

# Teenage cyclist - Pick up crash by multibody simulation; HIC evaluation and comparison with previous results

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*Abstract:* The study of the injury caused by Pick-up vehicle-teenage cyclist crash is presented in this paper. The vehicle has high frontal part, in order to compare the results with those obtained previously in the sedan and SUV - teenage cyclist crash. No variation is executed on the model of the teenage cyclist and the bike. Three different positions are analyzed: front, rear and lateral position. The injury on the cyclist head is examined by HIC criterion, in the way indicated in the rules. Correlation HIC – AIS is used to calculate the lethality of the injuries. A comparison is made between the results of the simulations for Pick up, SUV and sedan, concluding that the injury of the head is more dangerous for Pick-up impact than SUV and the sedan, but only at the maximum speed (50 km/h). This value of the speed can be considered critical, since HIC values are very high for all the three vehicles. The more dangerous injury is the side impact. A further comparison is done between the impact points of the three vehicles concluding that both the shape of the bonnet that the height of the front part must be studied carefully in order to reduce the damage to cyclists and pedestrians.

*Key-Words:* teenage bicyclist, Pick-up impact, severe (AIS4+) injury, HIC, biomechanics

## 1 Introduction

Many works are found in literature on the impact between vehicle and teenager [1] [4] or adult pedestrian [2] [3] [5] [10] [19] [24] [29] [30], also numerous works study the impact between the vehicle and the adult cyclist [9] [11] [13] [17][18] [21] [22] or both cyclist and pedestrian [6] [7] [8] [12] [14] [23], but the papers on the accident vehicle - teenage cyclist; are not numerous in literature [15] [16] [20] [36] [37] [38]; other works are not found on this scope. In [22] Authors indicate that car-mounted countermeasures designed to mitigate pedestrian injury have the potential to be effective even for bicyclists, while in [34], [35] Authors investigate the deploying time (or response time) of an active hood lift system (AHLS) of a passenger vehicle activated by gunpowder actuator.

In general multibody technique is the applied method for numerical simulation; the most widely

used programs are MADYMO, Aprosys, PC Crash, while the Authors of this paper effectively use Sim Wise.

Studies give an idea of the shape of the front of the vehicle in order to reduce injuries, that may arise due to collision [19] [30], but these works are not frequent in literature. In particular the works [22][23][24] also address the crash between SUV vehicle against cyclist or pedestrian, but other papers on Pick up – cyclist impact are not found.

This paper extends the results already achieved in the papers [15][16][38] where the damages caused by the energy impact of a teenage cyclist with a sedan car are taken into account and analyzed. Analogous crash is studied in case of vehicle constituted by a SUV [36] [37] instead than a normal sedan, in order to fill the gap in literature: references are found only to an adult or to a child, in many cases without taking into account the type of vehicle.

A campaign of virtual simulations is conducted with the availability of the virtual model Pick Up-teenage cyclist, in order to quantify the damage caused to the head and chest on the basis of certain criteria such as HIC and 3 ms criterion. Only HIC results are reported in this paper.

## 2 Implementation of Virtual Models

The paper [1] is very useful for the study of anthropomorphic model of the human figure of a teenager, understood as a complex of bones, muscles and joints, while the paper [3] has analogous value for the adult; the book [27] and the paper [28] are very useful for the chassis design and the geometry of the bike (fig. 1). The implementation of the virtual model of the bike is the same for SUV and sedan simulations [36] [37]. Virtual simulations, performed with Sim Wise, allowed quantifying the damages in the teenager cyclist – Pick Up impact on head and chest. Specifically HIC criterion is used regard to head injuries.

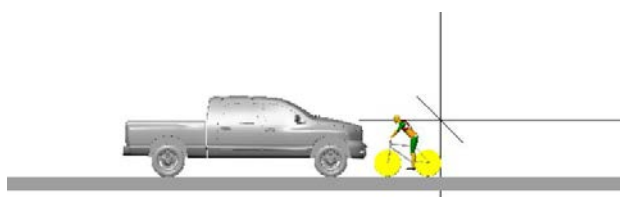


Figure1: cyclist model in Sim Wise

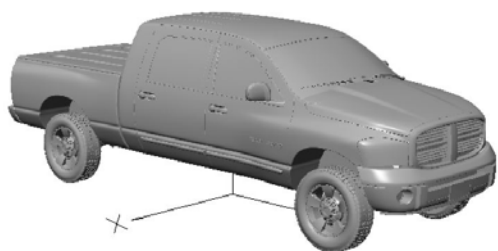


Figura2: Pick-up in Sim Wise

The choice of vehicle for the simulations is a Pick-up of the automaker Dodge. The information on pitch, height, length was provided by the manufacturer itself. Taking into consideration the impact mode, this type of Dodge Ram was chosen for its characteristics: the chassis has been completely redesigned for high-strength steels that increase stiffness and decreasing torsion vibrations and power; aerodynamics is better than every other Pick up, despite the new aggressive front. In this case Autodesk 3D Studio Max software is used to

get the STL model, which was subsequently imported into Sim Wise (fig. 2), attributing the masses, the centers of gravity and moments of inertia of the individual components such as wheel, body, chassis, bonnet, front bumper; these parameters are essential for the proper conduct of the tests and the acquisition of results.

## 3 Pick up - cyclist crash test

This article illustrates, through the use of charts, tables and representations, the tests to assess the damage produced on teenage cyclist under varying conditions of impact, in order to calculate HIC as regards the trauma to the head and the application of 3ms criterion for the evaluation of damage to the chest. Dynamic of impact of teenage cyclist – Pickup are reconstructed by Sim Wise.

The relative positions between the vehicle and the cyclist are the same as those used for vehicles already examined [15] [16] [36] [37] [38]. The positions are three: In the first he is positioned in the roadway with the side facing the Pick up about to occur (side impact); in the second case the cyclist is located opposite the Pick up about to occur (frontal impact), while in the third and last case the cyclist is placed behind the pick (telescoping or rear impact). Also in this paper, crash tests are executed at four different speeds: 20 km/h, 30 km/h, 40 km/h and 50 km/h.

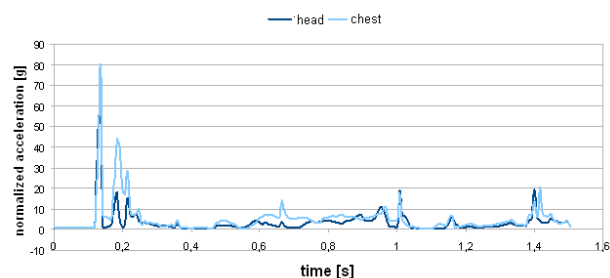


Figure1: Head and chest acceleration in the frontal impact at 20km/h

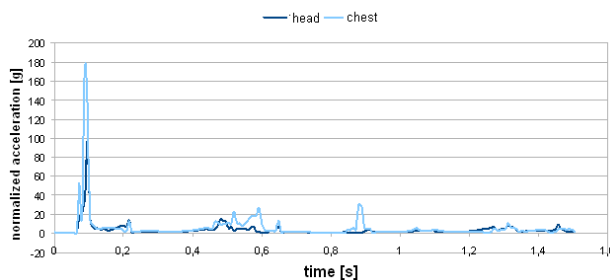


Figure 4: Head and chest acceleration in the frontal impact at 40km/h

### 3.1 Numerical Simulations, Crash Test Teenage cyclist – Pick up.

The parameters measured during the tests are:

- Acceleration in the head gravity centre;
- Acceleration in the chest gravity centre.

Acceleration performances of the head and thorax are shown in fig. 3-7, for some tests.

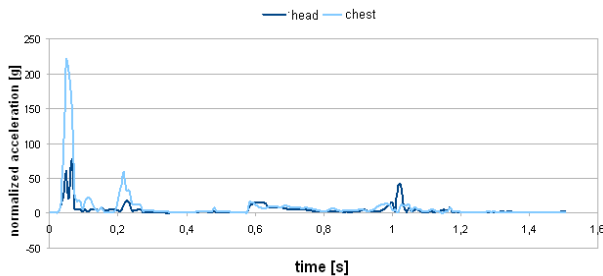


Figure 5: Head and chest acceleration in the side impact at 30km/h

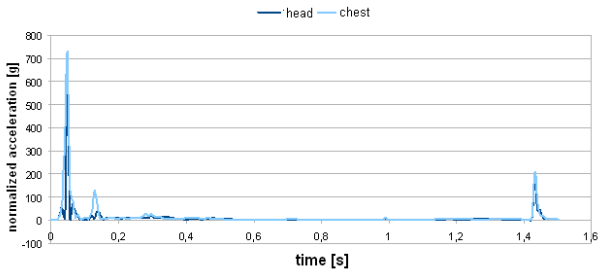


Figure 6: Head and chest acceleration in the side impact at 40km/h

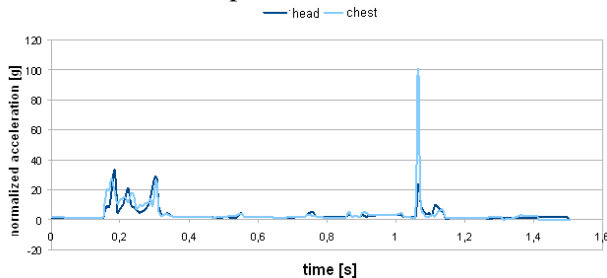


Figure 7: Head and chest acceleration in the telescoping at 20km/h

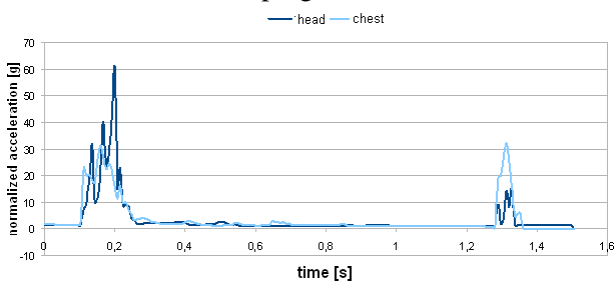


Figure 7: Head and chest acceleration in the telescoping at 30km/h

### 3.2 Test Analysis

Reconstruction in Sim Wise of events in certain conditions and circumstances allows observing the trajectories taken by the adolescent cyclist

throughout the collision, by comparing each time the extracted data from the trials with the test frames. The four sequences, represented in figs. 8, 9, 10 and 11, show the different trajectories taken in function of the different test conditions: fig. 8 illustrates the dynamic side impact at 20 km/h; one may notice the thrust of the front bumper and the forward projection of the cyclist. Fig. 9 depicts the trajectory taken by the cyclist who is invested posteriorly by the oncoming vehicle at a constant speed of 30 km/h. One may notice the thrust forward and the wheeling of the cyclist body. Fig. 10 shows the cyclist in a lateral position with respect to the pickup that proceeds at a constant speed of 40 km/h. One may notice the loading on the hood and on the same vault of the cyclist body. Fig. 11 show the cyclist in rear position with respect to the Pickup, which proceeds at a speed of 50 km/h. Also in this simulation one may notice the vaulting, typical of high-speed accidents.

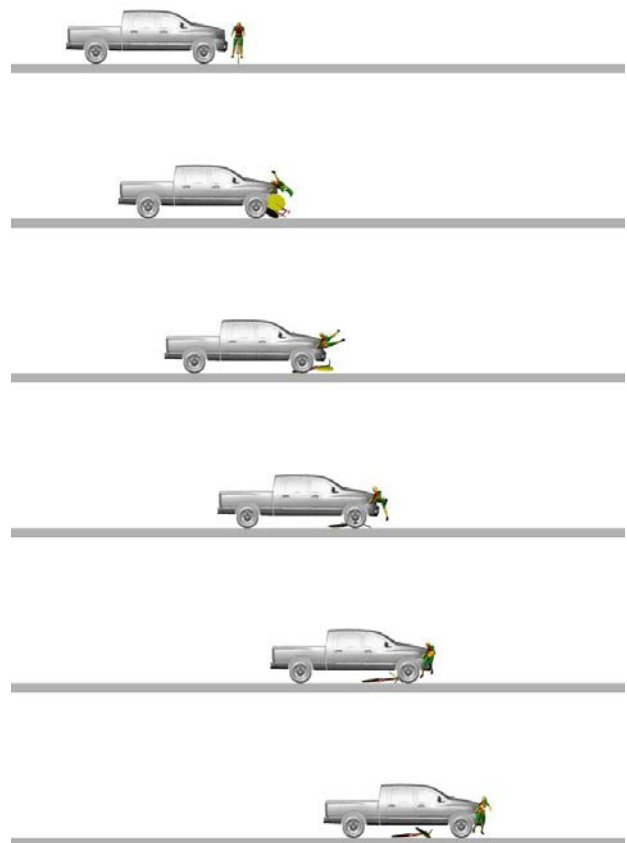


Figure3: side impact at 20km/h, constant speed.

#### 3.2.1 Results Analysis and HIC calculation.

The tests carried out revealed a host of very useful information to analyze the most important aspects.

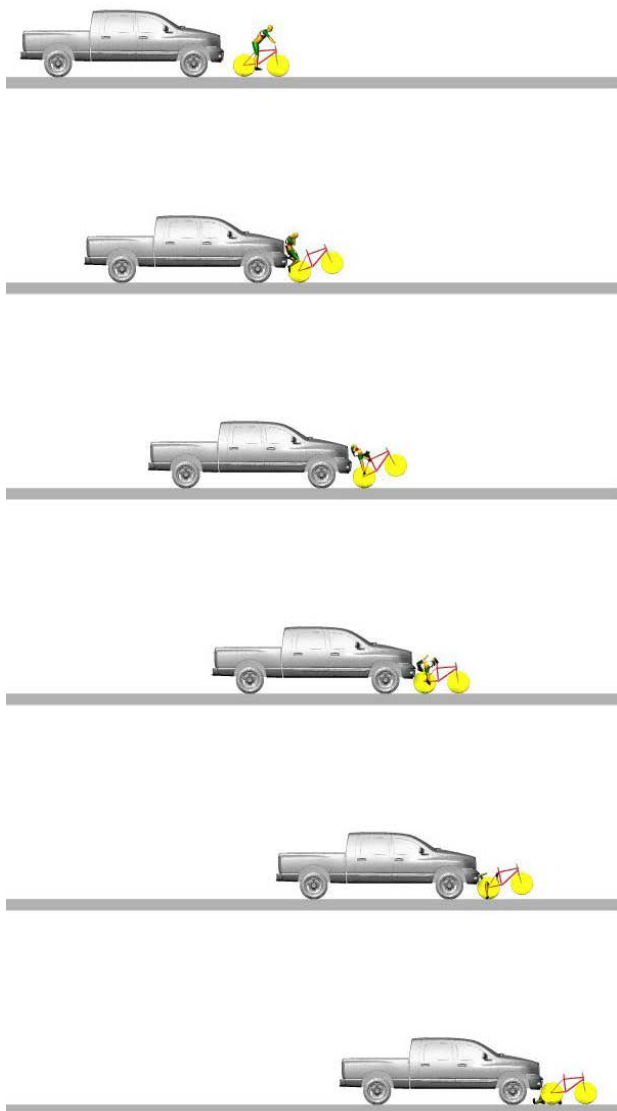


Figura4: telescoping at 30km/h, constant speed.

Table 1: obtained results and HIC values

Test	Position	Impact speed [km/h]	$A_{max\ head}$ [g]	HIC
1	Front	20	69,51	372,18
2	Front	30	78,94	411,72
3	Front	40	99,19	784,78
4	Front	50	177,01	4464,56
5	Side	20	111,85	213,04
6	Side	30	76,41	362,75
7	Side	40	563,19	4832,44
8	Side	50	236,56	7726,09
9	Rear	20	40,14	54,46
10	Rear	30	68,74	277,26
11	Rear	40	73,85	473,88
12	Rear	50	285,44	7543,26

Table 1 summarizes the obtained results and HIC values. Figure 12 shows the trend of HIC versus the impact speed for the three examined positions.

### 3.2.2 Impact Fatality and HIC-AIS Correlation.

Figure 13 show the correlation HIC-AIS in the case of side impact at constant speed. HIC data obtained in the tests with the injury scale AIS determine the fatality percentage. Analogous procedure can be used using the same correlation graphics for the other impact conditions; the values are reported in table 2.

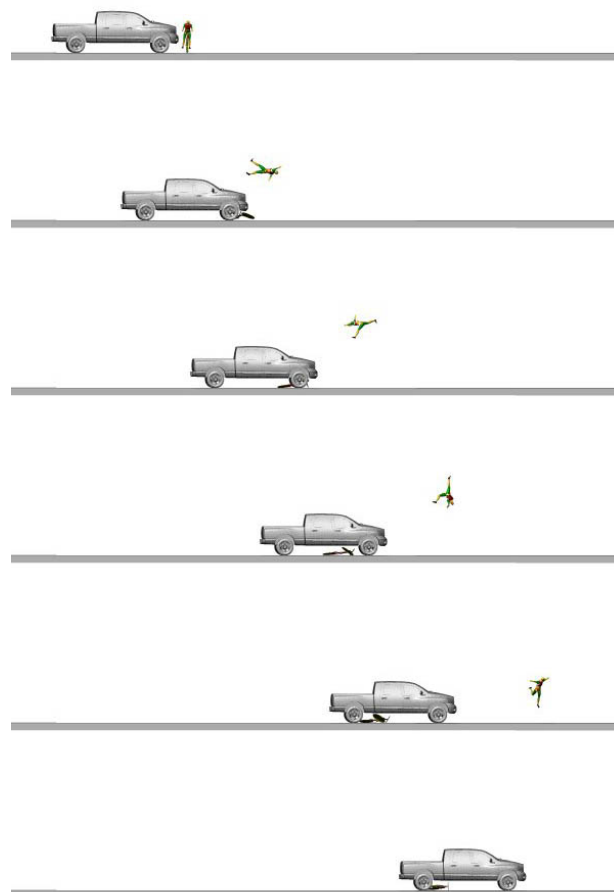


Figure 5: telescoping at 40km/h, constant speed.

### 3.3 Results and discussion.

Test can be distinguished in 3 groups:

1. tests 1- 4 conducted for side impacts;
2. tests 5 - 8 conducted for front impact;
3. tests 9 - 12 conducted for rear impacts.

In all the cases the graphs show a series of acceleration peaks caused by the impact on the lateral plane of the skull against the front of the

Pick-up (bumper and bonnet); the first contact with the bonnet occurs at the shoulder and at a later time with the head.

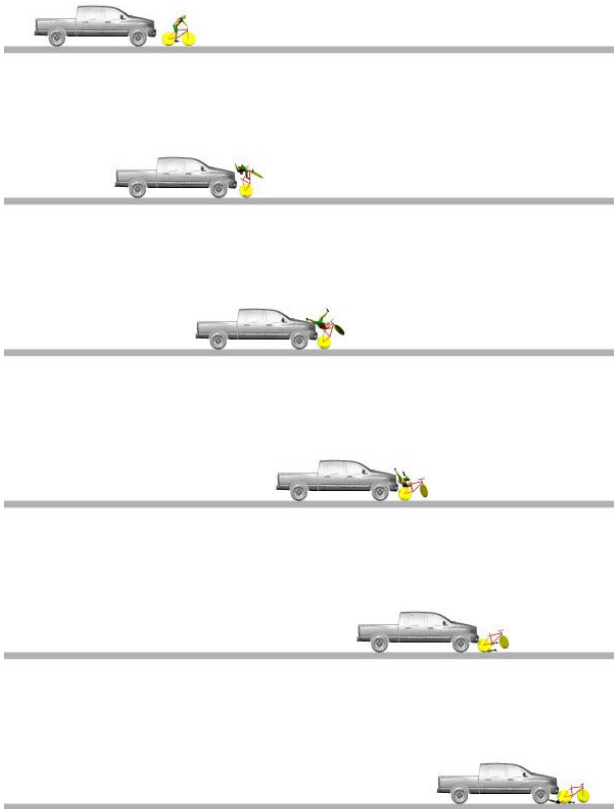


Figura6: telescoping at 50km/h, constant speed.

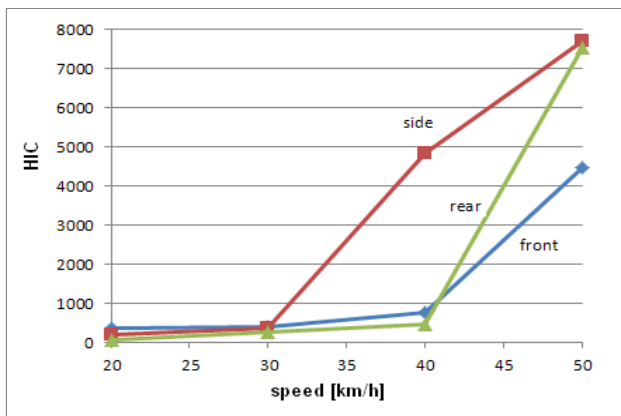


Figure 12: HIC values in the several positions

These peaks are repeated generally in the short around the 0.01s, due to some rapid rotations of the head around the articulation of the cervical neck. The subsequent peaks are quite random and not dependent on the assumed speed for the test, so that the graphics acceleration - time appear very different at different speed. This is because the head of the teenage cyclist is projected back strongly, due to the first contact with the vehicle bumper. In this

way the center of the instantaneous rotation of cervical joint varies by determining a variation of the moment of momentum which results in a substantial increase of the angular acceleration of the whole head.

A considerable growth of the accelerations measured for the chest is noted when, in some cases, there is an overlap of the head bump and of the chest contact on the bonnet.

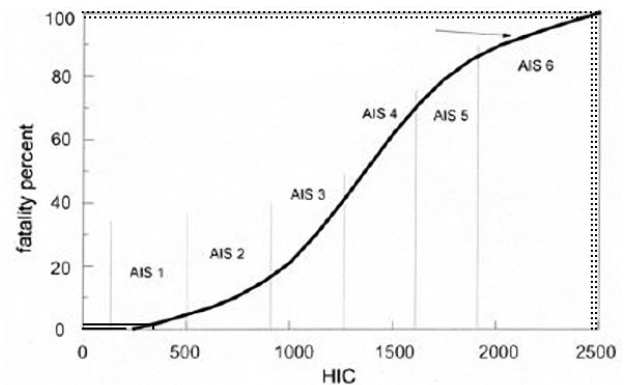


Figure7: HIC-AIS correlation (Side impact at constant speed)

Table 2: fatality percentage following the correlation HIC – AIS

Test	Posit.	Impact speed [km/h]	AIS	fatality [%]
1	Front	20	1	0-5
2	Front	30	1	0-5
3	Front	40	1	10-20
4	Front	50	6	100
5	Side	20	1	0
6	Side	30	1	0-5
7	Side	40	6	100
8	Side	50	6	100
9	Rear	20	1	0
10	Rear	30	1	0-5
11	Rear	40	1	0-5
12	Rear	50	6	100

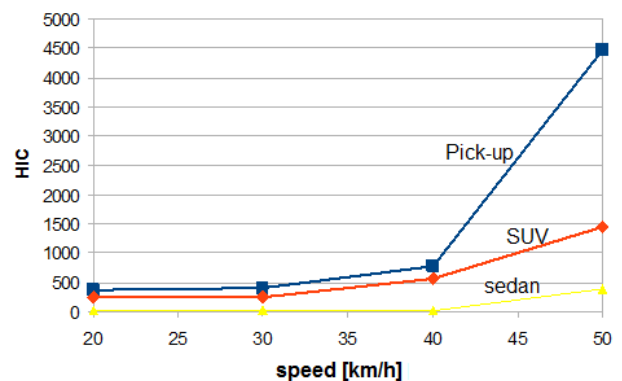


Figure 14: frontal impact Pick up – SUV – sedan

### 3.3.1 Results Comparison

Table 6 shows the percentage difference between the impact analysis Pick up - cyclist with SUV-Cyclist [36] [37] and sedan-cyclist [15] [16] [38], in term of HIC. The small, low-speed differences can be attributed to the elaboration acceptable imprecision.

Test	Posit.	Impact speed [km/h]	HIC Difference with	
			SUV	sedan
1	Front	20	+55,39%	+3027,53
2	Front	30	+32,74%	+3019,1
3	Front	40	+37,83%	+2930,4
4	Front	50	+207,17%	+1059,93
5	Side	20	+1934,77%	+512,18
6	Side	30	+90,62%	-30,48
7	Side	40	+754,86%	+695,33
8	Side	50	+486,57%	+1099,52
9	Rear	20	+16,37%	-45,65
10	Rear	30	+52,37%	-12,37
11	Rear	40	-42,42%	+37,68
12	Rear	50	+146,85%	+1411,37

Table: comparison HIC Pick Up – SUV and sedan

Figures 14, 15 and 16 show the trend and the visual comparison.

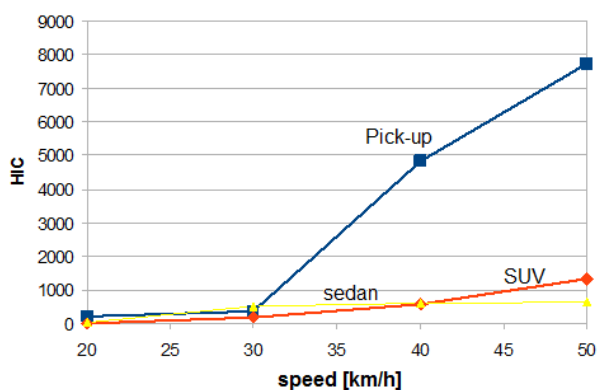


Figure 15: side impact Pick up – SUV – sedan

Comparison shows that the teenager cyclist has even more limited possibilities to survive the front, side and rear impact with Pick up in the speed range of 40-50 km/h since HIC values are consistently above the previously reported values for SUV or Sedan.

### 3.4 Localization of the contact points and comparison.

Figures 17 and 18 show the bonnet area that is more involved when the rider head hits the front of the

Pick up during the impact. The marking of the vehicle for identifying the same areas (WAD) occurs according to the Euroncap directives.

Dispersion of the impact points is localized in the WAD area 1000 in all cases, except for impacts at 50 km/h (WAD 1000 - WAD 1500).

In the tests for side impact the dispersion of impact points concern a larger area than the front/rear case (fig. 17). Furthermore, the analysis of the contact points of both cases allows to obtain a new confirmation regarding the accuracy of values. The very intense acceleration peaks generally correspond to a collision against a rigid wall of the vehicle front (the bumper is more rigid than the bonnet).

Impact points are highlighted in figure 32, in the case of sedan, Pick-up and SUV simulations. Pick-up and SUV simulations stand out the same impact zones (WAD 1000) with a speed of 20 km/h. The rider hits the bonnet (areas between 1000 WAD and WAD 1500) with speeds of 40 to 50km/h. The teenager cyclist will end up in the impact area between WAD 1500 and 2500 in the event of a collision with a sedan, with the exception of the 20 km/h speed.

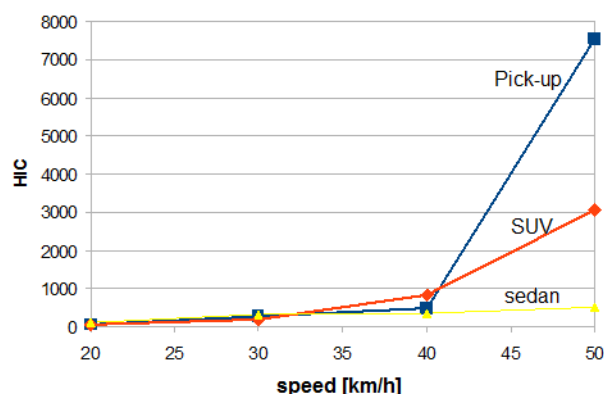


Figure 16: telescoping Pick up – SUV – sedan

## 4 Conclusions

Objective of this work is not only to assess the damage caused by an accident, by analyzing the impact dynamics between Pick up and bike, but, above all, to look for and suggest possible improvements and solutions to increase security, in order to limit the damage accused by the weakest subject.

The simulations show the importance of some key elements such as the rider height, and Pick up front profile and its minimum height from the ground, as well as the rigidity of those parts coming in contact

with the cyclist at the moment of impact so jeopardize the outcome.

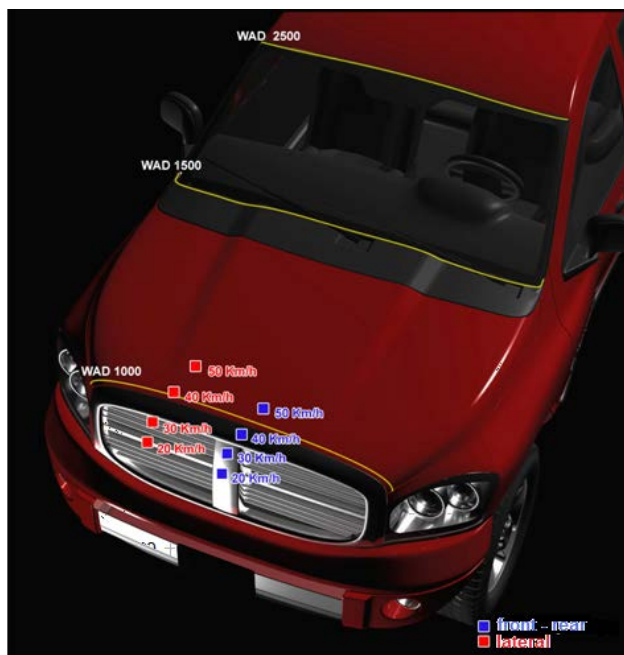


Figure 17: contact points head – Pick-up in the three series of tests.

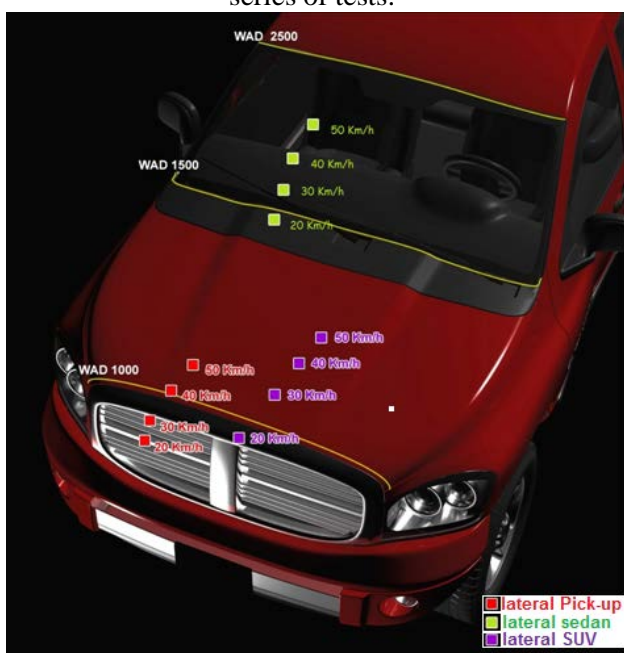


Figure 18: lateral crash tests; contact points of the head with sedan, SUV and Pick-up.

Position taken by the cyclist at the time of the accident can affect the outcome: the lateral position is more damaging than the front, in fact HIC values obtained by the simulations show that: during side impact the values are higher since the head of the cyclist immediately strikes the bonnet of Pick up; it overwhelms him and not the bike that could absorb the shock, but it does not happen.

Different thing happens in the front and rear impact. In these cases the vehicle affects primarily the bike that absorbs the shock, the point of impact then is highlighted in the vicinity of the wheel and the cyclist falls in a different way, because he is located at a seemingly insignificant distance, but in reality more.

In the simulations, all HIC values fall within the value 1000 (limit imposed by law); this is possible because good bump part is absorbed from the bicycle and not by the cyclist body. Moreover the simulations show that HIC values are much higher at 50km/h which is the critical speed.

The use of a virtual method as the multibody for the implementation of the simulations is beneficial; with it there were not a few adaptations, especially when one considers that the prototypes existed only as CAD drawings. In this way, the study of the accelerations transmitted by Pick up is certainly easier and can lead to reliable results thus cutting also excessive costs.

This kind of simulation has not only an impact on the costs, but especially on security, thanks to the tests on the effectiveness of passive and active devices for a flawless and more efficient performance.

The front edge of the bonnet can be improved by eliminating all the unnecessary rigid structures. Finally, the ability to lift up the bonnet during impact improves the protection of the head of the rider and this result can be achieved by leaving greater space between the bonnet and the engine block.

Finally, making use of proximity sensors, the presence of a cyclist on the trajectory of the vehicle can be determined more effectively and rapidly, by communicating the data to a control unit that provides to implement a braking in less time than those obtainable by human reflexes.

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