First Experience with Simulia's Headform Models for Pedestrian Protection Analysis

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The development of countermeasures for pedestrian protection in automotive design is based on numerical analysis. The quality of the development depends on the quality of the provided impactor models. Here, the requirements of pedestrian protection testing and the standard procedure of the numerical analysis are explained. First experience with the recently by Simulia developed headform models are described.

Keywords: Crashworthiness, Pedestrian Protection, Impactor Modeling

1. Introduction

The safety of automobiles might be divided into the fields of passive and active safety. The focus of passive safety had been the safety of the car's passenger first. With Working Group 10 (WG 10) of the European Committee the research on regulations for pedestrian and cyclist protection started in 1988. Based on hardware tests, accident analyses and numerical simulation, WG 10 suggested test procedures for the frontal impact of pedestrians in his final report in 1994, [EEVC 1994]. Based on that report and on the report of Working Group 17, [EEVC 2002], different regulations have been developed by consumer organizations as well as governments.

The numerical simulation of passive safety testing for pedestrian protection has achieved the status of a basic development tool in the automotive industry. Nearly all experimental hardware tests are covered by finite element simulations. A steady development of the numerical methods is needed to obtain the quality of result prediction.

Within this paper the basic regulations of pedestrian protection are described. The finite element simulation of a head impact on the car's bonnet is shown. The results of the recently developed headform models of Simulia are compared against the models used at BMW.

2. Regulations

Today, different regulations for pedestrian protection in frontal impact have to be taken into account. Within these regulations the test procedures according to Phase 2 of the Working Group 17, to the Euro Ncap organization and to the Global Technical Regulation (GTR) of the United Nations may have to be considered mainly. A detailed overview of these regulations is given in [carhs 2011].

Those tests can be divided into legform and headform impact in the frontal region of an automobile. The original proposal of Working Group 10 with different impacts on bumper and bonnet, indicated in figure 1, has been modified and is still under development.

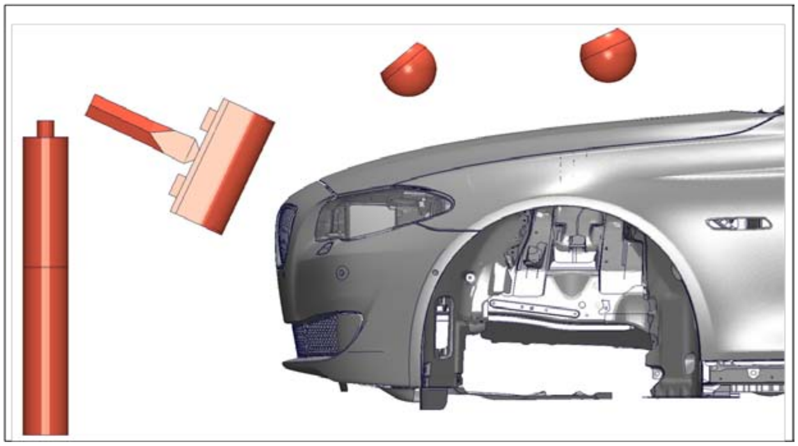

Figure 1: Possible impact situations for pedestrian protection testing

The impact of the lower legform, representing tibia, femur and knee, at different locations of the frontal area of a car is the first type of legform tests. The severeness of injuries is measured by the tibia acceleration as well as by the bending and shear of the knee, figure 2.

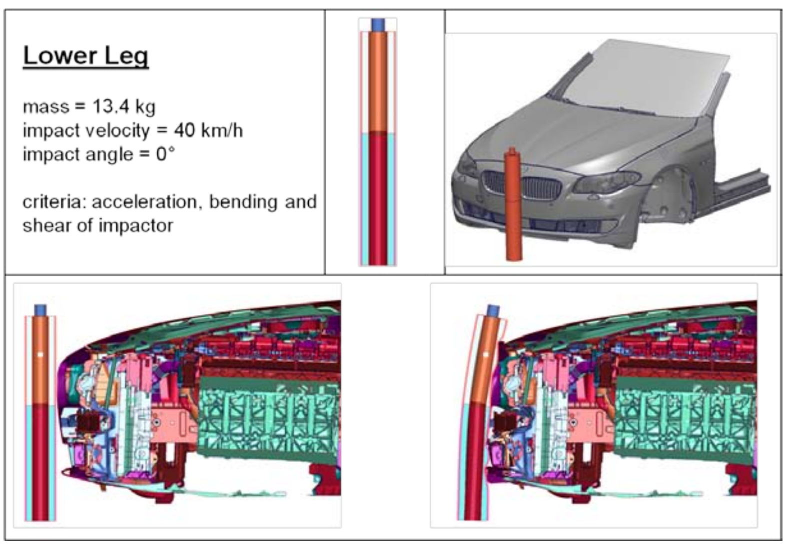

Figure 2: Lower Leg test criteria set by EU Regulation 78/2009 Phase2

The impact of the upper legform, representing the femur and pelvis, at different locations on the bumper leading edge of the car is the second type of legform tests. Depending on the regulation and the type of automobile additional tests have to be done on the bumper area as well. The severeness of injuries is measured by pelvis force and pelvis moment, figure 3.

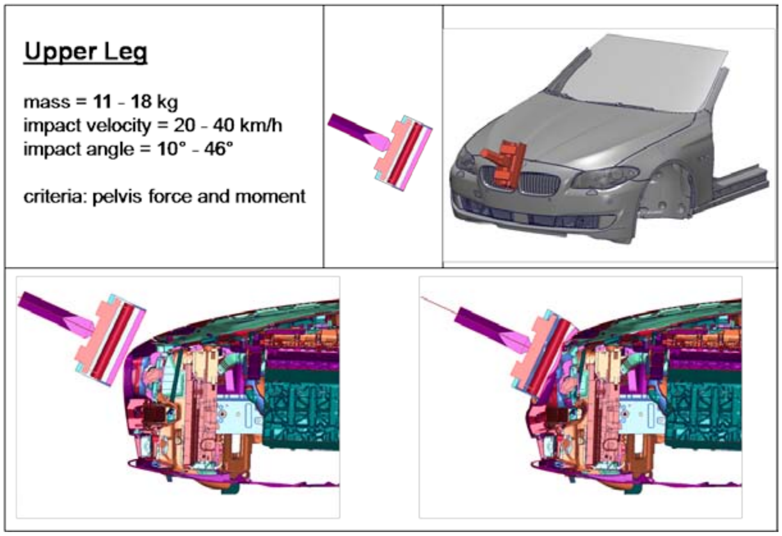

Figure 3: Upper Leg test criteria set by EU Regulation 78/2009 Phase2

The headform tests are divided into an adult headform and a child headform test. The differences of those tests are given by the headform's size, mass, impact angle and impact area on the bonnet. The severeness of injuries is measured by the resultant acceleration and the calculated HIC value.

The adult headform impacts the rear part of the bonnet, figure 4. The windscreen, wiper and A-pillar are impacted in some regulations as well.

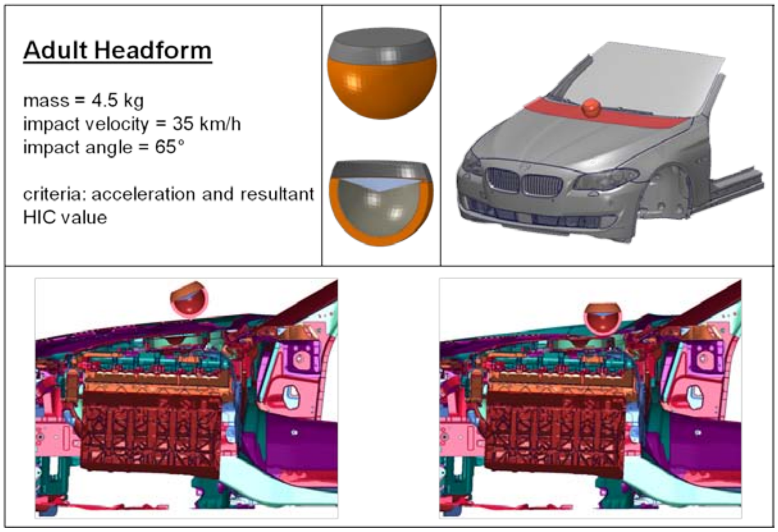

Figure 4: Adult Head Impact test criteria set by EU Regulation 78/2009 Phase2

The child headform is impacting the frontal part of the bonnet, figure 5.

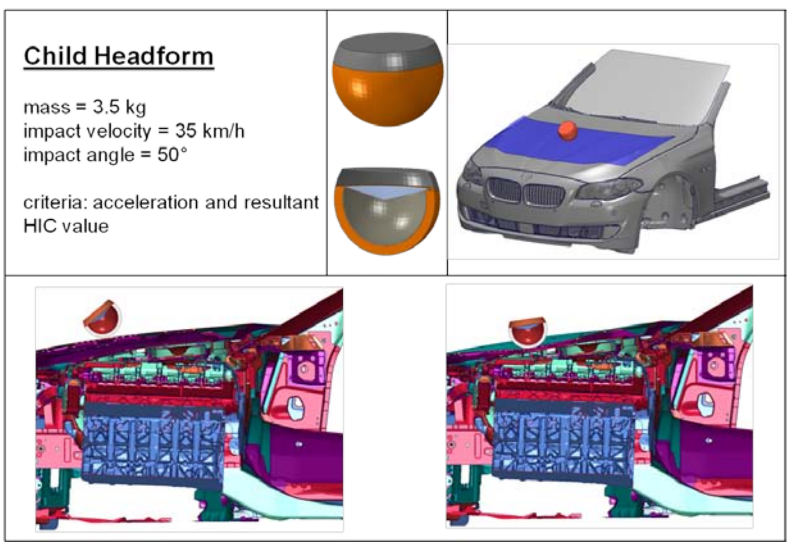

Figure 5: Child Head Impact test criteria set by EU Regulation 78/2009 Phase2

The focus of this paper is the headform impact and the comparison of different modeling. Here, the tests are done with headform models according to EU regulation 78/2009 Phase 2.

3. Headform Models

During the development of different regulations the headform models have changed slightly. A good overview of different headform models for the different regulations can be found in [carhs 2011]. The headform models consist of an end plate (base), a sphere (core), an accelerometer mount and accelerometer, bolts and skin, figure 6. The skin is clamped between end plate and sphere. A more detailed description of the headform model is presented in [Lawrence 2005].

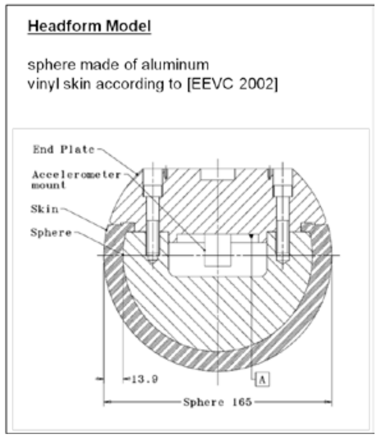

Figure 6: Adult headform design according to [EEVC 2002]

Today, mainly two different headform models are used – the child, former small adult, headform and the adult headform. Both models have the same diameter, 165 mm, but differ in mass, which is 3.5 kg and 4.5 kg. The width of the vinyl skin is 13.9 mm. The headform models used at BMW, figure 7, are set up of rigid membrane elements modeling the plate, sphere and accelerometer mount. Solid elements are used to model the vinyl skin. The vinyl skin of both headform models is just fixed in the clamping area mentioned above.

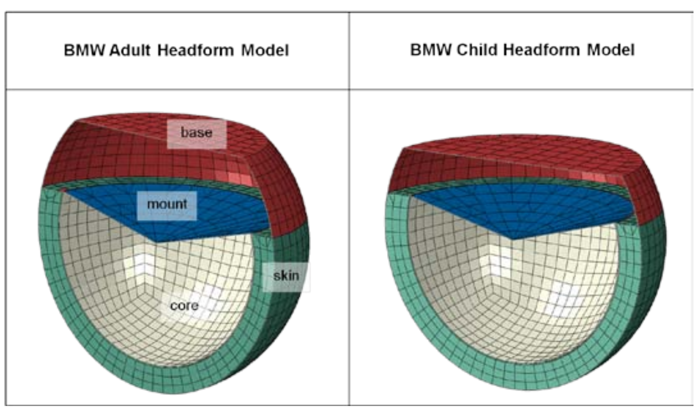

Figure 7: Adult and child headform model - BMW

The headform models provided by Simulia are modeled quite differently, figure 8. For modeling base, accelerometer mount and sphere solid elements are used. The mass of the adult headform model has been reduced from 4.8 kg to 4.5 kg by decreasing the density via the NONSTRUCTURAL MASS option, as the material data are provided in binary form. In all subsequent simulations the reduced mass model has been used.

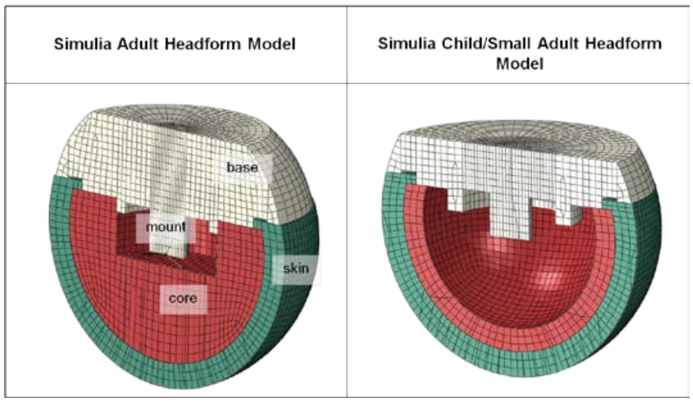

Figure 8: Adult and child (small adult) model - Simulia

In both Simulia headform models the vinyl skin of the adult headform is partially tied to the end plate and sphere as described above. The tied skin nodes are shown in figure 9.

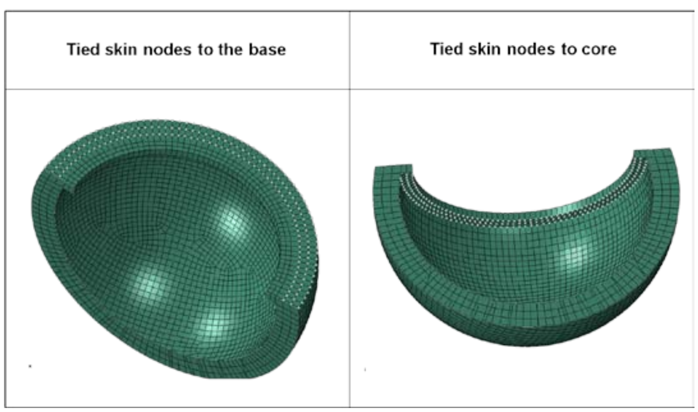

Figure 9: Tying skin and core in the area of clamping

The different geometrical modeling leads to differences in the location of the center of mass and in different moments of inertia of the axis of rotation. Using those models different tests have been done.

4. Headform Model Testing

Three different test cases have been used to compare the behavior of the different headform models. The vertical and angular drop tests to a rigid plate are just numerical tests. An initial velocity of the headform has been defined in those tests. The third test is the given calibration test for headform models.

The vertical drop test of the adult headform shows a good correlation between the different models. In figure 10, the deformed headform models as well as the resultant accelerations are shown. The accelerations show small deviations for Simulia's and BMW's models. The deformation of the vinyl skin is quite different. The vinyl skin is modeled stiffer and more elastic in BMW's headform. With those high impact forces, the BMW model tends to show small contact penetrations.

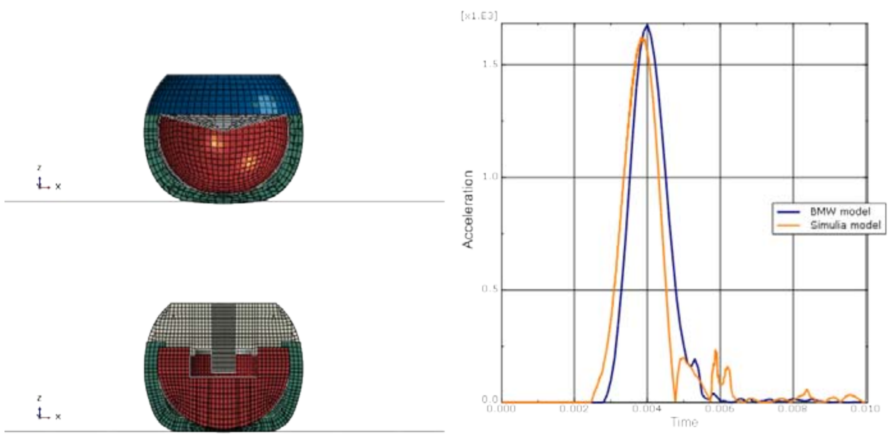

Figure 10: Vertical drop test – adult headform

The results of the child headform models show more differences in resultant accelerations of the headforms, figure 11. The differences in the stiffness of the vinyl skin are similar to the adult headform.

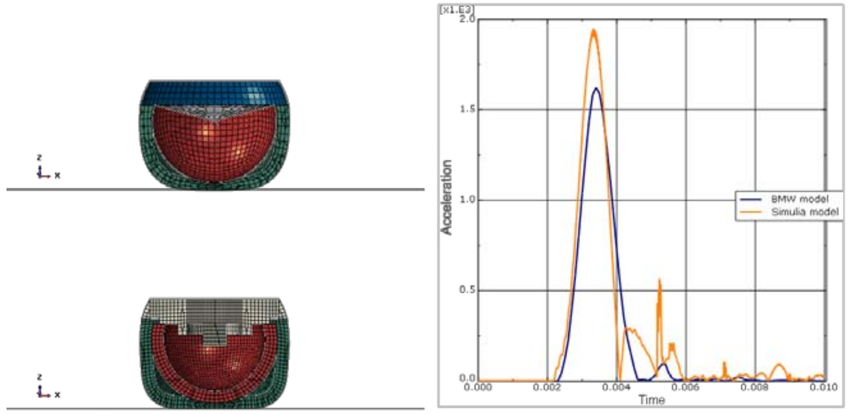

Figure 11: Vertical drop test – child headform

The angular drop test on a rigid plate has been chosen to examine differences in rotation behavior influenced by modeling issues.

The resultant accelerations show again a good correlation, figure 12. The differences in rotation of all headforms are bigger than expected but do not influence the stiffness behavior in that test.

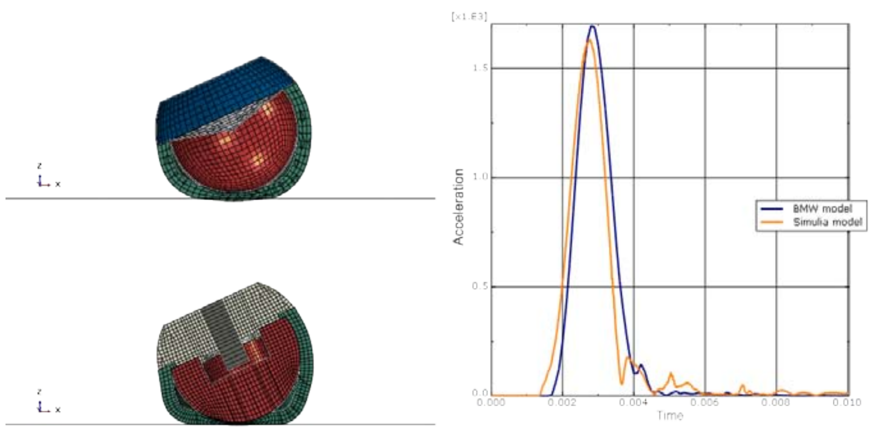

Figure 12: Angular drop test – adult headform

Simulia's child headform shows again a stiffer behavior compared to BMW's model. The differences of the rotation behavior of all models are smaller here.

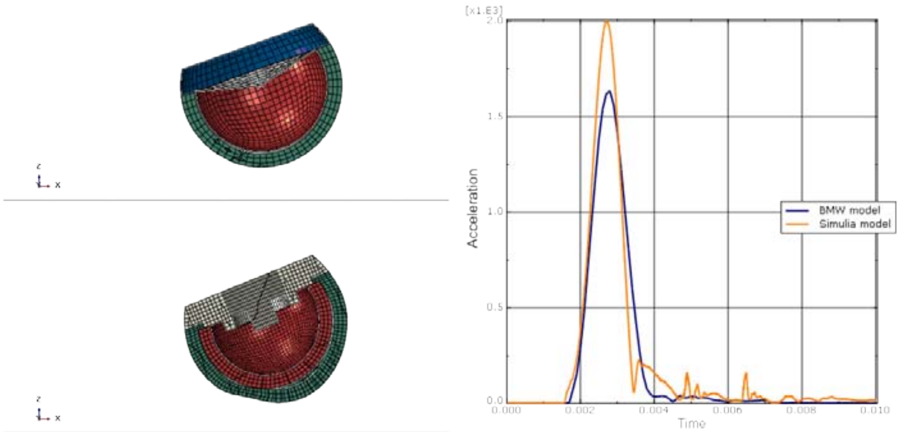

Figure 13: Angular drop test – child headform

The third test is the proposed headform calibration test, according to [Lawrence 2002] and [EEVC 2002]. Numerical and experimental data can be compared for the child headform. In contrary to the observations before, results of Simulia's headform are now very close to BMW's headform, figure 14.

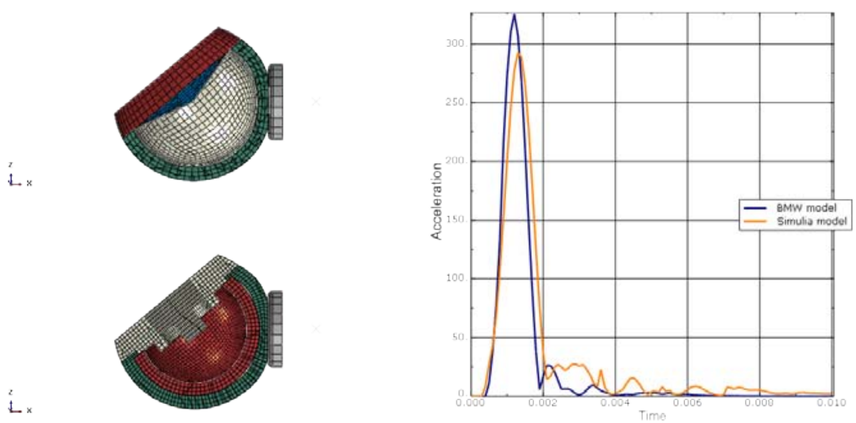

Figure 14: Calibration test according to [EEVC 2002] – child headform

When comparing the resultant acceleration with experimental data, both headforms show a good correlation, figure 15.

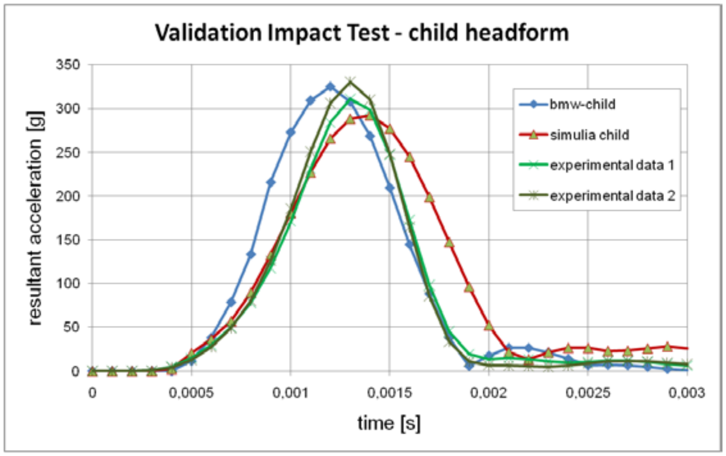

Figure 15: Calibration test of child headform compared to experimental data

The different modeling of the examined headform models result in small and bigger differences in stiffness and dynamic behavior. Those differences may have a bigger influence on the results of the headforms impact on the bonnet of an automobile, which has been examined in the following chapter.

5. Impact Simulation

The impact of adult and child headforms on a bonnet of an early design state of the actual BMW 5 series has been chosen as an example to compare the different headform models, figure 16. The model includes the whole frontend of the car up to the windscreen, detailed discretized with a relative small element length of the finite element mesh. The simulations have been done according to the configuration of the regulation Phase 2, that prescribes the geometrical form of the child and adult impactor model, the mass, impact angle and velocity.

Primary simulations with the BMW headform models were performed, a child impact at the middle area of the bonnet and an adult impact at the rear end. These results have been used as the reference for comparing the results of Simulia’s headform models.

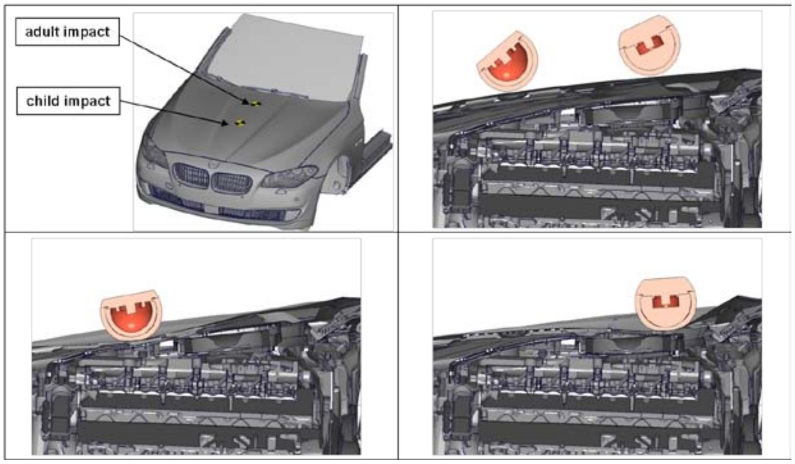

Figure 16: Simulia's headform model impact simulation

In figure 17, the resultant acceleration of the adult headform model is compared between the BMW's model and Simulia's headform model. The difference in the first gradient up to 3.5 ms is caused by the stiffness of the skin. Due to the less stiff outer skin and the deformable inner core the Simulia headform has a higher potential for energy absorbing in the early phase of the impact. After 3.5 ms, both curves show the same gradient and differ only in the level of the relative acceleration value, caused by the characteristic behavior of the bonnet's geometry. When the HIC value of the simulation with the BMW headforms is assumed to be 100%, the HIC value is reduced by 7.5 % when using the Simulia model. The disagreement between both headform models is acceptable in this case.

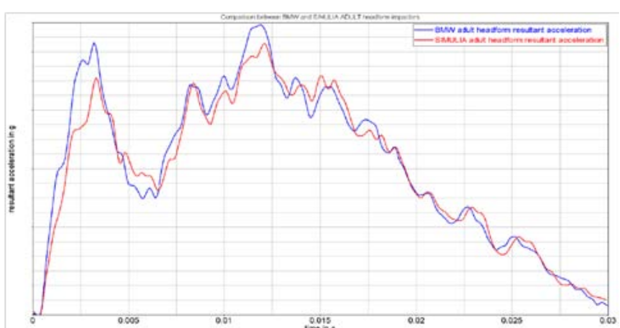

Figure 17: Comparison of resultant acceleration by an adult headform impact

The foregoing analysis of the headform modeling leads to the expectation that the moments of inertia cause different rotation angels during the impact simulation. However, the angles between both headforms differ not as much to affect neither the acceleration gradient nor the HIC value.

The head rotation starts at 3 ms and after this time step the curve characteristic of both headforms are almost the same, figure 18.

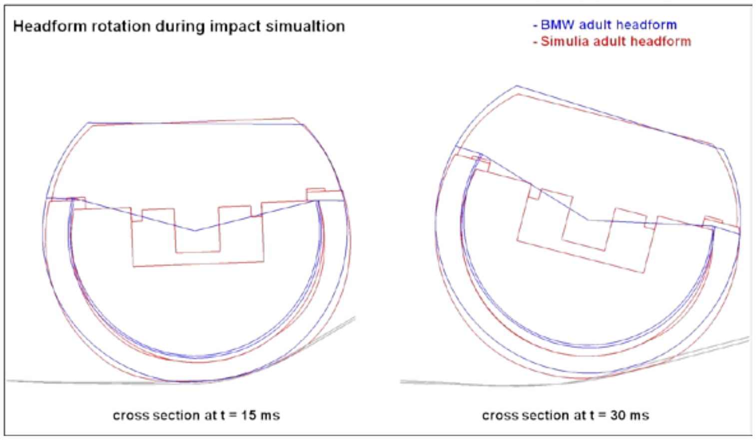

Figure 18: Comparison of the headform rotation during the impact simulation

The impact simulation and comparison of results using the child headform models lead to a similar result. Again, the differences in the stiffness of the skin have an influence on the resultant acceleration at the beginning, figure 19. After the first contact with the bonnet at the time 2 ms, the characteristic of the curves are nearly the same and both headforms start rotating. The following curve progression describes the behavior of the car. The calculated HIC values are almost the same. This is caused by the HIC calculation window that starts at 3 ms and ends at 18 ms. In this time period the Simulia headform has a lower acceleration level in the beginning but a higher level at the end compared with the BMW headform.

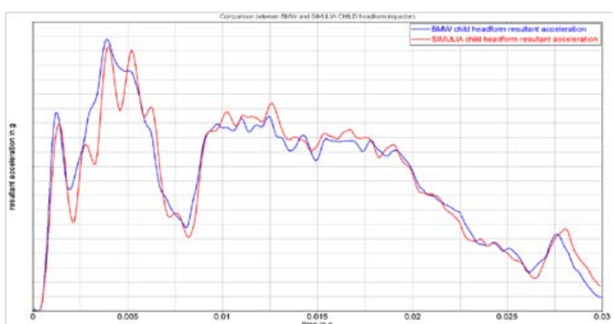

Figure 19: Comparison of resultant acceleration by a child headform impact

The head impact simulations on the bonnet with the different headform models show almost same results. The different modeling of the headform does not seem to influence the results so far.

6. Conclusion

The purpose of this paper has been the comparison of different numerical headform models used for pedestrian protection testing. Drop tests as well as impact simulations on a bonnet of a car were performed for that purpose. The drop test results indicate substantial differences in stiffness and overall behavior – at a very high level of load. Nevertheless, the impact tests on a bonnet show a very good agreement of the results – at a much lower level of load.

It seems that numerical headform model calibration should be based on more testing. Those tests should cover a wider range of load and impact situations. For design layout purpose in the automotive industry there is no advantage neither for nor against any of the headform models.

7. References

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