STRUCTURAL HOOD AND HINGE CONCEPTS FOR PEDESTRIAN PROTECTION

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Paper Number: 05-0304

ABSTRACT

Future legislation for pedestrian protection in Europe and Japan considers standardized test methods and test requirements relevant for a type approval. The first phase of legal introduction starts in 2005 and a more stringent second phase will follow in 2010.

This paper consists of three main chapters. The chapter "Requirements" starts with a summary of the pedestrian protection-related requirements for head impact and its conflicting requirements for the vehicle handling and driving.
The second chapter "Hood Concepts" discusses how the hood design could become compatible with the pedestrian protection requirements. Concepts for the hood design fulfilling both, the European as well as the Japanese requirements are described. The impact of the hood design parameters on the head impact performance are shown and different concept solutions are presented.
The third chapter "Hood Hinge Concepts" examines the hinge performance for pedestrian protection in detail. The mounting points of the hood, such as hinges, latches and bumper stops, are the most critical points for head impact. Different hinge concepts and their impact on the head impact performance are shown. The influence of the hinge parameters on the acceleration curves and the HPC values is discussed and conclusions for the hinge design as well as for the vehicle structure are drawn.

INTRODUCTION

Accident statistics (IRTAD, 2002) [1] show that in Europe about 41.000 fatalities occur in traffic participation. 6.100 (15%) of these are pedestrians and another 3.900 (10%) are cyclists.
For pedestrians the most frequent injuries occur in the head, upper and lower extremities. 62% of all fatalities are caused by head injuries. These head injuries occur when the pedestrian contacts the vehicle or the ground.
To reduce the frequency of pedestrian fatalities and injuries, measures from the automotive industry as well as environmental changes are required.
The European Enhanced Vehicle Safety Committee (EEVC WG 10 and WG 17) has developed test procedures to assess the level of pedestrian protection for vehicle fronts. Based on the EEVC WG 17 report, legal requirements have been derived. The European directive (2003/102/EC) [2] consists of head impact, upper leg impact and lower leg impact. The requirements will be enforced in two phases. The Japanese directive (TRIAS63) [3] consists of head impact only. Globally harmonized requirements are currently discussed by an IHRA working group.

The risk of head injuries is investigated by free-flying head form impacts against the vehicle front. The impact area is defined by reference lines determined at the vehicle front:

- WAD 1000 = wrap around distance 1000mm
- BLE = bonnet leading edge
- BSRL = bonnet side reference line
- BRRL = bonnet rear reference line

The impact area consists of the vehicle hood and its surrounding components such as grille, headlamps, fender, cowl and windscreen. Major changes to these components as well as to its mountings and the structure underneath are required to fulfill the requirements for pedestrian protection.
Concepts for the hood and its mountings have been investigated at OPEL ITDC in advance. Based on these investigations, design guidelines have been established to enable the development of future vehicles fulfilling these requirements.

The new OPEL ZAFIRA II [4] is GM's first car that has been designed to meet the targets for pedestrian protection. Its pedestrian protection concepts are based on the measures presented in this paper.

REQUIREMENTS

1. Legal Requirements

For EU Phase 1 as well as for Japan, the limit for HPC is separated into two different areas:

- bonnet top zone A: HPC≤1000
- bonnet top zone B: HPC≤2000

In addition, the bonnet top zone A must not exceed one third of the complete bonnet top zone. It is up to the manufacturer to define the locations of bonnet top zone A and B.

Europe Phase 1
Just one head form (ISO child head) is applied and will impact the vehicle with an angle of 50° to the ground reference line at a speed of 35 km/h.

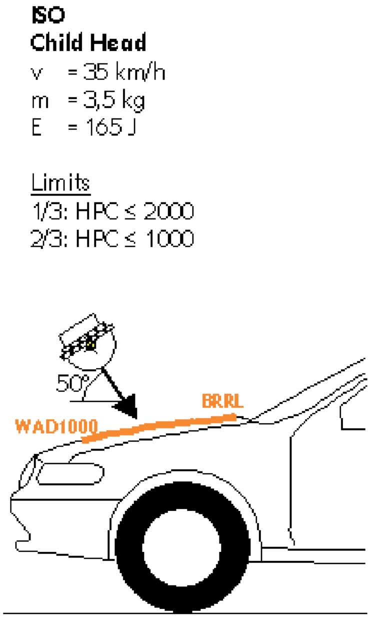

Figure 1: Head Impact EU Phase 1

Japan
Two head forms are applied: the ISO child head and the ISO adult head. The intersection for both head forms is located at a wrap around distance of 1700mm (WAD 1700). In comparison to EU Phase 1, the impact speed has been reduced to 32 km/h. The impact angle will be varied depending on the vehicle type (Sedan, SUV, Van).

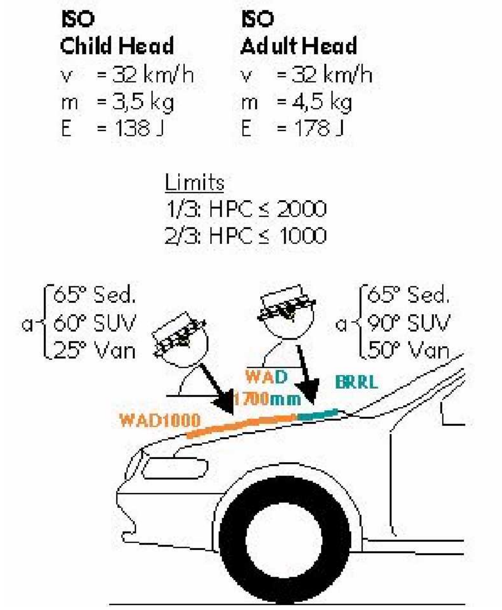

Figure 2: Head Impact Japan

Europe Phase 2
In the second phase, two head forms will be considered in Europe as well. Both head forms differ from those used in EU Phase 1 and Japan. The impact angle for the child head form is set at 50° to the ground reference line whereas the impact angle for the adult head form is set at 65°. Both head forms should contact the bonnet top zones at an impact speed of 40 km/h.

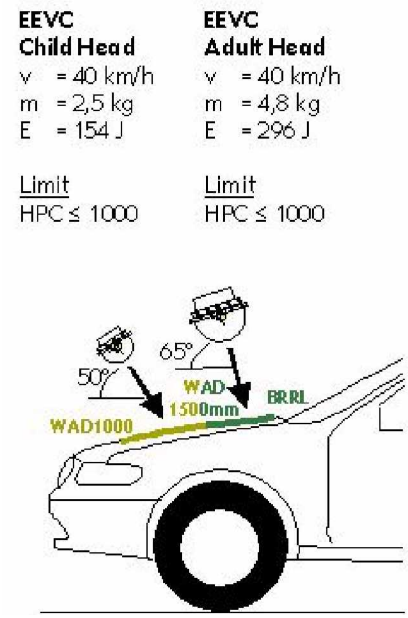

Figure 3: Head Impact EU Phase 2

Currently, the EU Commission is studying the technical feasibility of phase 2 content and alternative vehicle safety measures.

2. EuroNCAP Requirements

European consumer (EuroNCAP) [5] tests differ from the legal tests. The head forms used are identical to the head forms used by EU Phase 2. The intersection line is also located at a wrap around distance of 1500mm (WAD 1500). The rear limit of the bonnet top zone is not defined by the BRRL (bonnet rear reference line) but by the wrap around distance 2100mm (WAD 2100).

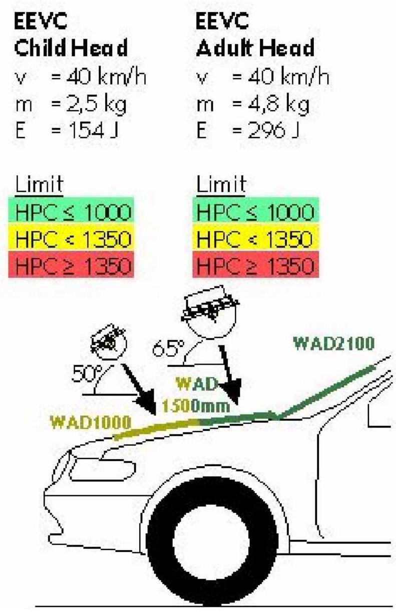

Figure 4: Head Impact EuroNCAP

3. Head Impact Performance Criterion

The head form impactors are equipped with a three dimensional accelerometer. From the measured resulting acceleration the HPC (Head Performance Criterion) is calculated as

$$HPC := \max\left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2,5}(t_2 - t_1)\right\}$$

The maximal time frame is limited to 15 milliseconds.

For the manufacturer, the optimum head impact is achieved when the HPC target is fulfilled and the impact on the vehicle architecture is as low as possible.

Minimized impact on the vehicle architecture means to provide the necessary energy absorption by the lowest possible deformation space. According to the HPC calculation algorithm the optimal acceleration pulse shows an initial high peak followed by a lower constant level [6].

To achieve the HPC target at a minimum intrusion, the following acceleration characteristic is recommended.

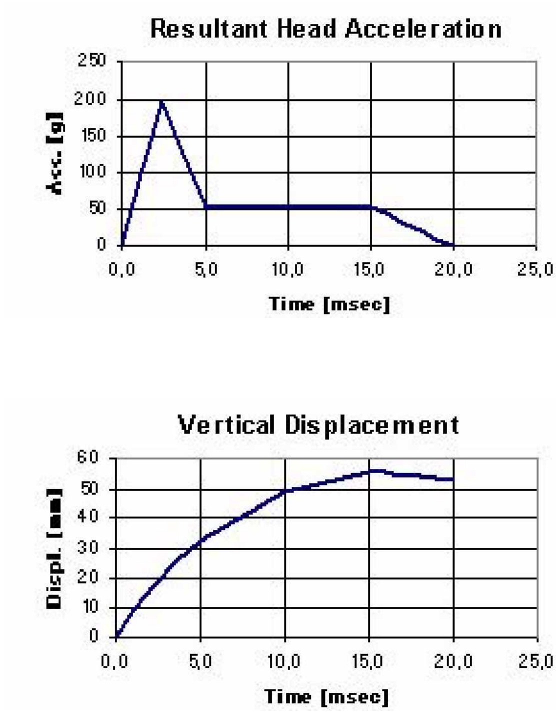

Figure 5: Optimal Acceleration Characteristic (2.5kg head form)

It needs to be noted that real technical designs deviate considerably from this theoretical reference and will require more deformation space.

The above graphs have been generated with a simplified Excel tool [7], which calculates the HPC value and head form intrusion based on the input of the key features for the acceleration.

To keep the HPC below the OPEL in-house target of 800, the initial acceleration peak should not exceed 200g. The later acceleration should remain at a continuous level between 50g and 60g:

- To be outside the HPC time frame
- To reduce the occurring intrusion.

To achieve the above listed targets, two main principles are necessary:

- Provision of sufficient deformation space
- Provision of a low stiffness of the impacted vehicle body parts

The deformation space is a physically necessary enabler, whereas the stiffness is a parameter that needs to be balanced and optimized for each vehicle. Details about the structural measures will be explained in other chapters.

The acceleration of the first few milliseconds is defined by the initial active mass. Therefore the materials, the gages and the number components struck are of major influence. The later acceleration is defined by the stiffness of the structure. The component sizes, their mountings and their design are of increasing influence at this stage.

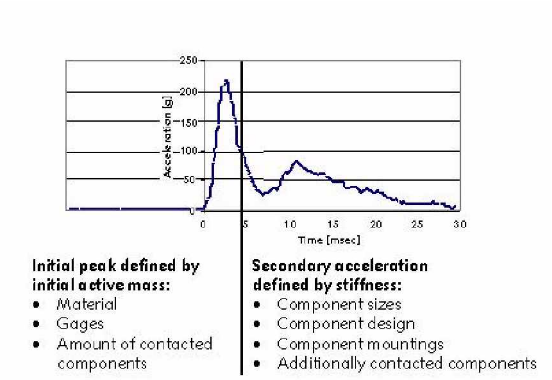

Figure 6: Influence of Mass and Stiffness on the Acceleration

4. Conflicting Vehicle Requirements

With regards to the upcoming targets for pedestrian protection, it is the aim of the vehicle manufacturers to develop future vehicles complying with both sets of targets: the performance targets for the vehicle driving and handling, as well as the new pedestrian protection requirements.

The most important load cases that have to be balanced with the pedestrian protection requirements are listed below:

- Boundaries for vehicle dimension
- Vehicle durability under driving conditions
- Endurance of movable hang-on parts
- Misuse of components and parts
- Performance under handling conditions
- Visual impression
- Acoustical impression
- Tactile impression
- Performance under crash conditions
- Insurance classification

Since the pedestrian impact areas are defined by the outer geometry of the vehicle, the pedestrian protection measures are very styling-dependent. The preferred concepts are those that leave as much design freedom as possible.

HOOD CONCEPTS

1. Overall Hood Structure

The optimal acceleration characteristic as described in the previous chapter is a theoretical reference value only. In reality, the characteristic varies with the impact location. The following list summarizes the main parameters influencing the acceleration:

- Active mass
- Stiffness
- Clearance to package components
- Impact location (hood center, hood edge)
- Interaction of parts

The active mass varies during the impact. More and more mass has to be accelerated, while the head causes the impacted structure to deform. A deformation front starting at the first point of contact runs in a circular wave to the outer. The active mass increases with the duration of the impact.

The active mass for a head impact at the hood edge will be less than for an impact in the hood center, as long as no other components (fender, hinges, headlamp, etc.) are contacted.

The stiffness of the hood depends on the material, the gages, the gluing and the design of outer panel, inner panel and reinforcements. Other components will add to the overall stiffness when located within the deformation zone.

A certain amount of clearance is necessary to achieve the head impact targets. To simplify the vehicle development process with regards to pedestrian protection OPEL has defined the clearance required for each head form to enable the HPC targets. These design guidelines are considered as general enablers. Sporadic deviations from the defined design guidelines could be accepted but requires an adoption of contacted components (collapsible design and/or reduced mass).

Based on the defined clearances, the required head impact deformation space will be generated below the styling surface. Package components that penetrate the generated deformation space are considered as critical and need to be relocated or tuned to fulfill the HPC targets.

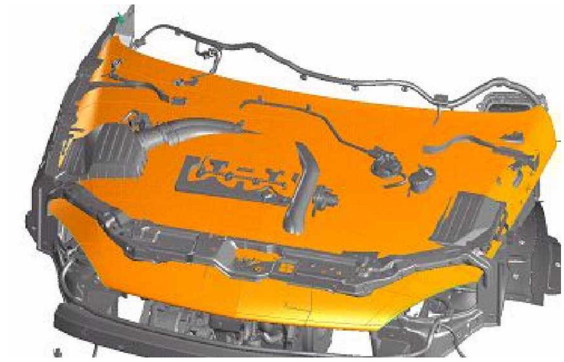

Figure 7: Penetrating Package Components

Interactions with components underneath the hood would result in a secondary acceleration peak. Whether this second acceleration peak is relevant for the HPC value depends on:

- The maximal acceleration value
- The duration
- The relative level to the first acceleration peak to the secondary peak value
- The timing distance between the first and the second acceleration peak

The acceleration characteristic varies with the impact location. A short single peak usually characterizes an impact in the center portion of the hood, as long as no component underneath the hood is contacted. The acceleration of a head impact close to the hood edge usually shows several peaks and a longer HPC relevant time frame, since many additional components (e.g. hinge) have to be deformed during the impact.

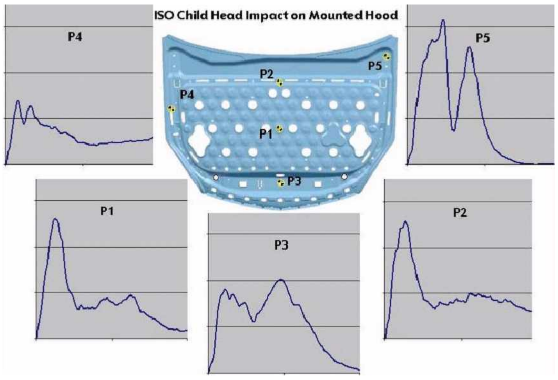

Figure 8: Variation of Acceleration Characteristic

2. Hood Inner Design

In the vehicle development before pedestrian protection was necessary, the hood inner was designed to meet the standard load cases as listed in the chapter "Conflicting Vehicle Requirements". The following summarizes the main load cases derived from these standard requirements that influence the design of the hood inner panel:

- Vehicle durability
- Hood closing endurance
- Hood slam test (misuse)
- Lateral stiffness for mounted hood
- Hood stiffness for bending and torsion
- Denting and buckling
- Hood fluttering
- Manufacturing requirements for drawing
- Manufacturing requirements for single part stiffness
- Hood performance for frontal high speed crash (ODB)
- Hood performance for low speed crash (AZT)
- Hood surface quality

The exact targets for these load cases are laid down in the vehicle manufacturers technical specifications and test procedures.

The hood has to fulfill the HPC target at every single point within the impact area in the bonnet top zone. Traditionally, the hood inner panel is designed with a rib structure supporting the hood outer panel.

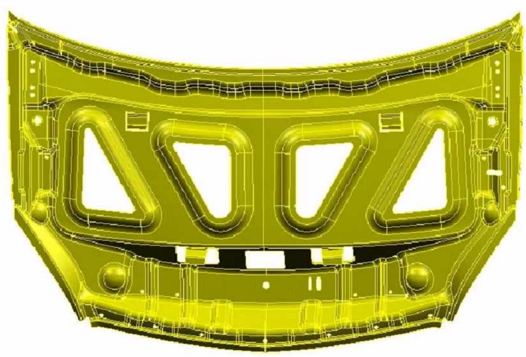

Figure 9: Traditional Hood Inner Design

Such a design usually has weak points and stiff points. For pedestrian protection, it is preferable to design the hood inner panel with a more uniform stiffness distribution. This could be achieved with:

- Increased number of ribs
- Alternative hood inner

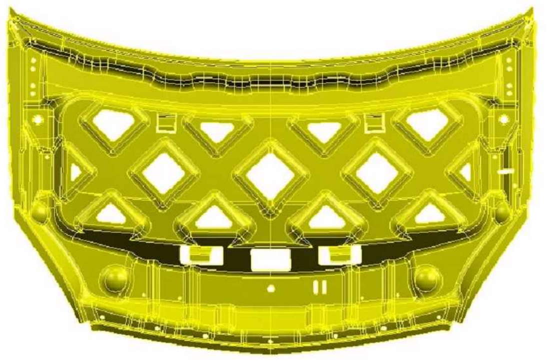

Figure 10: Hood Inner with Increased Number of Ribs

OPEL has adopted a technology from the US GM brands that was originally invented to enable the manufacturing of very thin aluminum inner panels. Multi-cones are drawn into the inner panel instead of a rib structure. These multi-cones are glued to the outer panel.

Figure 11: Hood Inner with Multi Cone Design

This technology has previously been used for weight reasons to design the vehicle hood with particular thin aluminum gages as implemented in the Cadillac Seville.

Figure 12: Cadillac Seville

Figure 13: Cadillac Seville Hood Inner Design

Since there are no ribs and no cutouts, the local stiffness does not vary as much as for a traditional hood inner design. The main advantage of such a continuous stiffness distribution is that it is easier to tune the hood to be stiffer or weaker overall. Less impact positions needs to be investigated.
The hood stiffness can be tuned by various parameters:

- Geometry of cones
  - o Upper and lower diameters
  - o Drawing depth
- Cutouts of cones
- Glue type and amount

The closed structure of the multi-cone inner panel increases the torsion stiffness of the assembled hood. In addition, the stiffness of the single inner panel is increased and enables a reduced inner panel gage. Therefore the active mass as well as the local stiffness is reduced, with benefits for head impact.
The outer frame of the inner panel mainly defines the bending stiffness of the hood and the hood reinforcements at the mounting points for hinges latch and bump stops. This frame structure of the inner panel is therefore kept and the multi-cone design replaces the inner portion of the inner panel only.

3. Hood Edges Design

At the hood edges, the active mass of the hood itself is reduced but other components such as the fender and the hood mountings are within the deformation zone. The influence of these components is usually more significant than that of the hood itself. Structural changes are required, such as reduced

section heights for the brace wheelhouse to provide additional deformation space or weak fender mountings.
One way to weaken the side edges of the head impact area (bonnet top zone) is to locate the cut lines between hood and fender at the vertical sides of the vehicle; out of the bonnet top zone

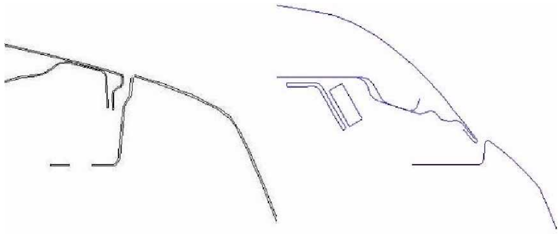

Figure 14: Inlaid Hood versus Wraparound Hood

Such a design with a so-called wraparound hood does not automatically fulfill the head impact targets. Also required is deformation space between the hood flanges and the vehicle structure (brace wheelhouse, A-pillar etc.).
For two reasons, the wraparound hood may not be a preferred design:

- The location of the cut line affects the styling. A wraparound hood design restricts the styling freedom and is not acceptable for all vehicle categories.
- A wraparound hood design increases the overall mass of the hood. Therefore, it is in conflict with the targets for fuel consumption, exhaust emission and driving dynamics (mass distribution).

Another way to weaken the side edges of the bonnet top zone is to design weak fender mountings. The description of this technology is beyond the scope of this paper. Instead the consequences for the design of the hood edges will be discussed.
If the fender mounting provides deformation space, the hood design should enable the use of this space: At the side edges, a vertical flange or a hem flange connects the hood inner and outer panels.

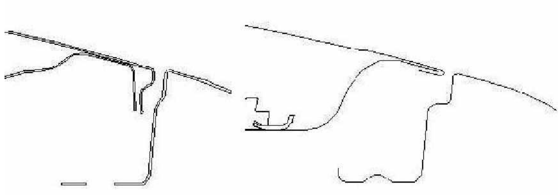

Figure 15: Vertical Flanges versus Hem Flanges

The vertical flange increases the local stiffness more than the hem flange. Shortening the height of the flange could reduce this disadvantage. The height of the flange is restricted by the clinch point diameters. The smaller the clinch point diameter, the lower the necessary flange height. Designing cut outs in the flange might reduce the local stiffness even further.
The main disadvantage of the hem flange is not the increased local stiffness, but the reduction of the deformation space. A head impacting the hood side edge would force the hood to move downwards until the bottom edge of the flange touches a rigid structure underneath. The applied forces would be too low to enable a local buckling of the flange.
Although the hem flange may be preferred from the exclusive pedestrian protection point of view, other requirements may override this to make the vehicle compliant with all requirements. The hood of the new OPEL ZAFIRA II [4] has been designed with a vertical hood flange.

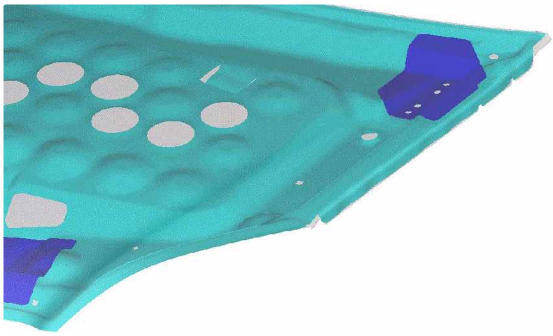

Figure 16: Hood Flange, OPEL ZAFIRA II

For the ZAFIRA II, a vertical flange is necessary for manufacturing reasons. Since the steel gages have been reduced to a minimum of 0.6mm for the outer panel and 0.5mm for the inner panel, the vertical flanges provide the required handling stiffness for the single parts before assembly.
As for many vehicle components, it is always a trade-off between different requirements that leads to the final design.

4. Hood Material

The hood material affects the active mass, as well as the stiffness of the hood and therefore is an important parameter that has to be adjusted to the pedestrian protection requirements.
Around the edges of the hood and the mountings of the hood, it is most important to keep the mass and the stiffness of the hood at the lowest possible level,

since other components will add to the active mass and the overall stiffness that the head form will "see" at an impact.
In the center of the hood, a certain stiffness and mass is required to limit the intrusion and to avoid a secondary impact. Secondary impact means a second acceleration peak, which occurs when the deforming hood touches an engine bay component underneath. Depending on its maximum level and the time gap to the primary acceleration, the secondary impact might increase the resulting HPC value (see chapter "HPC and Acceleration Characteristic"). The larger the hood, the weaker it will become in the center and the more likely a secondary impact becomes.
Based on investigations by simulation and physical impact tests, OPEL came to the conclusion that two options will work for an inlaid hood with a sheet metal design:
Option 1= reduced gages for a steel hood
Option 2= aluminum hood

Again, it is a necessary trade-off between pedestrian protection and deformation space on the one hand side and mass, front axle load, fuel consumption and exhaust emissions on the other side, that leads to the final, well-balanced solution for any new vehicle.

5. Consequences for EuroNCAP Performance

In all cases, there is a limitation in feasibility to reduce the HPC values at the outer edges below the HPC<1000 target while also satisfying the basic handling requirements for the vehicle. Therefore it is recommended to locate the less stringent head impact area with the target HPC<2000 at the left and right outer sixths of the bonnet top zone. Within the HPC<2000 zone, no points can be gained for the EuroNCAP rating. The EuroNCAP points have to be collected in the inner four sixths. Consequently, the frontal hood mounting points (latch and bump stops) should be located in front of the 1000mm wrap around distance if the vehicle concept allows.
At the 1500mm wrap around distance (WAD 1500), EuroNCAP has impacts with both head forms: the 2.5kg child head as well as the 4.8kg adult head. The more sensitive child head requires a weak hood structure. The impact at the same spot with the heavier adult head (higher energy) causes a larger intrusion. This conflict is even more difficult to be solved in the cowl area.

HOOD HINGE CONCEPTS

It is obvious that the hood hinges, latches and bump stops are essential to mount the hood to the structure of the vehicle. It might be questionable whether hinges are always necessary, but some mountings are certainly needed.
These mounting points are usually the most difficult to fulfill head impact even for compliance with HPC<2000. In this paper, the hinges have been selected as an example to describe the demands of pedestrian protection compliant mountings.

1. Vehicle Related Demands

Hood mountings such as the hinges are needed to transfer forces from hood to vehicle and vice versa under handling and driving conditions. The requirements for the hood hinges are again derived from the standard requirements listed in the chapter "Conflicting Vehicle Requirements" and listed below:

- Acceleration forces caused by driving conditions should not result in visible hood movements or material fatigue
- Aerodynamic forces should not result in visible hood fluttering or material fatigue
- Pre-stresses are applied to the hinge in the closed position to eliminate the play in its joints that might cause visible movements and/or rattle noise
- Forces are applied when the hood is pushed into the stop position that prevents the hood from being opened too wide
- Force, applied by somebody leaning against the hood in the open position or leaning on the hood in the closed position, should not cause plastic deformation or damage due to hood contacts with surrounding components as fender etc.
- Hood movement at the hinges in the low speed insurance tests has to be minimized to avoid damage at the hood and the fenders
- The hood should not intrude into the windscreen under high speed frontal crash conditions

The hinges also guide and hold the hood when opened. Their kinematics has to ensure that the hood does not contact other components. For hinges with a single joint, the choice of position is very limited. In many cases, this problem can be overcome by selecting a multi-joint hinge.

2. Pedestrian Protection Related Demands

The ideal acceleration as described in chapter "HPC and Acceleration Characteristic", can usually not been achieved in the areas of the hood mountings. In these areas, the result is more likely to be a longer lasting acceleration, which needs to be kept at a lower constant level.

Most vehicles are designed with the hood hinges located at the left and right rear edges of the hood. A head impact in that area is influenced by many components:

- Hood
  - Outer panel
  - Inner panel
  - Hinge reinforcement
- Hinge
- Fender
- Wiper system
- Cowl

All these components and mountings have to react together in a manner that satisfies the requirements for head impact.

A certain amount of deformation space has to be provided to fulfill the targets for head impact. Therefore, the rigid structure of the vehicle (A-pillar, brace wheelhouse, etc.) needs to be located at a certain minimum distance below the outer styling surface. Additionally, the bottoming-out depth of the deforming components needs to be considered in order to define the required distance from the styling surface to the structure.

Providing deformation space is regarded as an enabler to fulfill the head impact requirements, whereas the relevant target values depend on the mass and the stiffness of the components impacted.

A certain level of stiffness is required to fulfill the handling and driving requirements for the vehicle. These demands are contrary to the required softness for pedestrian protection. Due to these target conflicts, parts of the relaxation zones with the lower target of HPC<2000 are located at the hinge regions. The total area with HPC<2000 is limited to one third of the bonnet top zone. The amount of the HPC<2000 zone that needs to be located in the hinge region depends very much on the styling and the design of the vehicle.

3. Possible Concepts

Different design concepts for hinges have been found which provide the deformation space required for head impact.

Single-joint hinges:

- With joints located well outside the impact area
- Designed with deformable parts
- Designed with a collapsing mechanism

Multi-joint hinges:

- Designed with travel space in the vertical direction
- Designed with a collapsing mechanism

A single-joint hinge with its rotation point outside the head impact area could provide the required deformation space when the following additional measures are provided:

- Pivot point located with a sufficient distance to the closest head impact point
- Sufficient deformation space above and below the hood-side hinge part in the head impact zone
- Limited mass added to the active mass by the hood-side hinge part

The larger the distance of the hood-side hinge mounting to the pivot point becomes, the stiffer the hinge has to be designed. However, that is contrary to the wish of a limited hinge mass and needs to be balanced.

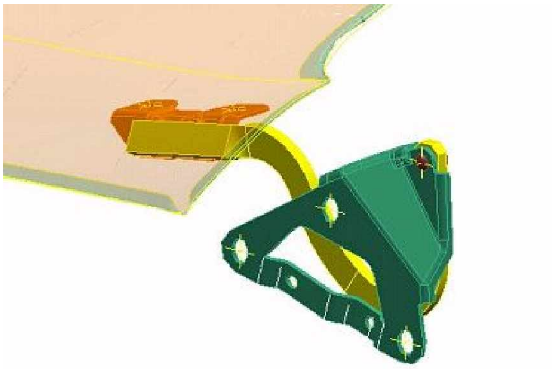

Figure 17: OPEL CORSA Hood Hinge

The current OPEL CORSA is an example of how the turning point could be located well outside the head impact deformation zone. This hinge concept provides an inertia and stiffness, which would be non-compliant.

A single-joint hinge with deformable parts could also be compliant with the head impact requirements. Its advantage is the possibility of keeping the pivot point within the head impact zone. Its disadvantage is the constant reaction force caused by the plastic deformation of the hinge parts during the head impact.

Figure 18: OPEL ZAFIRA II Hood Hinge

The new OPEL ZAFIRA II is equipped with a deformable single-joint hinge, which complies with the EU Phase 1 requirements. Its design is described in the paper PEDESTRIAN-FRIENDLY OPEL ZAFIRA II [4].

A third possibility to design a single-joint hinge, which does comply with the pedestrian protection requirements, could be offered by a collapsible mechanism.

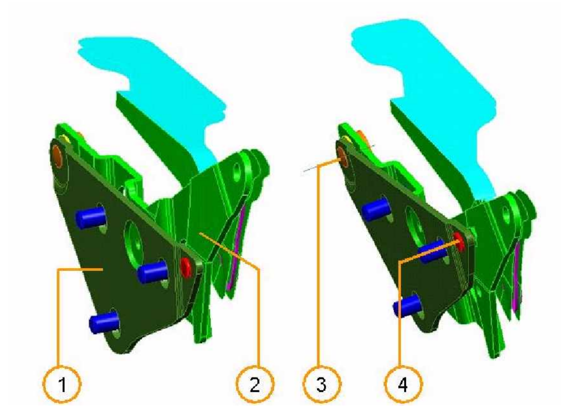

Figure 19: Collapsible Single Joint Hinge

The collapsing mechanism consists of two body-side parts (• + ,) that are combined by a pivot point ƒ and a shear pin „ . The load transmitted by the impacting head would cause a failure of the shear pin. Due to the relative rotation of the two body-side hinge parts, the required deformation space would be provided.
The failure of the shear point as well as the location of the pivot points need to be balanced for each new vehicle.

A multi-joint hinge usually consists of a body-side part and a hood-side part, both connected by two levers.
Depending on the arrangement of the levers in the closed hood position, the multi-joint hinge could provide deformation space for the head impact. The levers needed to be designed in such a way that they deform in the lateral direction to give way in the vertical direction under head impact loading.

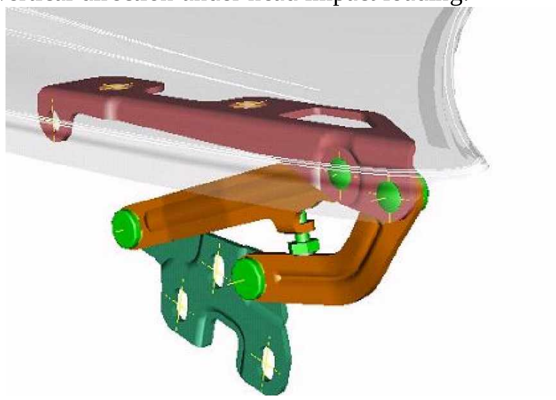

Figure 20: Multi-Joint Hinge

Such a multi-joint hinge could be located within the impact area of the head form and usually offers less resistance to the head impact than the deformable single-joint hinge. Its increased spatial requirement is a disadvantage.

If the flexibility of the multi-joint hinge itself is not sufficient, adding a collapsing mechanism could increase it. Separating one of the two hinge levers into two levers (• + ,) connected by an additional turning point ƒ and a shear pin „ could provide increased deformation space. A failure of the shear pin under head impact forces would add another degree of freedom to the kinematics of the hinge. In this way, an additional travel in the vertical direction could be provided.

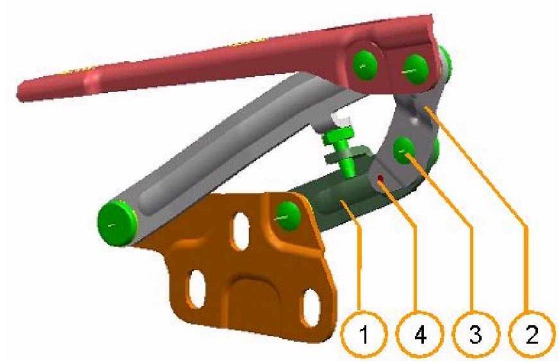

Figure 21: Collapsible Multi-Joint Hinge

The failure of the shear pin could be adjusted to the requirements for head impact, but needs to be balanced with the vehicle handling and driving requirements. Unfortunately, the larger number of parts will increase the complexity of the mechanism.

It needs to be noted, that all solutions were just able to deliver an acceptable margin for compliance with EU phase one requirements (HPC<2000, 35km/h impact speed and the given impact direction).

CONCLUSION

This paper summarizes the concepts for vehicle hoods and hood hinges that have been developed by OPEL to fulfill the upcoming requirements for pedestrian protection. In addition, the basic theory of how to optimize the vehicle with regard to head impact is discussed. Since the measures for pedestrian protection are contrary to many other vehicle handling and driving requirements, it is obviously a challenge for the automotive industry to develop future vehicles in a sufficient balance. Many of the former valid vehicle targets for stiffness and performance will have to be modified with the focus on pedestrian protection.

Since the pedestrian protection performance of a vehicle is very styling and design dependent, the concepts presented need to be adjusted for each new vehicle and cannot be regarded as settled off-the-shelf technology to make a vehicle pedestrian protection compliant.

It is obvious that the necessary measures affect the architecture of a vehicle. Therefore, the targets have to be fixed at the very beginning of the vehicle development process and need considerable pre-development time. It would not be possible to implement pedestrian protection measures at a late stage or even within a minor facelift.

Pedestrian protection requirements cause tremendous additional workload within the vehicle development particularly for styling, design, simulation and the testing departments.

The concepts presented were developed in advance of any vehicle-related activities. The new OPEL ZAFIRA II is GM’s first pedestrian protection compliant vehicle that has been developed based on the concepts shown. It has successfully been designed to meet the EU Phase 1 requirements.

Figure 22: OPEL ZAFIRA II

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