DEVELOPMENT OF PLASTIC COMPONENTS FOR PEDESTRIAN HEAD INJURY RISK REDUCTION

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Paper No. 294

ABSTRACT

During the development of vehicles for pedestrian protection, plastic components are often regarded as minor contributors to the impact stiffness. Laboratory testing with and without these plastic components led to the hypothesis that they significantly increase this stiffness and subsequently the injury risk measured by the pedestrian headform impactor. This paper will focus on the contribution of the plastic cowl top to impact stiffness. Preliminary testing for specific impact locations found that more than 50% of the Head Injury Criteria (HIC) and 35% of the average stiffness was attributed to the cowl top. Based on these findings, Finite Element Analysis (FEA) was used to assess the potential effects cowl top stiffness reductions may have in terms of injury risk assessment. Further FEA was performed to assess various design changes, including thickness and shape, on the injury risk assessment. The analysis of cowl top changes led to a HIC reduction of 45% for the case focused on in this paper. The results of this study support the hypothesis that plastic components add significant stiffness to the impact, however with FEA supported design efforts, these components may be modified to minimize their influence.

INTRODUCTION

Every year road crashes around the world claim the lives of over 1.17 million people. Of these fatalities, 65 percent involve pedestrians [1]. While the majority of pedestrian fatalities occur in developing countries, the United States' losses are nearly 5000 people annually [2].

To assess the risk various vehicles pose to pedestrians, test procedures have been developed by the European Enhanced Vehicle-Safety Committee (EEVC) [3,4]. These procedures have been adopted into the EuroNCAP protocol to assess the injury risk newly developed vehicles pose to pedestrians [5].

The current test methods and acceptance levels were developed for "assessing the protection afforded to pedestrians by the front of cars in an accident". The test method is based on sub-system tests and focuses on "each part of the vehicle structure with respect to both child and adult pedestrians, at car to pedestrian impact speeds of 40 km/h" [4].

Disagreement remains about the validity of the kinematics involved in the EEVC Working Group 10 and 17 (WG10 and WG17) procedures [6,7,8]. For the purposes of this study, a combination of the EEVC WG10 and WG17 test methods was incorporated because no alternative procedure is developed and agreed upon at the time of this publication. The current assessment for head impacts involves the headform impacting the vehicle at a velocity of 40 km/h. The headforms are dimensioned as either adult or child in size, and the zone over which they are tested is based on the areas the head might potentially contact, given the persons stature.

Regardless of the specific stature and impact kinematics, it is considered desirable to have sufficient clearance below the hood to reduce head injuries. However, due to limited packaging space, hood-underlying components must be developed "to absorb energy efficiently with minimum crush stroke to reduce head injuries" [7].

Protective systems for pedestrian safety are primarily passive systems that typically focus on the vehicle's metal skin and substructure. However, underlying plastic components of the vehicle (e.g. cowl top) can also add significant stiffness to the overall structure governing the head impact deceleration. This paper focuses on the effects that these underlying plastic components, specifically the cowl top, potentially contribute toward the severity of the head impact deceleration pulse.

METHODS

Head Injury Risk Assessment

HIC was adopted as the Injury Assessment Reference Value (IARV) for this study as the primary tool for assessing injury risk. HIC, eq. (1)., is an injury risk formulation based upon the resultant head deceleration taken from the center-of-gravity and its profile as a function of time.

$$HIC = \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a_r dt \right]^{2.5} (t_2 - t_1) \qquad (1).$$

Other IARVs considered in the analysis process include the resultant head deceleration taken as a 3 ms continuous clip, and the average stiffness over the critical time clip—the time over which the HIC calculation is measured.

Preliminary Vehicle Testing

Preliminary testing focused on points of maximum IARVs which were considered to be impacts directly through the metal fender mount and hood hinge (Figure 1). However, the protection package afforded by this construction already included significant modifications to these structures. First, a large clearance is designed between the hood and main body structure (e.g. upper member) of the vehicle. Second, the intermediary supporting structure for the hood and fenders (e.g. hood hinges and fender mounts) has been purposely designed to efficiently deform under pedestrian headform impact.

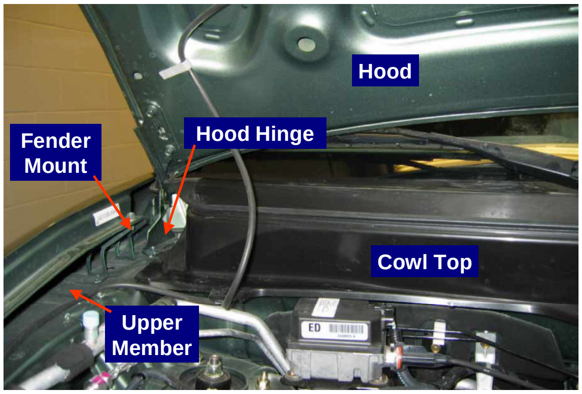

Figure 1. Vehicle construction for preliminary testing.

Assessment of preliminary testing showed that a significant stiffness factor remaining for impacts in this area of the vehicle was the cowl top. In order to understand the effects the cowl top can contribute toward the impact stiffness, matched laboratory tests were conducted with and without the cowl top to isolate its contribution. The testing was performed according to the EEVC WG17 test procedures [4] with a complete vehicle (Figure 2).

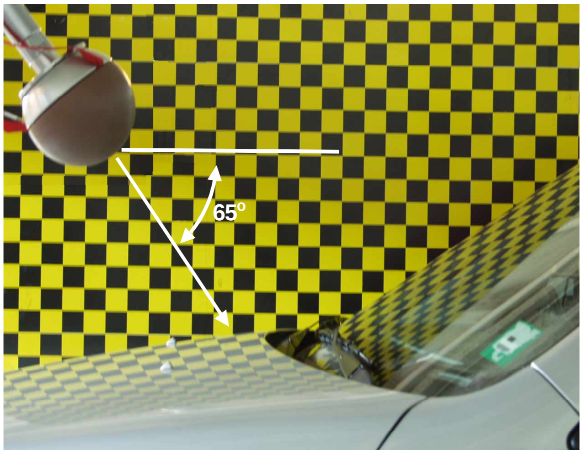

Figure 2. Typical configuration for an EEVC WG17 style adult headform impact test.

For the cowl top tests involved in this study, the impact locations were within the adult zone based on the vehicle wrap-around-distance (WAD). For the adult head impacts, the headform is 165 mm in diameter and is impacted at a velocity of 40 km/h with an impact angle of 65° measured down from horizontal and inline with the vehicle.

Preliminary tests indicated that the cowl top stiffness contribution accounted for over 50% of the HIC and 35% of the overall average stiffness. The case presented in Figure 3 depicts the deceleration change due to removal of the cowl top, which subsequently accounted for the reduced HIC. The deceleration data still maintains a high, short-duration peak early in the event as the headform initially engages the hood and underlying components.

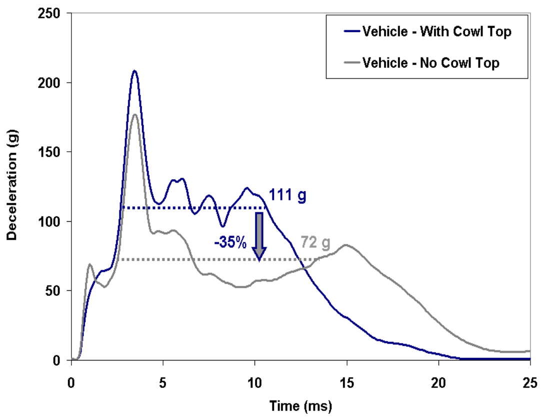

Figure 3. The preliminary data for head impact tests with and without the cowl top showed a reduction of HIC by 50% and overall average stiffness by 35%.

Cowl Top Variables

The cowl top serves many functions for the vehicle including air handling, water management from windshield runoff, and styling between the hood and windshield. The primary functionality for the cowl top is to prevent engine room air from entering the HVAC system as well as minimizing water penetration.

While elimination of the cowl top is not feasible because of these necessary functions, attention to key variables in its design can reduce its contribution toward the impact stiffness. Shape, thickness, and material properties can be modified to optimize the design with little or no effect on the functional performance. This study focused on the shape and thickness, while leaving the material constant. The case investigated was for a polypropylene based cowl top.

FEA Model Setup

FEA was used to understand the effect of construction changes of the cowl top on headform impact stiffness and HIC. The vehicle model was only constructed in detail forward of the B-pillar and was constrained at the cut plane. The initial velocity of 40 km/h was applied to the headform in the 65^{o} specified angle of incidence. The headform and vehicle models were constructed and then solved using the software package LS-DYNA©.

Prior to FEA investigations of design changes to the cowl top, the model was validated against laboratory testing. Two steps were taken in order to correlate the model. First, the headform model was correlated using a virtual representation of the certification procedures specified by the EEVC WG10 [3]. Second, the correlated head model was used in conjunction with the vehicle model to calibrate various locations via correlation with laboratory tests.

<u>Headform Correlation</u> – The headform model was developed for this study and therefore required calibration. A virtual calibration test, as performed for the actual headform, was modeled to verify its performance. In accordance with the EEVC WG10 calibration procedures, drop tests from 376 mm [3] are performed with the adult headform (Figure 4). For the purpose of FEA, the headform was impacted into a rigid plane with a velocity of 2.72 m/s. This velocity is equivalent to the velocity of a mass falling from 376 mm.

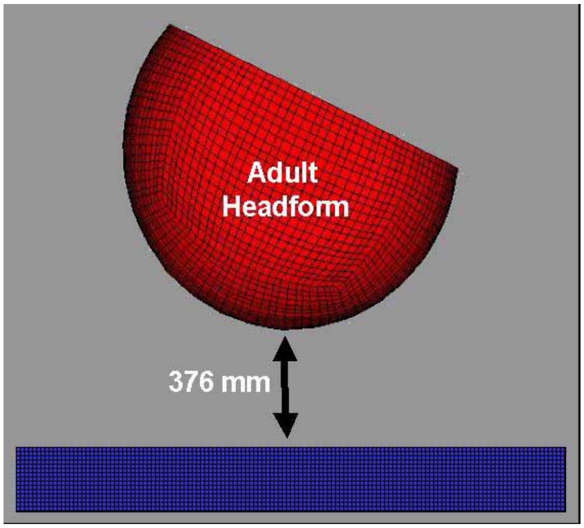

Figure 4. Calibration test configuration: The headform is simulated as being dropped from 376 mm (Not to scale).

The resultant deceleration versus time curve is required to be uni-modal and fall within the range of 225-275 g's. Figure 5 illustrates that the FEA headform's performance meets the requirements.

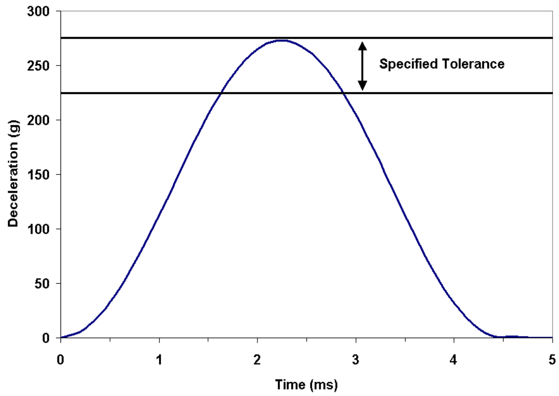

Figure 5. FEA data of a virtual certification test.

<u>Vehicle Correlation</u> - After establishing a correlated headform model, several impact locations were selected across the vehicle surface by which to correlate the vehicle model. Figure 6 depicts the result of a selected test showing good correlation between laboratory testing and the FEA model.

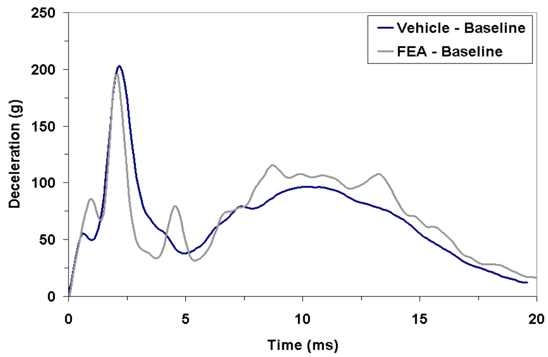

Figure 6. For the impact shown, the data indicated a strong positive correlation between test and FEA.

For the case illustrated in Figure 6, the average error was 4.2 ± 22.5 g's, while the absolute average error was 14.8 g's for the critical time clip, as defined previously. Considering data within the critical time clip, the root-mean-squared (RMS) error was 19.4 g's indicating well-correlated data. Further, the correlation coefficient (R=0.863) implies a strong positive correlation. The correlation coefficient further suggests that 74.4% (R^2 = 0.744) of the variation of the laboratory test is captured by the FEA model.

A range of correlation values was seen for the various locations on the FEA model. The case presented is a typical representation of the correlation levels achieved. Using similar modeling techniques in other cases, some impact locations have evinced correlation as high as R^2 = 0.971, while some cases were as low as R^2 = 0.550 (Figure 7). However, this lower correlation value still corresponds to a moderate positive correlation level.

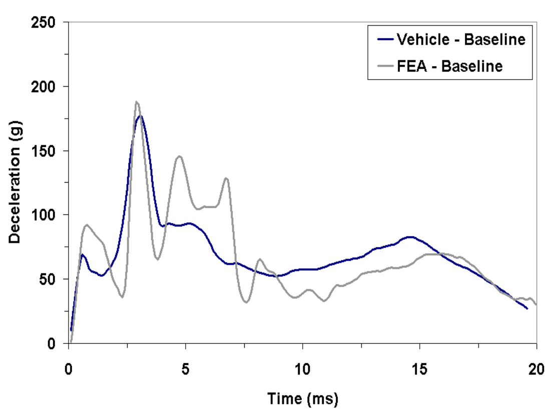

Figure 7. For the impact shown, the data indicated a moderate positive correlation between test and FEA.

The worst-case correlation involved complicated underlying structures and was impacted significantly far away from the location presented in this study. The underlying structures that were the hardest to simulate with FEA were parts that were intricate in design and typically involved materials that fractured with little or no deformation first. The FEA was limited in its capability to fully characterize material properties.

Overall the correlation showed that the FEA model was well correlated to actual vehicle testing. With this correlation, confidence exists such that various cowl top designs, at least qualitatively, can be assessed in terms of injury risk assessment.

RESULTS / DISCUSSION

FEA Investigations

With confidence in the FE model, the analysis proceeded to consider various cowl top constructions. The FEA focuses on a single impact location determined to have significant effect on the hinge and fender mount impacts, but also maximize the cowl top contribution. The impact location is therefore different than that indicated in the preliminary testing and correlation analyses.

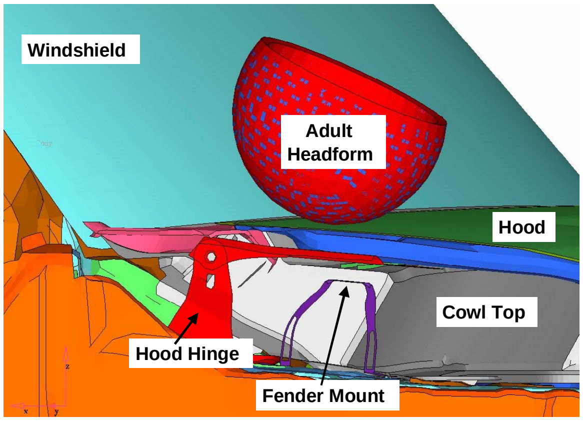

Figure 8. Adult headform impacting the hood over the fender seam.

Assessment of preliminary testing and FEA showed that a significant factor remaining for impacts in this area of the vehicle was the cowl top (Figure 8). Therefore, the case selected and presented is an impact delivered near the front corner of the cowl top through the fender seam. This portion of the fender seam is typically a very stiff area of the bonnet because of the support mounts for both the fender and the hood. The required application of the cowl top in this area further increases the potential stiffness.

No Cowl Top – Assessing Potential Effects - For the chosen location, the potential effects of cowl top modifications were investigated by solving the FEA model with and without the cowl top. The IARVs showed nearly a 50% reduction in HIC and a 35% reduction in the resultant head deceleration compared to the with cowl top condition (Figure 9). The IARVs were significantly reduced despite late bottoming out against the substructure, which shows that improvements potentially exist by altering the cowl top construction.

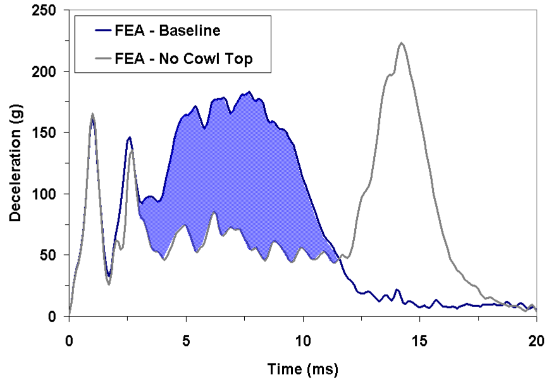

Figure 9. Comparison of the FEA baseline model versus the no cowl top model. The highlighted region indicates the cowl top contribution.

Examination of the data curves shows two things. First the deceleration data maintains high, early, short-duration peaks as the head initially engages the hood and fender, and will remain inherent to the system. Second, the absence of the cowl top allows the headform to bottom out on the substructure, which limits the extent by which the HIC and the resultant head deceleration are reduced.

To characterize the full extent to which the cowl top can affect the impact stiffness, the deceleration-displacement curve was adjusted to eliminate the bottoming contribution. The additional stiffness from bottoming is a separate issue from this study of the cowl top and therefore is temporarily neglected.

For this investigation, the work done on the system by the head during the bottoming event was replaced by an alternate profile of equal work (Figure 10). The alternate profile maintains a constant level of deceleration starting from the time at which bottoming begins. The deceleration continues until the amount of work encompassed by the new profile equals the amount of work it is replacing in the actual curve.

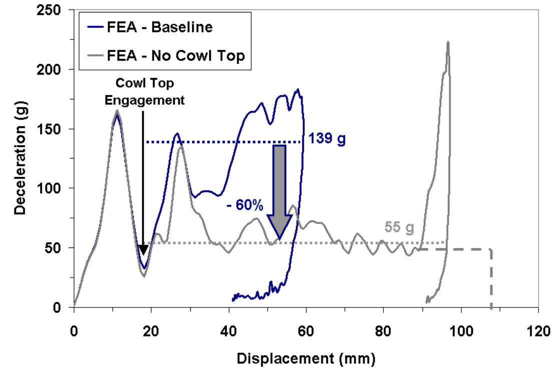

Figure 10. Deceleration versus displacement traces of the FEA baseline versus no cowl top condition. The bottoming event is replaced for analysis purposes with an alternate, but equivalent work, function.

Reassessing the injury assessment values for the alternate profile evinced a 77% reduction of HIC and a 66% reduction in resultant head deceleration. Overall, the average stiffness of the system was reduced by 60% for the time interval of the hood's engagement with the cowl top. This data served as a lower bound for the potential improvement due to cowl top modifications.

Thickness Reduction - The first variable of the cowl top considered was thickness reduction. Limits exist to the level of thickness reduction feasible due to both formability and the intended performance of the cowl top. However, it was concluded a part might be manufactured and maintain its performance level with a 20% reduction in thickness local to the fender seam area.

At this impact location, the 20% reduction in thickness of the cowl top reduced the HIC by 28% and the resultant head deceleration by 21% (Figure 11).

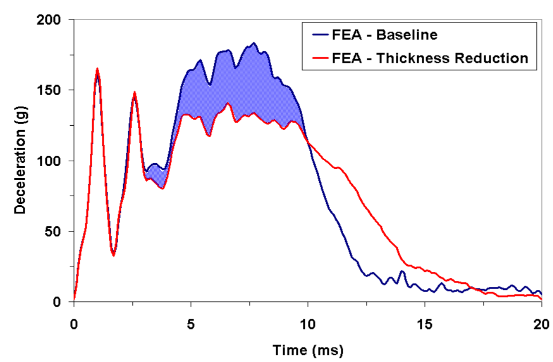

Figure 11. A 20% reduction in thickness of the cowl top in the impact zone reduced HIC 28% and resultant head deceleration 21%.

Shape Change - Further investigation for reducing head injury risk was performed by reshaping the cowl top while maintaining the thickness reduction (Figure 12). The abrupt corner was removed and stress fracture points were added to reduce breaking force. The differences seen in the data show that the thickness and shape are significant in terms of the stiffness and subsequent injury risk (Figure 13).

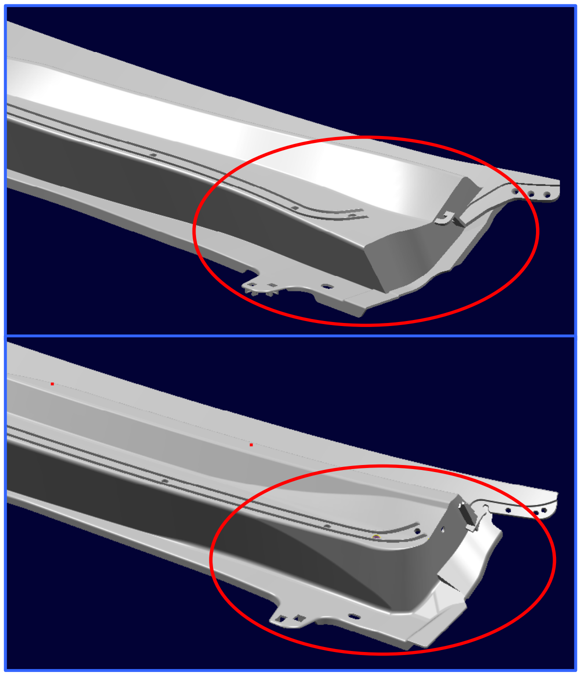

Figure 12. Reshaping of the cowl top.

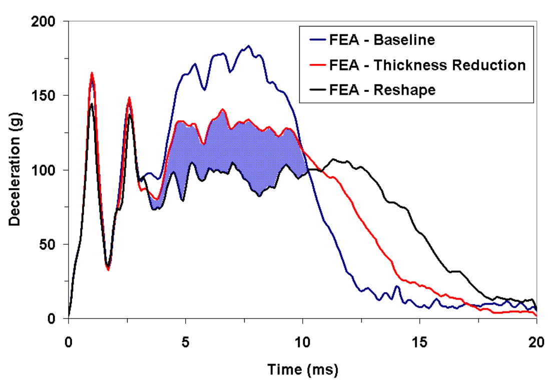

Figure 13. Reshaping the cowl top, as illustrated in Figure 12, accounted for an additional 17% reduction in the HIC and 18% in the resultant head deceleration.

Reshaping the cowl top resulted in an additional 17% reduction in the HIC (45% net). Further, the resultant head deceleration was reduced an additional 18% (39% net) over the thickness reduction alone. The overall average stiffness reduction for the reduced thickness and reshaped cowl top compared to the baseline part was 32% (Figure 14).

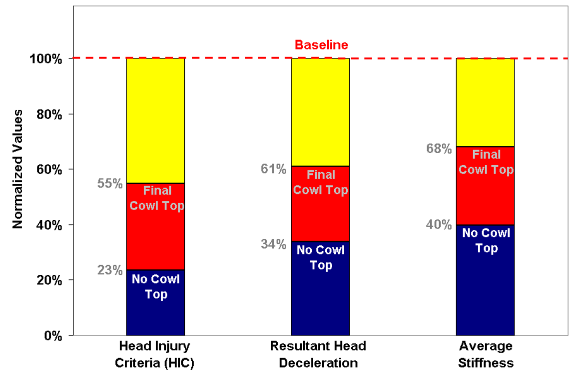

Figure 14. The bar graph indicates the percentage contribution of the cowl top to and the final results of the HIC, resultant head deceleration, and average stiffness.

Examining the cowl top contribution only, the modifications made to the cowl top had significant improvements. The HIC and resultant head deceleration were both reduced 59% and the average stiffness was reduced 53% (Figure 15).

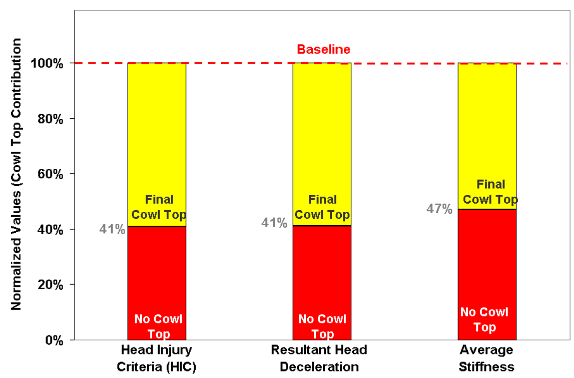

Figure 15. The independent improvements in the IARVs as a function of the cowl top only.

Follow-up Testing

After the FEA investigations, follow-up testing was performed again for the locations for which the IARVs were the highest. For a matched follow-up test to the FEA model, it is expected that the data would have a similarly high percentage improvement in the IARVs as seen in FEA. However, follow-up testing focused on other locations that had the highest overall IARVs.

An example of such a stiff location that benefited from the cowl top modifications is an impact through the fender seam, forward of the fender mount. For this location the cowl top modifications reduced the overall HIC by 14% (Figure 16). The relative improvement for this location cannot be deduced as no without cowl top tests were performed.

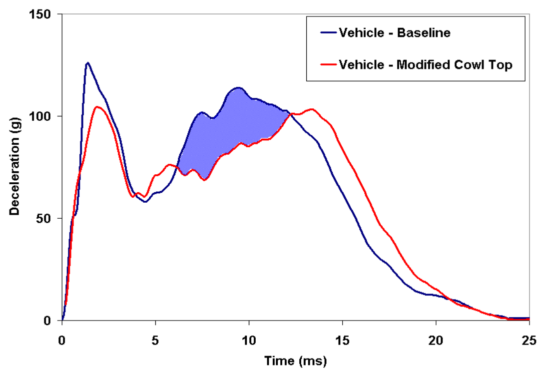

Figure 16. Follow-up testing showed significant IARV improvement.

CONCLUSIONS

Previous research has identified the risk of pedestrian injury from vehicles. This same research has helped to develop means by which to assess the protection afforded to pedestrians by the fronts of vehicles in a collision [3]. Protective systems for pedestrian safety are primarily passive systems that typically focus on the vehicle's metal skin and substructure. However, underlying plastic components of the vehicle (e.g. cowl top) can also add significant stiffness to the overall structure governing the head impact deceleration.

Preliminary testing was performed with and without the cowl top on the vehicle. This initial testing showed that the cowl top stiffness accounted for over 50% of the HIC and 35% of the overall average stiffness, which supports the hypothesis of this study.

Testing without the cowl top showed that it is a significant factor in the impact stiffness. As the cowl top is a required component for vehicle functionality, FEA was incorporated to understand the effects of various design changes of the cowl top. After careful correlation of the headform and vehicle models, modifications to the cowl top were analyzed.

FEA allowed for several iterations of design change investigations in terms of modifications to the cowl top. The case studied showed that the potential effects of cowl top modifications are more than 75% reduction in HIC and 65% reduction in resultant head deceleration.

Removal of the cowl top in the FEA showed bottoming of the headform on the underlying substructure. While the IARVs were reduced, cases may exist that the bottoming is significant enough that the IARVs might increase. Therefore, cowl top modifications should not be reduced to the point that significant bottoming occurs and IARVs are subsequently increased.

Developing the cowl top and other plastic components is important in all of the hood areas. However it is most important where their stiffness is added in conjunction with other stiff components (e.g. hood hinge, fender mount brackets, or wiper assemblies) and the IARVs are near the injury threshold.

ACKNOWLEDGEMENTS

The author would like to thank Douglas Longhitano for his support in the pedestrian impact development and Emily Nutwell for her assistance in developing the FE headform models. The author would also like to thank Christos Agouridis and Matt Wolfe for their support of cowl top design changes and investigations.

REFERENCES

[1] Road & Highway: Road Safety. The World Bank Group. Dec. 1, 2002. http://www.worldbank.org /html/fpd/transport/roads/safety.htm.

[2] Traffic Safety Facts 2001: Pedestrians. DOT HS 809 478, US DOT, National Highway Traffic Safety Administration, National Center for Statistics and Analysis. Washington, D.C.: 2001.

[3] Glaeser, K.P., "Development of a Head impact Test Procedure for Pedestrian Protection", The 13th International Technical Conference on the Enhanced Safety of Vehicles, November 1991.

[4] EEVC Working Group 17 Report. "Improved Test Methods to Evaluate Pedestrian Protection Afforded by Passenger Cars." European Enhanced Vehicle-safety Committee. December 1998.

[5] European New Car Assessment Program, Pedestrian Impact. EuroNCAP. Dec. 1, 2002. http://www.euroncap.com/tests.htm.

[6] Okamoto, Y., Sugimoto, T., Enomoto, K., "Pedestrian Head impact Conditions Depending on the Vehicle Front Shape and its Construction – Full Model Simulation, IRCOBI Conference, p.281-290, September 2000.

[7] Okamoto, Y., Akiyama, A., Nagatomi, K., Tsuruga, T., "Concept of Hood Design for Possible Reduction in Pedestrian Head Injury", The 14th International Technical Conference on the Enhanced Safety of Vehicles, May 1994.

[8] Higuchi, K., Akiyama, A., "The Effect of the Vehicles Structure's Characteristics on Pedestrian Behavior", The 13th International Technical Conference on the Enhanced Safety of Vehicles, Novermber 1991.