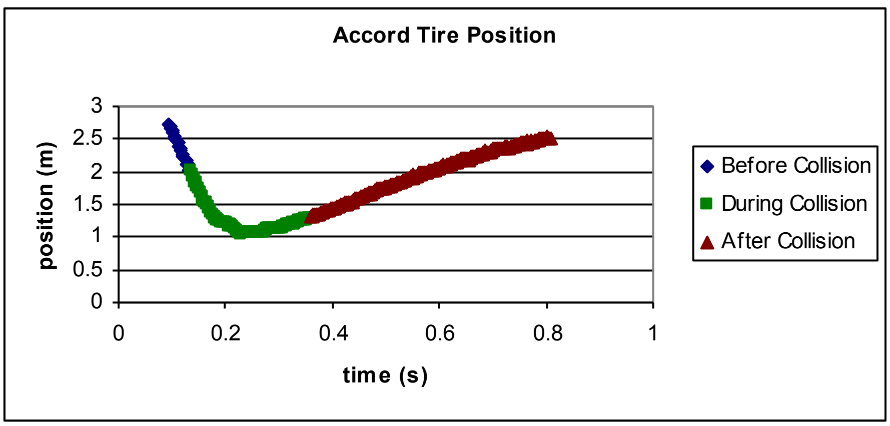

Figure 19 Position of tire vs. time

The data for each of the graphs was broken up into three parts: before, during, and after the collision. Using modeling techniques, we found that the velocity of both the tire and the dummy's head were constant before and after the collision. During the collision the position data acquired is non-linear, showing that the tire and the dummy's head do not have a constant velocity.

The data collected from VideoPoint was entered into Excel. The time was corrected by modeling the false data and then creating a graph of the position vs time, the slope of which was the false velocity. Knowing that the actual velocity should be approximately 17.88 m/s, equation 1 was used to obtain the actual time.

$$t_r = \frac{-17.88\text{m/s}}{-1.045\text{m/s}} * t_f$$

Vehicle Make	*Velocity Before Collision (dummy's head)* (m/s)	*Velocity After Collision (dummy's head)* (m/s)
Kia Sedona	**-17.88**	**1.53**
Cadillac CTS	**-17.88**	**5.92**
Ford Explorer	**-17.88**	**5.88**
Honda Accord	**-17.88**	**5.45**

Figure 20 Velocities before and after collision (dummy)

Vehicle Make	*Velocity Before Collision (vehicle)* (m/s)	*Velocity After Collision (vehicle)* (m/s)
Kia Sedona	**-17.88**	**2.98**
Cadillac CTS	**-17.88**	**3.12**
Ford Explorer	**-17.88**	**3.56**
Honda Accord	**-17.88**	**3.01**

Figure 21 Velocities before and after collision (vehicle)

Vehicle Make	*Time During Collision dummy's head* (s)	*Time During Collision vehicle* (s)
Kia Sedona	**0.241**	**0.221**
Cadillac CTS	**0.200**	**0.235**
Ford Explorer	**0.185**	**0.172**
Honda Accord	**0.146**	**0.226**

Figure 22 Collision time for dummy and vehicle

The change in momentum of the dummy’s head in Kia Sedona was calculated by using equation 2 which produced the impulse.

Δp =((4.5kg)(1.54m/s)-(4.5kg)(-17.88m/s)) ($\hat{x}$)

=87 kg*m/s ($\hat{x}$)

The change in momentum of the vehicle for the Kia Sedona was also calculated using equation 2:

Δp = (2120.45kg)(2.99m/s)-(2120.45kg)(-17.88m/s)

= 4.42 x 10^4 kg*m/s

Using the same method the change in momentum for each of the dummy’s heads in each of the vehicles is as follows:

Vehicle Make	*Change in Momentum: dummy’s head (*kg*m/s*)*	*Change in momentum: vehicle (*kg*m/s*)*
Kia Sadona	**87**	**4.42 x 10^4**
Cadillac CTS	**107**	**3.46 x 10^4**
Ford Explorer	**108**	**4.43 x 10^4**
Honda Accord	**106**	**3.03 x 10^4**

Figure 23 Change in momentum for dummy and vehicle

The average net force on the dummy’s head from the collision in the Kia Sedona was calculated using equation 3:

$$< F_{NET} >= \frac{87.3\text{kg} * \text{m/s}}{(.321\text{s} - .080\text{s})}$$

$$< F_{NET} >= 363\text{N}$$

The average net force on the vehicle for the Kia Sedona during the collision was calculated using equation 3:

$$< F_{NET} >= \frac{4.43x10\text{^}4\text{kg} * \text{m/s}}{(.309\text{s} - .088\text{s})}$$

$$< F_{NET} >= 2.00x10\text{^}5\text{N}$$

Using the same equations average net force for each of the vehicles was calculated.

Vehicle Make	*Average Net Force on the dummy's head (N)*	*Average Net Force on the vehicle (N)*
Kia Sedona	**363**	**2.00 x 10^5**
Cadillac CTS	**535**	**1.44 x 10^5**
Ford Explorer	**717**	**1.85 x 10^5**
Honda Accord	**721**	**1.34 x 10^5**

Figure 24 Average net force for dummy and vehicle

The net work was calculated using equations 4 and 5 for the dummy's head during the collision of the Kia Sedona:

$$W_{NET} = \frac{1}{2}(4.5\text{kg})(1.54\text{m/s})^2 - \frac{1}{2}(4.5\text{kg})(17.88\text{m/s})^2$$

$$W_{NET} = -714\text{J}$$

The net work calculated for the vehicle during the collision of the Kia Sedona:

$$W_{NET} = \frac{1}{2}(2120\text{kg})(2.98\text{m/s})^2 - \frac{1}{2}(2120\text{kg})(17.88\text{m/s})^2$$

$$W_{NET} = -3.29 * 10\text{^}5\text{J}$$

Using the same equations net work for each of the vehicles was calculated.

Vehicle Make	*Net Work: dummy (J)*	*Net Work: vehicle (J)*
Kia Sedona	**-714**	**-3.29 x 10^5**
Cadillac CTS	**-640**	**-2.55 x 10^5**
Ford Explorer	**-651**	**-3.19 x 10^5**
Honda Accord	**-650**	**-2.26 x 10^5**

Figure 25 Net work for dummy and vehicle

From this data we were able to use equation 6 to find the maximum force exerted on the dummy.

$$-714J = \frac{1}{2}(.321s - .08s)F_{MAX}$$
$$F_{MAX} = -5925.3N$$

Using the same methods the maximum force exerted on the vehicle during the collision for the Kia Sedona.

$$-3.29*10\text{^}5J = \frac{1}{2}(.309s - .088s)F_{MAX}$$
$$F_{MAX} = -2.98*10\text{^}6N$$

Vehicle Make	*Maximum Force on the dummy (N)*	*Maximum Force on the vehicle (N)*
Kia Sedona	-5.93*10^3	-2.98*10^6
Cadillac CTS	-6.40*10^3	-2.12*10^6
Ford Explorer	-8.65*10^3	-2.66*10^6
Honda Accord	-8.84*10^3	-2.00*10^6

Figure (26) Maximum Force on dummy and vehicle

Conclusion:

The developed prediction was incorrect as the data show. According to the Insurance Institute for Highway Safety, the Cadillac CTS, Honda Accord and Ford Explorer achieved a “Good” rating in a frontal offset collision test in their mass class. The Kia Sedona achieved an “Acceptable” rating. VideoPoint data reflect differently, however.

Data shows (Figure 24 and Figure 26) that the Honda Accord's occupant receives the largest amount of force during the collision while the occupant in the Kia Sedona receives the least amount of force during the collision. Interestingly, the Kia Sedona itself undergoes the most amount of force while the Honda Accord undergoes the least. Therefore, if safety is defined as the amount of force the occupant receives, the Kia Sedona is the safest vehicle. The difference for the average net force on the dummy compared to the vehicle comes from the air bag's ability to lengthen the amount of time during the collision. Also, the dummy has much less mass compared to the vehicle, so the force needed to change the momentum is less.

Figure 25 shows that kinetic energy was not conserved during any of the collisions. This means that energy is being lost to thermal, sound and deformation energy. According to Bobrek et al 2001, "The amounts of energy and deformation involved in collision are significant, and must be well understood to be harnessed into mechanisms that will protect vehicle occupants. In recent years considerable effort has been directed toward development of computational methodologies for simulating the mechanical response of automotive structures in collisions" (p1). When each vehicle hits the deformable barrier the vehicle crumples as is collides with the wall. This action increases the collision time with the barrier thus decreasing the net force acting on the dummy. This is known from past data and is shown in figure 26 below, as collision time increases with the presence of crumple zones, force will decrease dramatically (autoracing1.com).

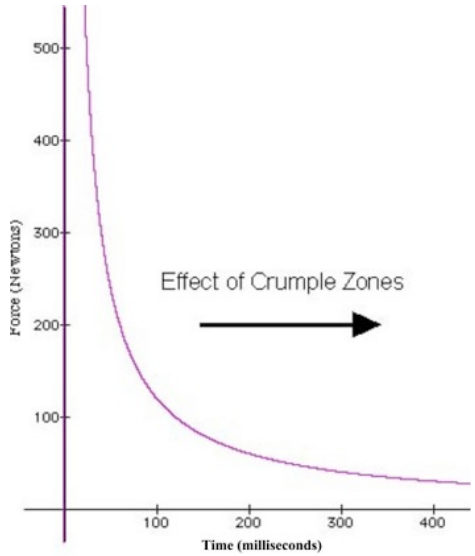

Figure 27 Effects of crumple zones

Therefore, the Kia Sedona is thought to best use the crumple zone technology. Looking at the data, because of its mass, the Kia Sedona vehicle receives the most amount of force, although the occupant receives the least due to these crumple zones.

Discussion:

Overall, this experiment turned out to produce, seemingly, nice data. All graphs developed (Figures 12-19) matched data from previous experiments and validated laws discussed in physics, such as Newtons First Law and Second Law. Although, it must be mentioned this experiment did contain some areas of uncertainty that, if preformed again, could be fixed. Some areas of the experiment that may have contained uncertainties were the use of VideoPoint in following the exact same point and losing both the tire in the bumper and the dummy's head in the airbag. The correction of the time scale is another area that could cause a level of uncertainty in our data. Another major uncertainty for this experiment was in determining the exact length of time for the collision. In this experiment collision time was determined to be the moment the car touched the wall until the moment it left. However, this could be incorrect and the wall may not affect the car during that entire time period.

If this experiment was repeated it would be beneficial to study the collisions of more vehicles within each of the four categories studied because we could determine if flaws occurred within the data and to help generalize the results.

Since this experiment did produce such wonderful data, further investigation are required to fully understand it. Understanding exactly where all of the lost Kinetic energy went is an area to be examined. This could possibly lead to better safety developments in vehicles. Also, examining this would help validate a new hypothesis that resulted from data collection in this experiment as to the affectivity of crumple zones.

This project has not only provided a deeper understanding in various principles of physics but will also help dissolve the myth, such as mass and cost correlating positively with safety for occupants, surrounding these vehicles experimented with.

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