

# Numerical Simulation of a Child's Head Impact in a Frontal Car Collision

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**Abstract** - Car-pedestrian collisions account for a significant proportion of automobile fatalities in developed countries. Automobile collisions appear to be a source of concern for head injuries. Since the head is the most critically injured component of many crashes, including pedestrian car accidents. In order to minimize the incidence of such accidents, the International Safety Committee has recommended subsystem experiments in which headform impactors are impacted against the car hood. The aim of this study is to investigate the head injury criteria for child headform with two different parameters. A first investigation deals with responses of the baseline bonnet when it is subject to the child headform at various positions on the bonnet with the influence of engine compartment components such as radiator, engine cover and battery cover and investigating the head injury criteria especially when the rigid parts underneath bonnet were engaged in the impact. A second investigation involves Pop-up hood systems where the gap between the hood and rigid components increases, and the head injury criteria are monitored in all grid positions.

**Key Words:** Pedestrian Safety, Head Injury Criteria, Pop-Up Bonnet, Child headform, Head Impact, Head Impact analysis.

## 1. INTRODUCTION:

According to accident reports, over 270,000 pedestrians die on the world's roads each year, accounting for 22% of the total 1.24 million road traffic deaths. A forward-moving car is involved in many pedestrian accidents. In such a collision, a standing or walking pedestrian is struck and accelerated to the car's speed before continuing forward while the car brakes to a halt. The pedestrian is struck twice, first by the vehicle and again by the pavement, but the majority of fatal accidents are caused by the interaction with the car.

Vehicle models usually concentrate on comprehending the car-pedestrian relationship, which is described by the following series of events:

The car bumper strikes the pedestrian's lower limbs first, the leading edge of the hood strikes the upper thigh or pelvis, and the top surface of the hood and/or windshield strikes the pedestrian's head and upper torso. The majority of pedestrian injuries are caused by traumatic brain damage

as a result of a rough hit of the head on the Stiffener hood or windshield.

As a result, the hood and its surroundings are critical for head protection. In a pedestrian collision, the bonnet of a modern car is designed help control the impact energy of a pedestrian's head. However, a bonnet's ability to absorb impact energy is often hampered by its proximity to engine components i.e., by its underneath bonnet clearance. If there is inadequate clearance between the hood and the rigid underlying engine components, the most severe head injuries occur.

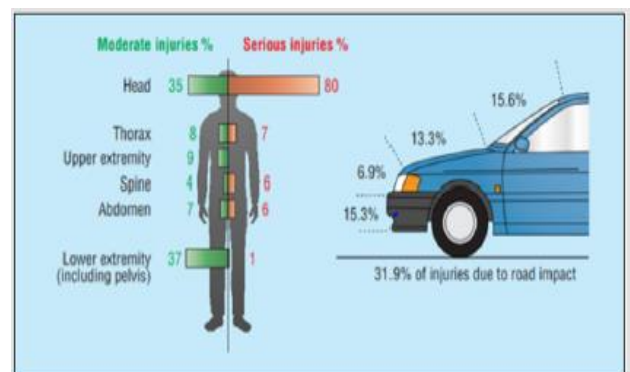


Fig -1: Pedestrian Injuries due to impact

A distance of around 10 cm is normally sufficient to allow for a controlled deceleration of the pedestrian's head and a substantially reduced risk of death. Making space under the hood isn't always simple since there are typically other design constraints.



Fig -2: Pop-up Bonnet Testing

Pop-up hood systems were developed as a pedestrian safety technology for vehicles with a narrow space between the inside surface of the hood and the rigid parts in the engine compartment. These systems are designed to help minimise the head injury criterion (HIC) by raising the hood and increasing the gap between the rigid parts in the engine compartment

## 2. PEDESTRIAN HEAD INJURY

In a pedestrian collision due to the almost abrupt halt, the vehicle experiences a very high negative acceleration (tens of times greater than = 9.8 g/m2). The absolute (positive) value is often referred to as the car's deceleration. The effect is only felt for a fraction of a second (typical values of 100 to 250 milliseconds or so) as the dummy is subjected to a crash forces. The head, in particular, can undergo very significant and brief accelerations as a result of contact with the steering wheel, windshield, side window, or head rest. These impacts, which last just fractions of a second, may also result in severe or fatal head injury. As a result, the HIC number and HIC criteria is an indicator of the probability of an impact head injury.

The HIC number is derived from the short-lived but extraordinarily high time-dependent acceleration  $a(t)$  encountered by a person's head after an impact. The HIC criteria attribute various probabilities of head injuries to different HIC number ranges [6]

It is defined as:

$$HIC = \max_{t_1, t_2} \left\{ \left[ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) dt \right]^{2.5} (t_2 - t_1) \right\}$$

Fig -3: HIC Formula

Where  $t_1$  and  $t_2$  are the initial and final times (milliseconds) chosen to maximize HIC and acceleration 'a' is measured in gs (standard gravity acceleration). The time duration,  $t_2 - t_1$  is limited to a maximum value of 36 ms usually 15 ms. This means that the HIC includes the effects of head acceleration and the duration of the acceleration. Large accelerations may be tolerated for very short times. At a HIC of 1000, there is an 18% probability of a severe head injury, a 55% probability of a serious injury and a 90% probability of a moderate head injury to the average adult [5]

## 3. REGULATIONS FOR THE SAFETY OF PEDESTRIANS

The EEVC has released several standards for the pedestrian safety scheme. The experimental setup was created in accordance with Regulation No. 127, which was published in 2014 [5]. On the pedestrian safety test, this technique is used. The head impact area is the first boundary condition to be calculated for the head impact calculation. That is determined using Wrap Around Distance (WAD).

Wrap Around Distance is a measurement of the distance from the pavement to the head impact zone around the car's exterior surface

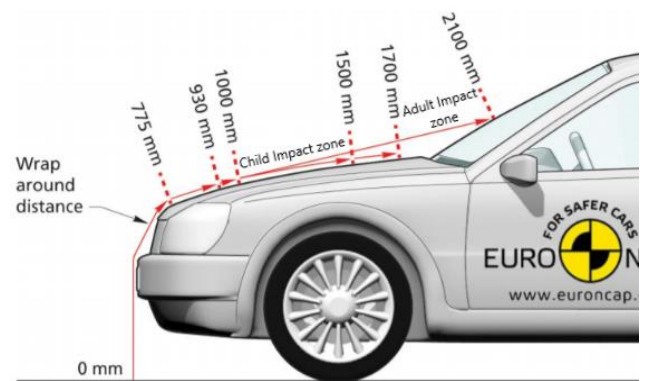


Fig- 4: Wrap Around Distance

The wrap around distance is measured from the ground longitudinally in the middle of the vehicle. During the crash study, two test zones will be developed depending on the Wrap Around Distance (WAD), namely the Child head impact zone and the Adult head impact zone.

The head impact zone for children is 1000 to 1700 mm WAD, while the adult head impact zone is 1700 to 2100 mm WAD. According to the regulations, the Child headform velocity at the moment of impact must be 9.7 m/s. The direction of impact must be 50 ° to the horizontal in the longitudinal vertical plane of the vehicle to be measured.

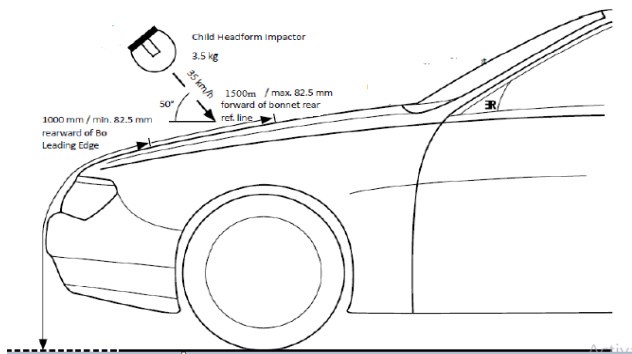


Fig -5: Regulation for Child head Impact

#### 4. METHODOLOGY

In this study the head injury criteria over a standard bonnet and pop up bonnet were investigated. The Child headform were impacted over different grid points (over child head zone) on bonnet and the results were studied, so the first step to create a FE model of vehicle and child headform.

##### 4.1 Child Headform

The child headform impactor is made of a spherical shape of 165 mm overall diameter. This sphere is covered with a 14 mm thick synthetic rubber skin, covering more than half of the front face, while having provision for instrumentation at the flat rear face. The total mass of the Child Head is 3.5 kg, with the centre of gravity (CG) located at the geometric centre of the sphere. A triaxial accelerometer is mounted in the sphere recess, used for measuring the total acceleration of the impactor during impact and subsequently the Head Injury Criterion (HIC) value. [2]

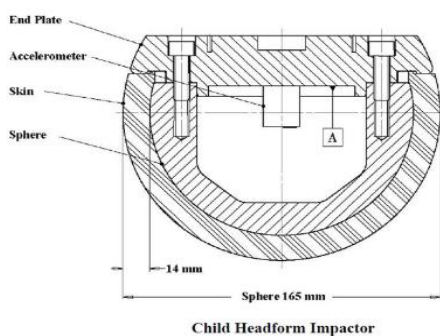


Fig -6: Child headform Impactor

Except for the outer skin, which is made of synthetic rubber, the entire headform is not deformable. So the outer skin of

the headform was assigned to \*MAT\_OGDEN RUBBER, and the remaining components were assigned to \*MAT\_RIGID. The density values for each component were assigned so that the physical properties such as mass C.G matched that of the actual headform.

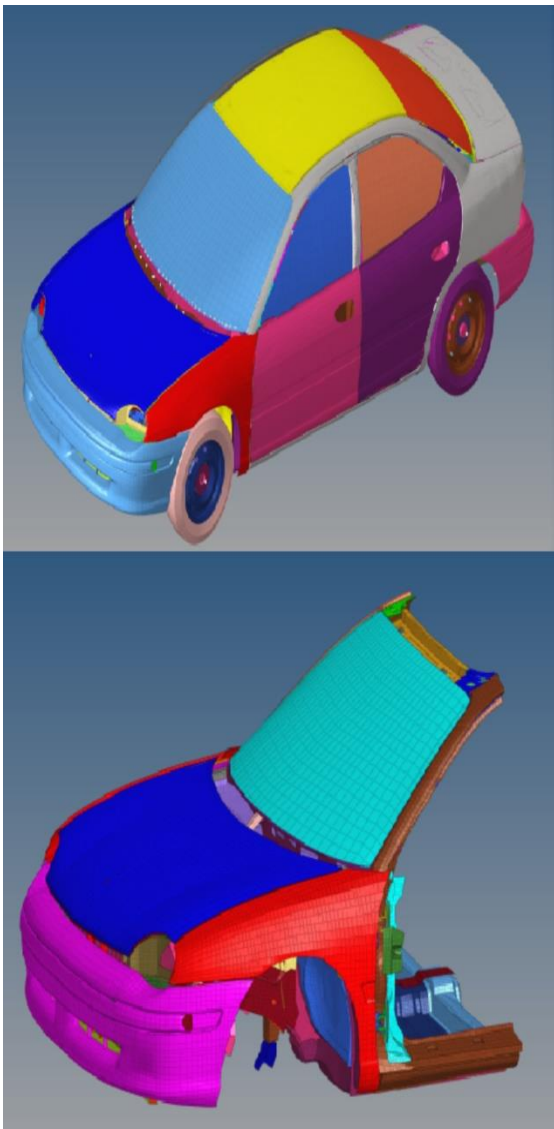
\*CONTACT\_AUTOMATIC\_SURFACE\_TO\_SURFACE with segment-based contact algorithm formulation (SOFT=2) was defined between the skin and skull. The accelerometer is on the Accel Block, ELEMENT\_SEATBELT\_ACCELEROMETER card with a local coordinate was used which is located on the head.



Fig-7: Child head FE Model

##### 4.2 Vehicle FE Model

The Dodge Neon Car model was used in this research. Two kinds of models with different hood edge height were used. The interaction occurs between the child's head and the car's front end. As a result, a reduced model is developed due to the CPU cost. CNRB (constrained Nodal Rigid Body) is created at the cutting plane of the vehicle so that all degree of freedom can be constrained.



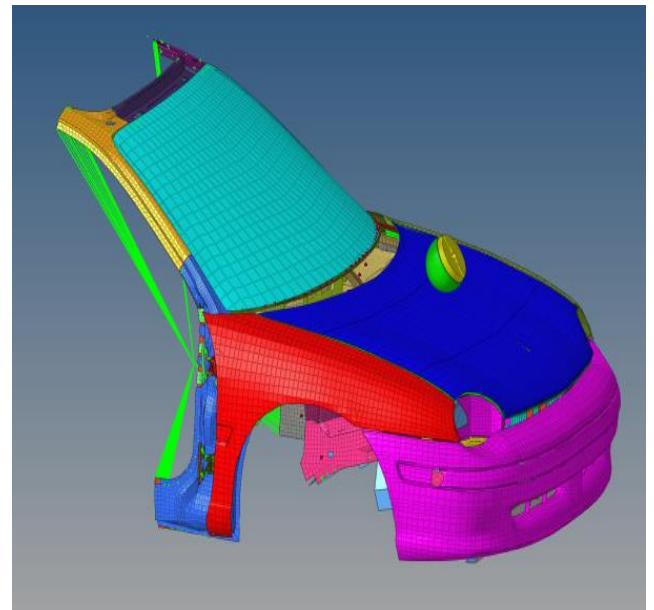
**Fig -8:** Vehicle Full model and Reduced Model

\*CONTACT\_AUTOMATIC\_SINGLE\_SURFACE contact was assigned to the vehicle model to prevent from self-contact during the simulation.

\*MAT\_PIECEWISE\_LINEAR\_PLASTICITY material card is used for most elasto-plastic material in vehicle FE model and Bonnet assembly was assigned with aluminum material properties.

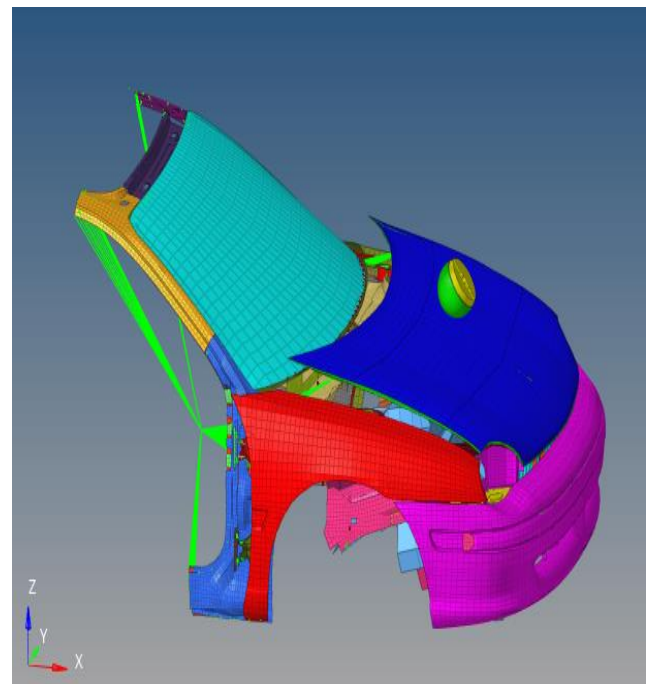
\*CONTACT\_AUTOMATIC\_SURFACE\_SURFACE contact was assigned to bonnet and child headform. The head is impacted at initial velocity of 35km/hrs. over the child impact zone as per the regulation.

Figure 10 shows Pop-up bonnet setup, The Bonnet assembly is tilted with 5 degree by keeping the front end of bonnet fixed and the lift distance is 10cm.



**Fig - 9:** Baseline Bonnet Setup

This study considers the effect of the engine compartment configuration on the head injury criterion (HIC) value. As results, all parts in the engine compartment that are close to the bonnet are ensured that are having proper clearance that matches the physical Car model, HIC values are investigated when any parts in the engine compartment engage with the bonnet during simulation.



**Fig -10:** Pop-up Bonnet Setup

The HIC Criteria value would provide a broad range of outcomes due to the effect of the engine compartment, hood stricture, and clearance between the engine compartment

and the hood. As a result of these conditions, Impact points for the test matrix were chosen Over a Child head impact zone, a total of 42 impact points were selected to obtain the HIC value at both crucial and significant points. Figure 11 shows these impact points, while Figure 12 shows the corresponding points in the engine compartment.

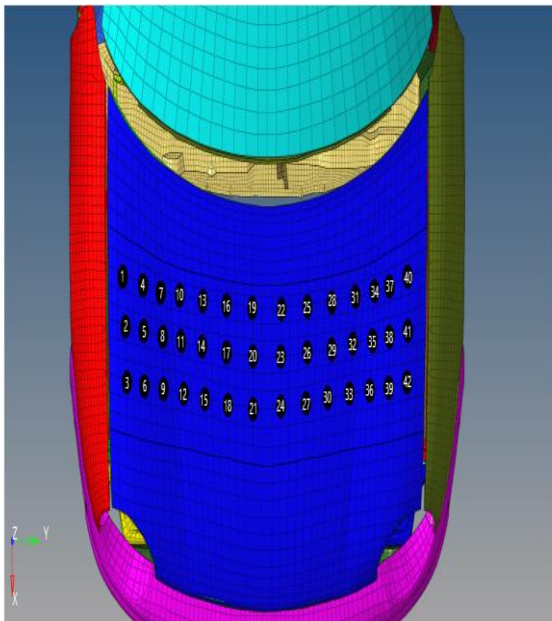


Fig -11: Impact Point on Bonnet

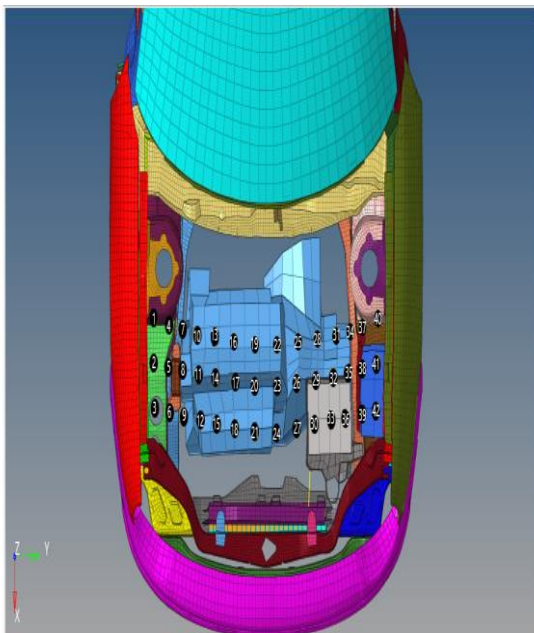


Fig -12: Impact Point

## 5. SIMULATION RESULTS

The child head impact analysis was performed for the baseline bonnet and pop up bonnet under the effect of engine compartment components at different grip points,

and the results were plotted in the form of head injury criterion (HIC).

The table 1 shows the intended HIC tolerance values in relation to brain damage and skull fracture.

Tablet- 1: Brain Injury based on HIC value

HIC range	Brain Injury	Skull Fracture
< 150	No concussion	No Fracture
150- 500	Mild Concussion	No Fracture
500-900	Severe Concussion	Minor Fracture
900-180	Severe Concussion	Major Fracture
>1800	Life Threatening	Life Threatening

Based on this margin, the highest permissible HIC value is 1800, and an HIC value less than 650 offers the highest pedestrian protection, which is zero harm. Head impactor acceptance criterion are Half of the area of Child head impact zone , HIC value should be below 1000 and combining the child and adult impact zone for two third area HIC value should be below 1000 and HIC should be less than 1700 in the remaining region.

As the result of analysis, Figure13 show the HIC value over grid point for Study 1 the Baseline bonnet setup. The engine is positioned in the compartment's left corner, resulting in a smaller space between the bonnet and engine. As a result, points 11, 14, 17, and 20 have the highest HIC values, which are greater than 1500. This is more than the acceptance criteria. The components underneath the bonnet have a large gap over the right section of the bonnet, allowing the bonnet to bend more and absorb more internal energy, reducing kinetic energy.

As a result, the HIC value over the right portion is less than 1000. However, because grid point 40 is near the edge of the bonnet, the HIC value 1659 is due to the effect of the side fender during the collision.

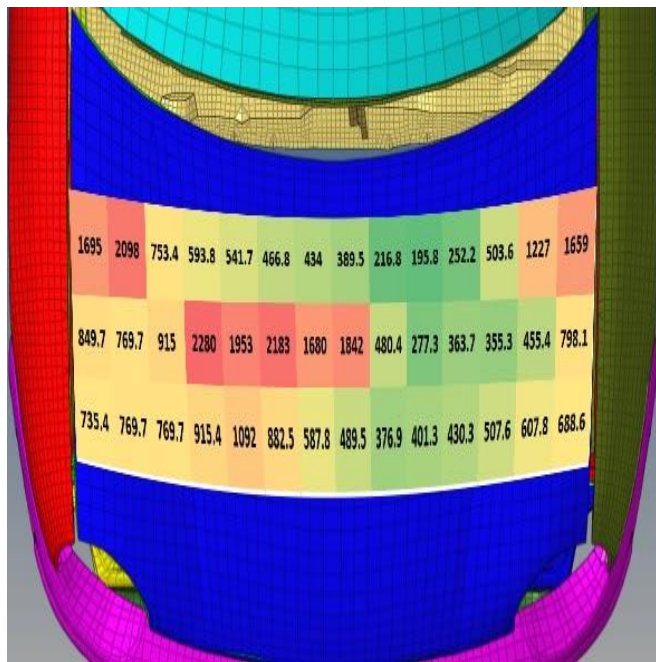


Fig -13: HIC result for Baseline Bonnet

Over 20% of the whole area is in the red zone, which is defined as an area with an HIC value more than 1500 and 30% area are in yellow region which around 700-1000 HIC. 50% of the whole area is in green zone which means the HIC values is less than 650 that can offer the highest pedestrian protection, which is zero harm.

The HIC value in Study 2 for the pop up bonnet setup is shown in the Figure14.

The front end of the bonnet is fixed and the lift distance is 10cm with the bonnet assembly inclined 5 degrees. Raising the hood has increased the gap between the rigid parts in the engine compartment and bonnet. As result HIC values over grid point have drastically decreased compare to the baseline bonnet. The 11th point on the baseline bonnet as 2280 HIC value whereas in popup bonnet the HIC value on 11th point is 208 The highest HIC value are over the corner of the bottom. Because the front end of the bonnet is fixed, the gap progressively widens, with the first row of grid points from 3- 42 having a smaller gap than the third row of grid points from 1- 40, which has a larger gap.

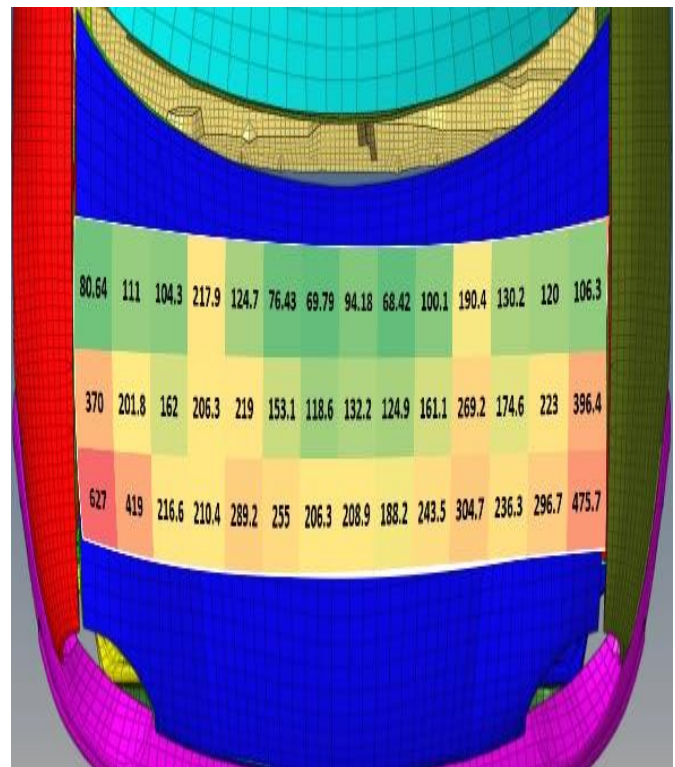


Fig -14: HIC result for Pop-up Bonnet

As a result, the HIC value on the first row (1-40) is lower, while the HIC value on the third row (3-42) is higher. The green zone covers 35% of whole area where the HIC value is less than 150 and HIC value between 150 to 350 are covered 52% yellow zone and HIC value more than 350 are covered by 13% of red zone ,Also there isn't any region of the popup bonnet that HIC value higher than 650.

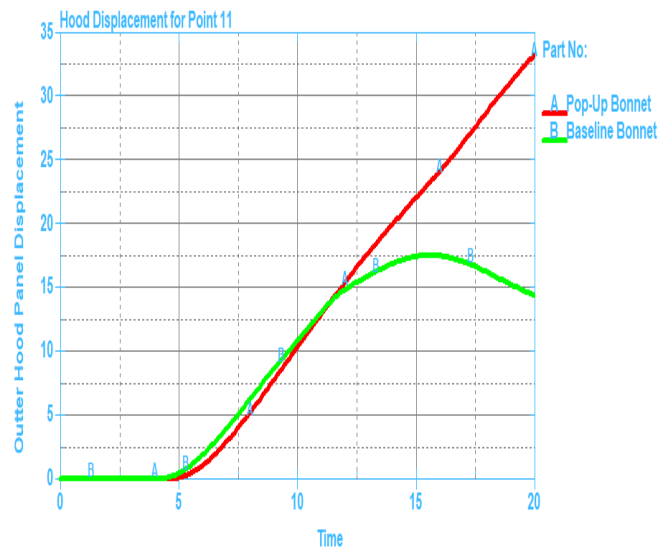
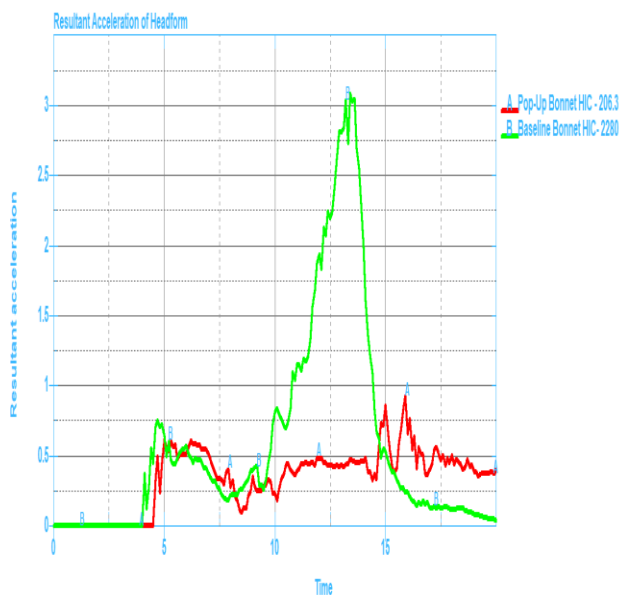


Fig -15: Hood Displacement

The figure 15 interprets the displacement of the bonnet in two scenarios. At 15ms, the baseline bonnet attained maximum displacement and rebounded somewhat due to contact with engine components as illustrated by the dip in the graph, however in the popup bonnet, the displacement curve steadily climbs without any decrease, indicating that there is no contact with engine components due to the extra clearance. The Maximum displacement occurs on the pop-up bonnet. Since it had more clearance between hood and engine components which made it feasible to deform more compared to the baseline bonnet



**Fig -16:** Resultant acceleration

The figure 16 evaluates the resultant acceleration taken from the head accelerometer to measure the head injury criteria. The resulting acceleration was about the same for both cases until 10ms, however due to the contact of the engine in the baseline bonnet, the acceleration of the head dramatically rises after 10ms. This dramatic increase in acceleration resulted in stricter Head injury criteria. So, by allowing the Hood to deform more, it absorbs more internal energy and progressively decreases the kinetic energy of the head as well as the acceleration as result head injury criteria are in acceptance range with little harm.

## 6. CONCLUSION

One of the most essential injury criteria for relating to human safety in diverse settings is the Head Injury Criteria. It is widely employed and utilized in the design of safe vehicles. The scenario presented in this study: the HIC criteria are evaluated for passenger cars with two Design parameters - (Baseline Bonnet and Pop-up Bonnet) for

ensuring pedestrian safety. Head Injury criteria were investigated for two different setup with influence of engine compartment. HIC values was observed on the baseline model were very higher because the insufficient clearance between the bonnet and engine compartment, Interestingly HIC were dropped from 10% to 50% in Pop up Bonnet setup just by increasing the clearance between the bonnet and engine compartment. This System Provides more Space between the Bonnet and the engine components by raising the rear end of hood before the head comes into the contact. As results in more deformation of hood and more energy absorbed thus reduced the head injury risk. It is a sophisticated system since it is a deployable design, including a bumper sensor, a hood hinge release mechanism, a hood actuator, and an electronic control unit (ECU).

It evidently proved that Pop- up Hood System has helped to improve the pedestrian protection for the vehicle which has narrow clearance under the hood. The stiffness and design of bonnet alone can't decide the kinematic of pedestrian during a crash, Position and stiffness of other compartment should also be considered in any test or simulation. As a result, in any vehicle front end design where pedestrian safety is the goal, ample room should be considered beneath the bonnet, allowing the bonnet to bend to lessen the effect of contact.

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## BIOGRAPHY

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