PEDESTRIAN MEASURES FOR THE OPEL ZAFIRA II

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ABSTRACT

In Europe & Japan, new legislation will come into effect from autumm 2005, which aims to reduce the number of pedestrian fatalities and serious injuries .

These pedestrian protection legal requirements are a new challenge for the automotive industry, deeply influencing front end styling, package, design & the complete development process. In the pedestrian tests for Type Approval, free-flying head, upper & lower leg impactors will be propelled aginst the vehicle front end. The vehicle must absorb these low impact energies by means of a "pedestrian-friendly soft nose", to ensure acceptable injury values. The size & shape of the pedestrian protection test impact areas are largely determined by the exterior styling theme.

When satisfying pedestrian protection, other vehicle requirements, e.g. insurance classification, panel dent resistance of diverse panels, high speed crash and hood slam tests must also be fulfilled. During vehicle development, all these loadcases must be balanced to produce the best possible vehicle.

The new Opel ZAFIRA II is General Motors´ first car worldwide which will provide a "soft-nose design" to comply with the new legal requirements in Japan and Europe Phase 1. The ZAFIRA will be launched in spring 2005.

In the new ZAFIRA II, specially developed passive deformation elements absorb impactor energies. Other components may collapse to decrease stiffness and increase deformation space. The light-weight thin steel hood is designed to ensure decreased acceleration values for the head impactors together with homogenous hood stiffness. In the lower bumper fascia area, a spoiler improves the lower leg impactor kinematics by reducing knee bending.

This presentation shows the Opel ZAFIRA´s pedestrian protection measures and reports on Opel´s experience gained in making a car more pedestrian-friendly.

INTRODUCTION

Major changes to current vehicle fronts are required to satisfy the proposed (and differing) legal requirements in Europe, Japan and possibly other countries, as well as to achieve a good Euro NCAP pedestrian rating. The aim of the legislation is to further improve pedestrian protection.

The Opel ZAFIRA II

The Opel ZAFIRA is a mass production family car in the minivan segment, see Figures 1a and 1b. It is a seven-seater with a highly flexible interior and seat system

This is a very important vehicle in the General Motors Europe / Opel product portfolio and is one of the top selling vehicles in Europe in its class. Therefore, it is a significant step for the ZAFIRA II to be made compliant with Japan and EU Phase 1 pedestrian regulations.

Figure 1a. The new Opel ZAFIRA II: a seven seater with a highly flexible seat concept.

Figure 1b. The new Opel ZAFIRA II

The ZAFIRA II is the first vehicle for Opel, and indeed for General Motors, to be compliant with the EU Phase 1 pedestrian protection requirements. Hence, its development was a considerable challenge for the General Motors Europe International Technical Development Center.

This paper will discuss the challenges and the solutions in some technical detail.

1. Main Legal Requirements and Consumer Tests

The forthcoming legal and Euro NCAP requirements define impacts by free-flying pedestrian impactors – heads of various sizes, lower leg, upper leg – against the vehicle front.

1.1 Head Impact Definition

The HIC (Head Injury Criterion) is the only criterion for legal and consumer head impact tests, see equation (1):

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

The EU and Japan have different head impactors and impact speeds. For both the EU and Japanese Phase 1 legal requirements, directives 2003/102/EC [1] and TRIAS63 [2] respectively, the pass criteria for head impact are as follows:

- HIC<1000 for 2/3 of the impact area
- HIC<2000 for 1/3 of the impact area

In addition, the EU Type approval includes adult head impact tests against the windscreen, which are for monitoring purposes. The EuroNCAP (European consumer) tests [3] for adult head are for impacts against the hood and other components e.g. windscreen, A-pillars, fenders.

1.2 Remaining Impact Definitions

In addition to the above head impactor tests, the EU Type Approval and EuroNCAP each specify impactor tests for the lower leg and the upper leg, with the upper leg Type Approval tests being for monitoring purposes. There are no upper or lower leg tests for Japan.

1.3 Summary of EU and Japan Legal Regulations

The definitions of the aforementioned EU and Japanese Type Approval tests are summarised in Figures 2 and 3:

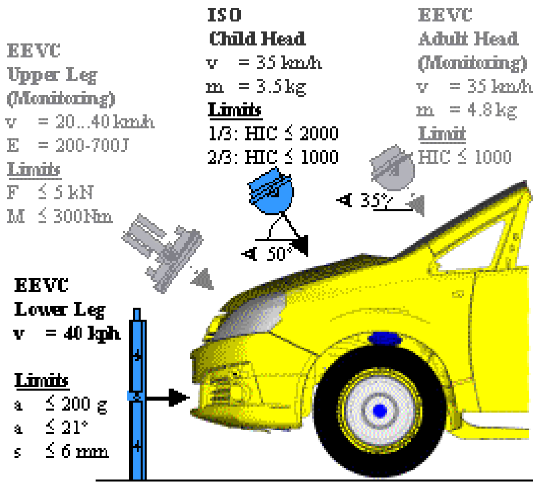

Figure 2. Main EU Legal Requirements

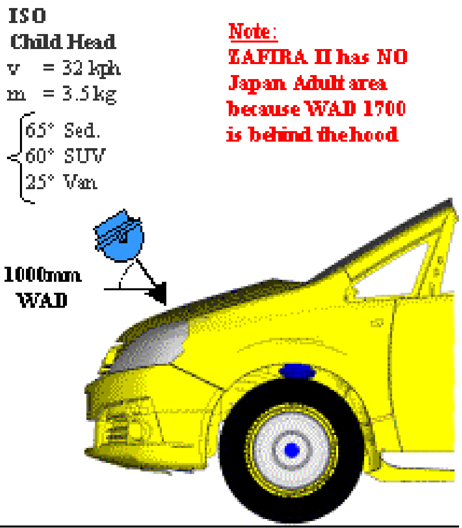

Figure 3. Main Japanese Legal Requirements

1.4 Summary of Euro NCAP Pedestrian Tests

The definitions of the Euro NCAP (European consumer) tests, together with the upper and lower limits for zero-maximum points, are summarised in Figure 4:

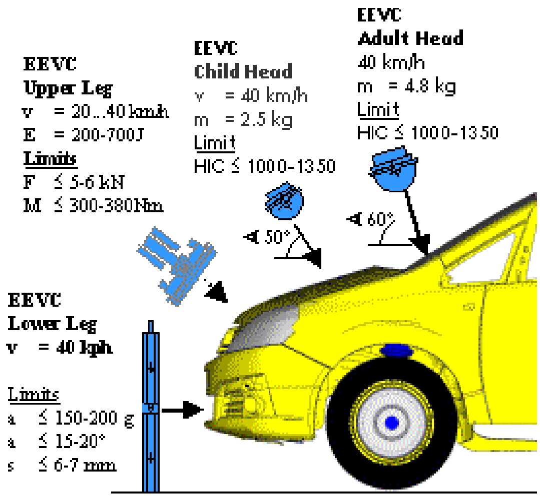

Figure 4. Euro NCAP Tests

2. Difficulties and Aims

Pedestrian protection basically requires the following principals:

1. Making available sufficient deformation space, so that the kinetic energy of the impactor or pedestrian can be absorbed
2. Making the vehicle structure in these deformation zones softer so that the necessary deformation can occur

The following pedestrian loadcases were considered for the ZAFIRA II development:

- 3.5 kg ISO Child Head @ 35 kph (EU Legal Phase 1)
- 4.8 kg Adult Head @ 35 kph (Monitoring EU Legal Phase 1)
- Lower Leg @ 40 kph (EU Legal Phase 1 and Euro NCAP)
- Upper Leg @ 700 J (Monitoring EU Legal Phase 1)
- 2.5 kg Child Head @ 40 kph (Euro NCAP)
- 4.8 kg Adult Head @ 40 kph (Euro NCAP)
- 3.5 kg Japan Child Head @ 32 kph (Japan Legal Phase 1)
- 4.5 kg Japan Adult Head @ 32 kph (Japan Legal Phase 1)

In developing pedestrian protection, it is necessary to frequently check that other vehicle loadcases and requirements are fulfilled, including:

- Low speed insurance classification test (soft nose design can lead to higher damage, hence higher repair costs)
- ODB crash (hinge integrity)
- Hood stiffness (torsion, bending, ..)
- Hood dent resistance
- Hood slam durability
- Hood flutter under aerodynamic loading
- Hood hinge stiffness (lateral stiffness, hood opening and gas spring load)
- Hood bumpstop bracket stiffness/ strength
- Fender brackets stiffness/ strength
- Fender stiffness

Vehicle development always requires optimizing and balancing a wide range of requirements to obtain the best possible vehicle. However, this balance is more difficult for vehicles which are pedestrian compliant.

3. Development Timing and Process

In the lean General Motors Europe development process, "Structure Car" prototypes (to check the basic car structure for performance) have been rendered unnecessary because of current simulation capabilities. However, since pedestrian protection is a new requirement, it was decided to build a prototype front end buck, the "Architectural Mule Upgrade", to examine the new ZAFIRA II properties, styling, package and design.

Therefore, in an early project phase, the CAE team was able to use test results to check the effectiveness of the pedestrian protection measures and concepts and to verify the previously non-validated pedestrian CAE models. This hardware phase reduced development risks and avoided high costs for late changes .

The development timing for the ZAFIRA II is shown in Figure 5 below:

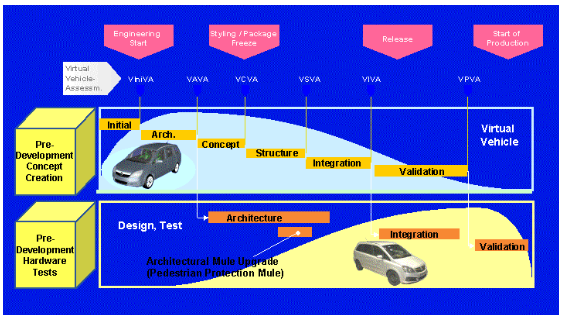

Figure 5. Development Timing

The development process was mainly CAE-driven, with multi-disciplinary teams to manage challenges and cross-functional interfaces.

4. Influence on Front End Styling and Package

The requirements for pedestrian protection had a considerable influence on the ZAFIRA II front end styling, front end package and body structure design, see Figure 6:

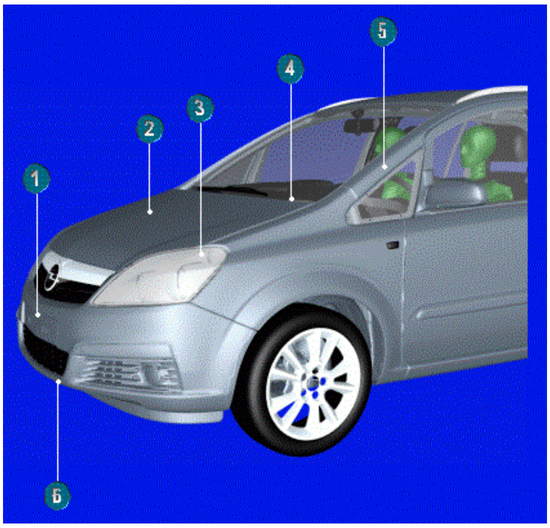

Figure 6. Front End Styling Influence

The styling of the ZAFIRA II shows several changes and optimizations, which were necessary to make the car compliant with EU Phase 1:

1. Increased bumper overhang to implement deformation elements in front of bumper beam
2. Increased hood height to ensure deformation space
3. Optimized headlight styling
4. Optimized windscreen front edge sweep to implement new cowl system for pedestrian protection
5. Cab-forward windscreen and A-Pillar position to stylistically compensate for increased hood height and increased bumper overhang
6. Moved forward lower bumper fascia area to control lower leg kinematics

5 Lower Leg Design in Opel ZAFIRA II

5.1 Design Overview

The main requirements for pedestrian lower leg protection are to minimize the knee bending angle and the tibia acceleration of the lower leg. If the lower leg acceleration and bending requirements are satisfied then, in practice, so is the shear displacement.

There were two key elements implemented in the Opel ZAFIRA II for pedestrian protection:

- Energy-absorbing components
- A system to control the leg kinematics

The following measures have been developed for lower leg protection, see Figure 7 and the associated list below:

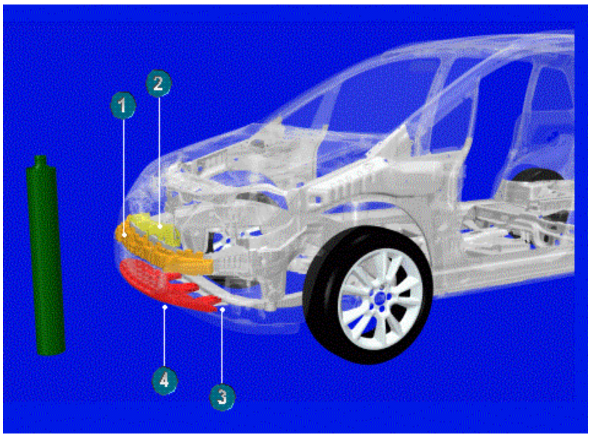

Figure 7. Lower Leg Impact Design

1. Optimized low-density pedestrian protection foam in front of a stiff aluminium bumper crossmember to absorb the impact energy, together with sufficient deformation space to avoid the impactor hitting the stiff, aluminium bumper crossmember or the foam bottoming out.
2. Optimized and elongated upper bumper support to stabilize the bumper fascia and to avoid the support being pushed backwards with bottoming out.
3. Interface bracket to firmly mount the Lower Bumper Stiffener to the front axle tube.
4. Optimized, ribbed, plastic lower bumper stiffener, firmly mounted to the chassis and bumper fascia, to control the leg kinematics by reducing knee bending.

Figures 8 and 9 illustrate the lower leg kinematics and performance:

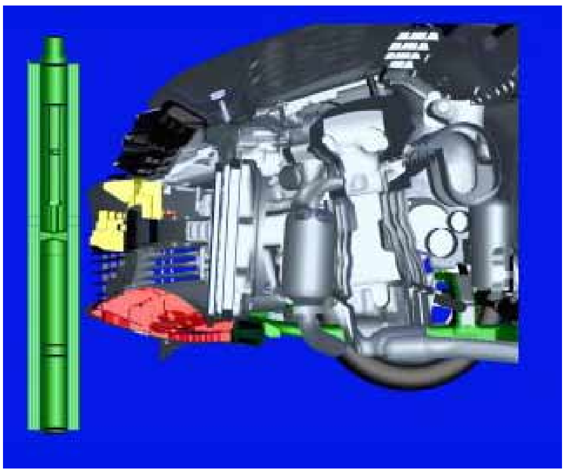

Figure 8a. Lower Leg Kinematics in Opel ZAFIRA II: Section through Center Line at Time = 0

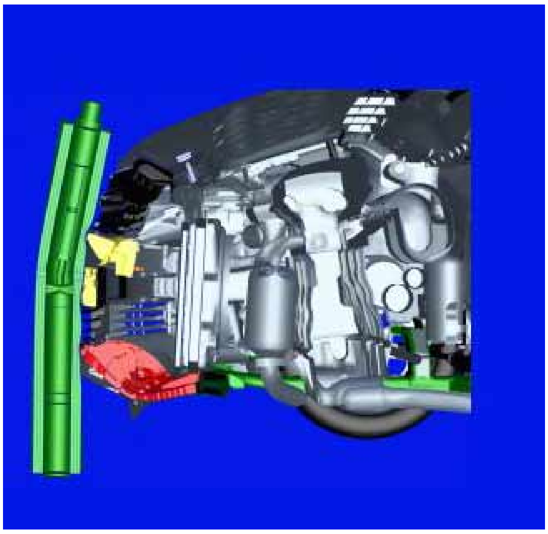

Figure 8b. Lower Leg Kinematics: Section through Center Line at Time = Rebound

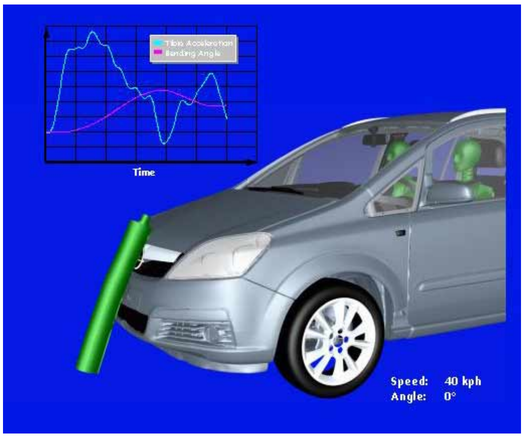

Figure 9. Lower Leg Kinematics, Acceleration and Knee Bending for the Opel ZAFIRA II

<u>5.2 Benefits:</u>

- Enables compliance with EU Phase 1 requirements (in advance of this law coming into effect)
- Optimized energy absorption capabilities
- Controlled lower leg kinematics
- Minimised knee bending angles
- Minimised tibia accelerations
- Minimised shear deformations in knee

6. Head Impact Design in Opel ZAFIRA II

<u>6.1 Design Overview</u>

To achieve the desired pedestrian head impact performance required considerable changes to the previous ZAFIRA I hood and the associated components. The main principles of the head protection design were:

- Optimized energy absorption capabilities
- Deformation space provided by optimized engine bay package and diverse deformable systems

The main elements of this design for head impact are illustrated in Figure 10 and listed below:

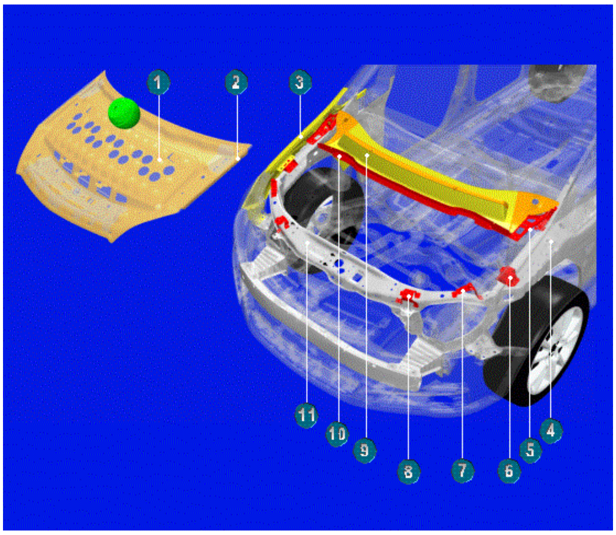

Figure 10. Overview ZAFIRA II Design for Pedestrian Head Impact

1. Thin steel hood with homogeneous, optimized "muffin tin" design for the hood inner panel
2. Cut-out hood flange
3. Thin steel fender with optimized cut out design
4. Lowered brace wheelhouse
5. Deformable hood hinge with cranked beam integrated fender bracket rear
6. Deformable fender bracket front
7. Deformable bumpstop bracket outer
8. Deformable bumpstop bracket inner
9. Deformable multi-part plastic cowl system
10. Plastic service panel with planned fracture points under pedestrian impact loading
11. Lowered front upper and front side

<u>6.2 Benefits:</u>

- Enabled fulfillment of EU Phase 1 and Japan requirements (in advance of these laws coming into effect)
- Sufficient deformation space available to enable absorption of impact energy
- Avoidance of hard points which could worsen head impact injuries.
- Minimised head accelerations
- Minimised HIC values

This performance is illustrated in Figure 11:

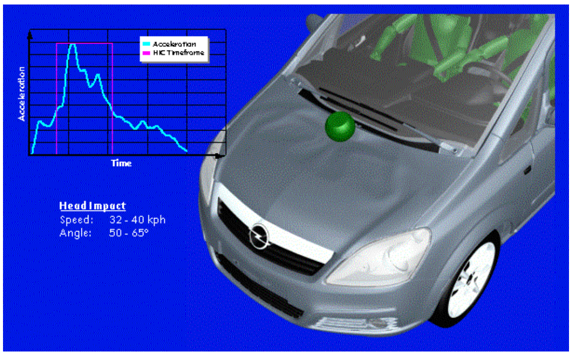

Figure 11. Head Impact Performance for Opel ZAFIRA II

6.3 Hood Design

The ZAFIRA II has steel inner and outer hood panels, which are of lower gages than the ZAFIRA I, to enable softer deformation behaviour under head impact. The hood was designed to have homogeneous stiffness for more uniform head impact characteristics, with an optimized "muffin tin" design for the hood inner panel.

This new concept has a further advantage: in addition to the benefits for pedestrian protection, the ZAFIRA II hood has lower mass than the ZAFIRA I, due to the thin steel design. This is summarised in Figure 12 and Table 1 below:

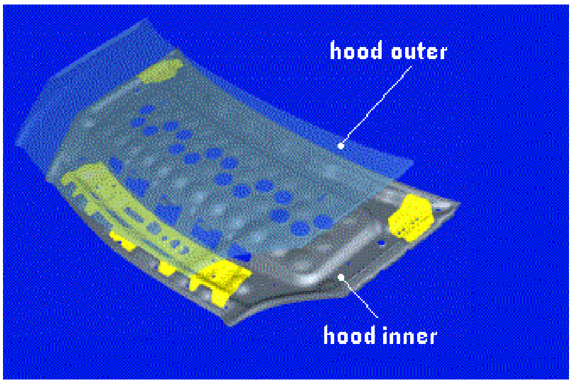

Figure 12. ZAFIRA II Hood

	ZAFIRA I	ZAFIRA II	ZAFIRA II Mass Saving
Hood outer panel gage	**0.8 mm**	**0.6 mm**	**26 %**
Hood outer panel gage	**0.7 mm**	**0.5 mm**	**18 %**

Table 1. Mass saving for ZAFIRA II Hood compared to ZAFIRA I

Some aspects of the pedestrian measures in the new ZAFIRA II will be discussed in more detail below:

6.4 Hinge Design

The hinge area is of particular interest when designing for head protection, because of the high stiffness in this region. The hinge area was part of the 1/3 zone with HIC < 2000, as it was not feasible to reduce the HIC to 1000 in this area.

The new hinge design for the ZAFIRA II is shown in Figure 13 and summarised below:

1. The body-side hinge part deforms easily in planned folding, absorbs energy and reduces the impactor´s acceleration.
2. The cranked beam integrated fender bracket at the rear deforms downwards, absorbs energy and softens the fender behaviour to reduce the impactor´s acceleration.
3. The hood-side hinge part bends slightly and transfers vertical loads into the pivot point.

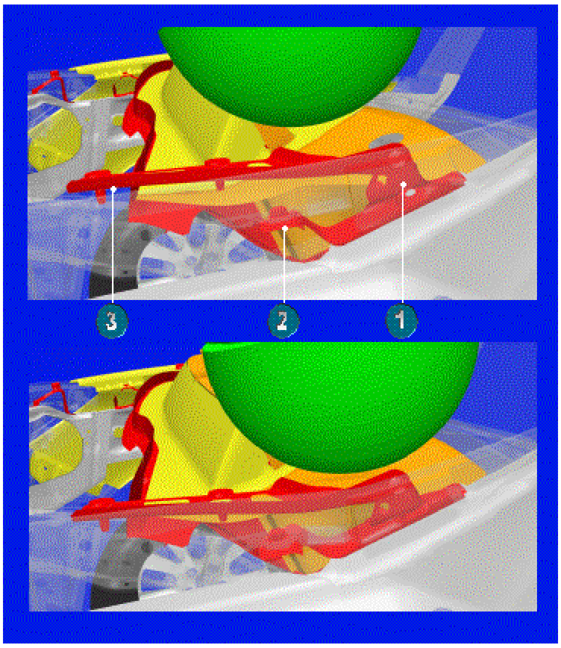

Figure 13. ZAFIRA II Hinge

The development of the hinge design involved balancing different requirements:

- Pedestrian protection for head impact (structure must collapse, with low vertical stiffness)
- Hinge lateral stiffness
- Fender stiffness (vertical and lateral stiffness targets, with no plastic deformations allowed)
- High speed front impact (hinge integrity must be maintained to prevent hood intrusion into the windscreen)
- Insurance test (minimal hood translation, rotation and plastic deformation)
- Hood opening (end stop to prevent the hood opening too wide)
- Body shop assembly (tolerance balance, height adjustability)

To optimize the hinge for pedestrian head impact, while still satisfying the other requirements, the following measures were developed, see Figure 14:

1. Increased material thickness to improve lateral hinge stiffness.
2. Turned edge on hood-side hinge part to increase buckling strength in low-speed insurance classification test (less hood rotation and translation).
3. Turned edge on body-side hinge part to increase buckling strength in insurance test (less hood rotation and translation).
4. End stop to prevent the hood being opened too wide.
5. Fold initiator for easy deformation in head impact loadcase.
6. Cranked beam integrated fender bracket rear to deform downwards in head impact loading.

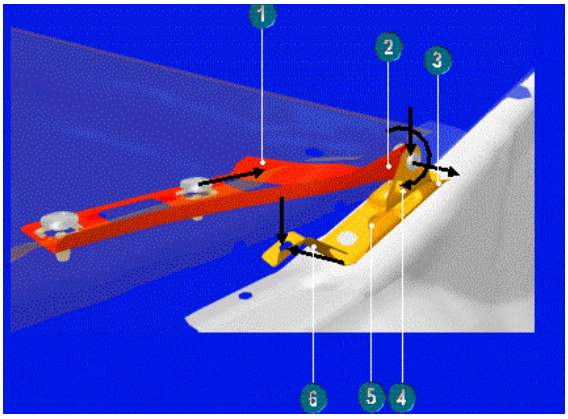

Figure 14. The ZAFIRA Hinge Optimized for Pedestrian Head Impact

6.5 Fender and Bumpstop Design

The fender and bumpstops are also usually difficult areas for pedestrian head protection, because of their high local stiffnesses. The ZAFIRA II has energy-absorbing brackets in this region which were optimized for head impact and other requirements.

The main design measures for the ZAFIRA II system are listed below and illustrated in Figure 15:

1. The fender brackets deform downwards, absorb energy and enable reduced head accelerations (see rear fender bracket in Figure 13 and front bracket in Figure 15).
2. The bumpstop brackets also deform to absorb impact energy and reduce head accelerations.
3. The fender (blended out of the picture) is made of thinner steel than in ZAFIRA I, to help reduce the stiffness in the region, but it remains sufficiently stiff to withstand normal service requirements.

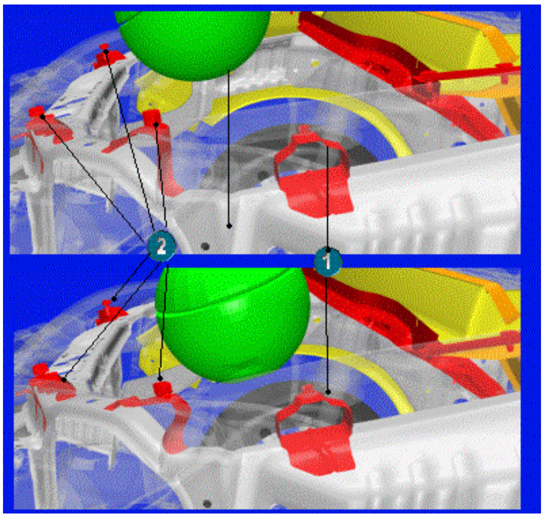

Figure 15. The ZAFIRA II Fender and Bumpstop Brackets

Impact on Insurance Classification/ Repair Costs

7.1 Overview of Insurance / Repair Costs

When developing pedestrian protection measures, other loadcases must always be considered, in particular the low-speed insurance classification test. The main reason for this is the inclusion of a deep, low density foam (30 g/l) positioned in front of the aluminium bumper crossmember, laterally across the vehicle, see Figure 16 :

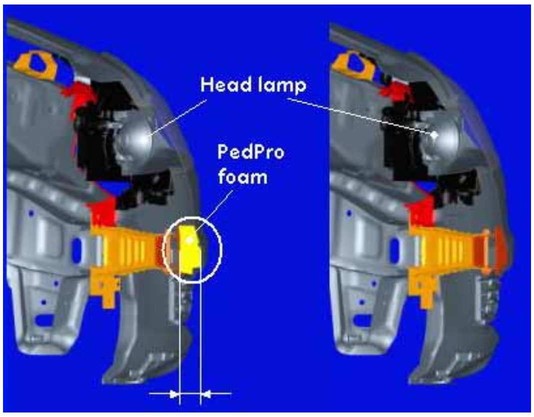

Figure 16. Vehicle front, with and without pedestrian leg impact protection: positioning of low-speed energy absorption system in relation to key components

For styling reasons, the vehicle cannot simply be elongated, by putting the pedestrian foam in front of the low-speed energy absorption system. Therefore, in the ZAFIRA II, the headlights, hood, etc have been moved forward to achieve a stylish and dynamic appearance. These components are much further forward than usual with respect to the low speed-energy absorption system and hence the risk of their being damaged is much higher.

Additionally, the pedestrian foam reduces the efficiency of the low speed energy absorption system, so that in the insurance test, the barrier intrusion is higher. Hence, without further measures, the vehicle damage and the repair costs would increase, which would worsen the insurance classification.

To compensate for the effects of pedestrian protection, several measures were implemented in the Opel ZAFIRA II, some of which are shown in Figure 17 and listed below:

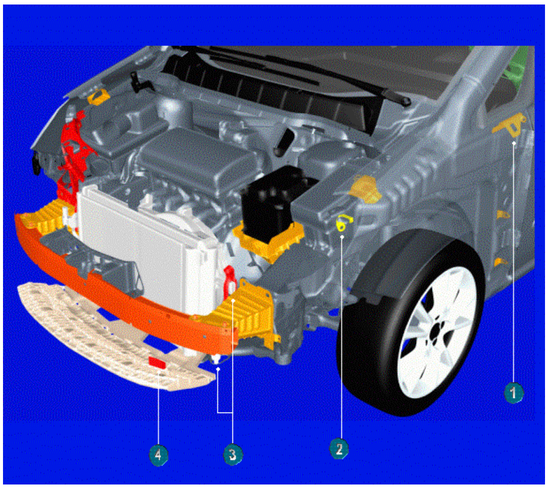

Figure 17. Front End Design to Compensate for Pedestrian Protection

1. Shear-stiff fender bracket to avoid the fender being pushed into the front door
2. Capture bracket to prevent the headlight being pushed outwards into the fender
3. Bolted upper and lower radiator brackets with load limiter
4. "Pushing bracket" for Lower Bumper Stiffener to improve radiator kinematics
5. Hood hinge measures (see section 6.4 and Figure 13) to decrease hood rotation and translation, hence avoiding paint damage to the fender on the non-impacted side

7.2 Benefits:

- Low front end damage
- Minimised effect of pedestrian protection on insurance classification
- Reduced risk of radiator leakage
- Reduced spare part and labour costs
- Simplified repair after crash
- Improved insurance classification

The performance of the ZAFIRA II in the front insurance test is illustrated in Figure 18:

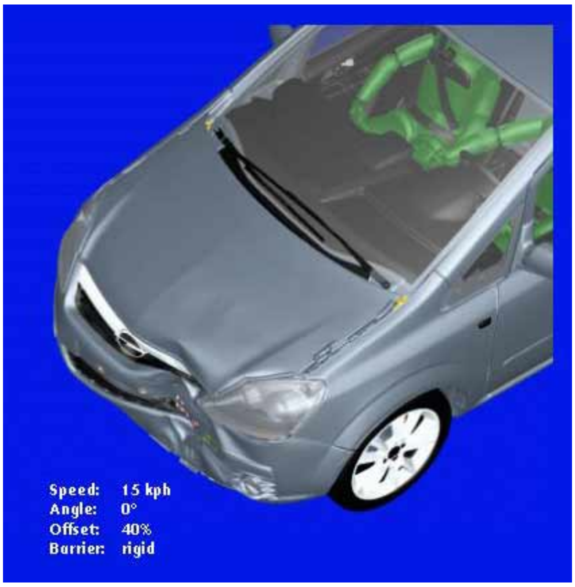

Figure 18. Insurance Test Front Impact Performance of the Opel ZAFIRA II

8. Influence on Hood and Fender Stiffness

8.1 Stiffness in Upper Fender Region

The soft fender attachments meant that the vehicle had to be further developed for additional loadcases, which conventional vehicles (without these advanced pedestrian protection measures) would automatically fulfill.

For example, during production assembly and later during servicing or repairs, a mechanic would probably lean on the fender when working on the engine compartment, see Figure 19. Additionally, anybody might lean against the fender or push the vehicle from the fender. Under these loadings, no unacceptable elastic or plastic deformations should occur.

Figure 19. The Opel ZAFIRA II Fender: expected loading under maintenance / repair work

Accordingly, the geometry and dimensions of the fender brackets were balanced and optimized between these loadcases and the pedestrian protection requirements.

It should be noted that this fender region could only satisfy HIC < 2000, not HIC < 1000.

Among other measures, this balance was achieved by making use of the material properties of mild steel: The low yield point of the mild steel fender brackets enables higher material thicknesses and therefore higher elastic stiffnesses for the linear elastic loadcases, while the brackets readily deform plastically under pedestrian head impact.

8.2 Hood Stiffness
The thin steel hood caused problems with the buckling and polishing strength of the hood outer panel. In particular, it was necessary to ensure that the front surface of the hood, where someone might press to close the hood, did not buckle under this type of loading.

To prevent such buckling and to support / stiffen this hood front area, the following measures were implemented, see Figure 20 and the list below:

1. Three tabs were formed on the hood inner panel and bonded to the hood outer
2. A small adhesive strip, applied by robot, was added to the undersurface of the hood outer panel.

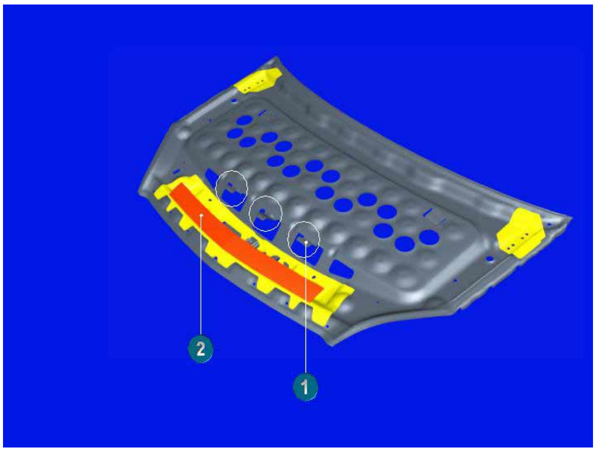

Figure 20. Thin steel hood of the Opel ZAFIRA II

With these measures, a balance was found to ensure good pedestrian protection performance and to allow weight reduction. The area-specific mass (the ratio of mass to area) of the hood was improved by 11% compared to the ZAFIRA I.

8.3 Hood Bumpstop Brackets
The bumpstop brackets were dimensioned to achieve the following requirements:

- Deformation under pedestrian head impact
- Compliance with fatigue and durability targets
- No plastic deformation with the hood slam test, see Figure 21:

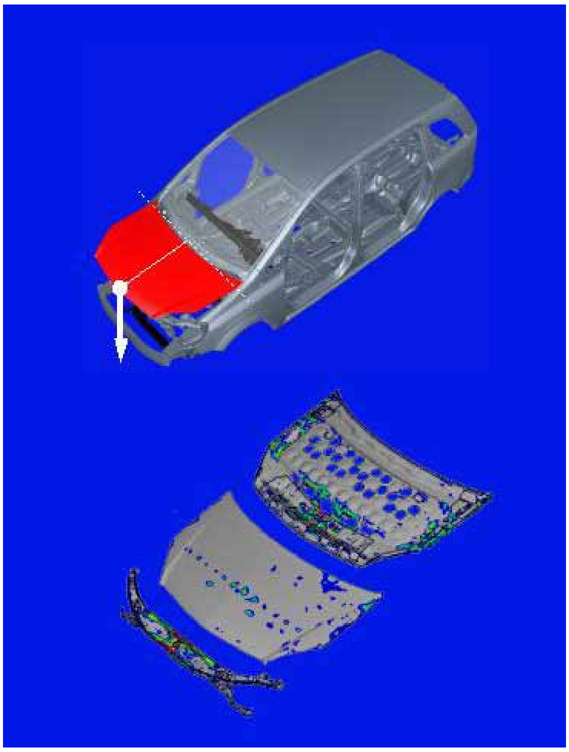

Figure 21. Hood Slam Test Performance

8.4 Hood Flutter
At high speeds, high aerodynamic loads are produced on the thin steel hood structure which may cause the hood trailing edge to flutter. To prevent this flutter, the entire rearmost “muffin tin” row of the hood inner panel was bonded to the outer panel.

9. CAE and Test Activities

Pedestrian protection measures for the new Opel ZAFIRA II were developed and optimized by means of detailed CAE modelling and then verified by an extensive test program at different stages.

9.1 CAE Challenges
Pedestrian CAE has particular difficulties compared to CAE for “standard crash”, i.e. impact with a barrier or another vehicle:

- Since the kinetic energy is only about 1% of that in a typical barrier impact, the degree of CAE accuracy and refinement required is even higher than that for standard crash.
- The accuracy required for head impact simulation is even higher for two reasons caused by the HIC definition: the acceleration

is raised to the power of 2.5 and the HIC time window is very sensitive to the curve form.

- Pedestrian injury is often heavily influenced by either very small components, e.g. screw heads, or components made from plastic or rubber, e.g. cowl, headlights, hoses. Such components, which do not play a significant role in standard crash, are therefore not normally present in their CAE models, or are not modelled in such detail.
- It is very difficult to obtain adequate material data for important non-metallic materials, particularly plastics, which are often anisotropic, heavily strain rate-dependent and susceptible to fracture.
- Material fracture of plastic components, e.g. cowl, headlights, may significantly affect local behaviour. However, such fracture is difficult to predict reliably and simulate, even when suitable material test data is available, since the material laws and algorithms in the commercial crash codes are not fully adequate for this.
- Pre-stressing of critical components, e.g. of the hood outer, may affect behaviour and this is also very difficult to simulate, particularly when performing a large number of simulations under time pressure, as is the case during vehicle development.
- The behaviour of some components, such as hood and fender, are particularly influenced by the forming process, which should be included within the CAE modelling.

9.2 Test Challenges

As with CAE, pedestrian impact brings additional problems compared to standard crash. Test variability (most importantly, the injury values), particularly for leg impact, is higher than for standard crash, since there are a large number of sensitive parameters – all interacting - which can significantly affect the behaviour:

- Variables within the impactor itself, such as the knee ligament and the foam "flesh" characteristics for the leg impactor and the rubber skin for the head impactors.
- Allowed tolerances within the test setup, for positioning, speed, angles etc.
- Thickness, geometry and material tolerances for prototype parts together with hand-built test bucks during the vehicle development further increase the variability, particularly since prototype materials can be very different to production ones.

9.3 CAE and Testing during Development

Pedestrian simulation requires a sophisticated integrated model, i.e. detailed modeling of both the pedestrian impactor and the vehicle, together with the complex vehicle / impactor interaction. Thus, the FE model must contain both the pedestrian impactor and the relevant parts of the vehicle front.

The ZAFIRA II pedestrian protection CAE model consisted of the complete vehicle front, containing all components from bumper to A-pillars and windscreen, including the relevant engine bay components and structure.

Model details for pedestrian CAE:

- Approximately 450,000 elements for the vehicle front
- All components within the expected deformation zone were modelled accurately, meshed exactly on the CAD data, with full geometric, material and kinematic properties
- Key components were modelled in particular detail, with 2-5 mm element length and strain-rate dependent material properties, e.g. the complete hood, hinge, lock, bumpstops, upper fender, fender brackets, cowl, service panel, wiper system, headlights, lower bumper stiffener, bumper fascia, bumper foam.
- Data was obtained from dynamic material tests for important plastic components, such as the fascia, grill, lower bumper stiffener, headlights etc.

This vehicle pedestrian CAE model, with the most important components highlighted, is shown in Figure 22:

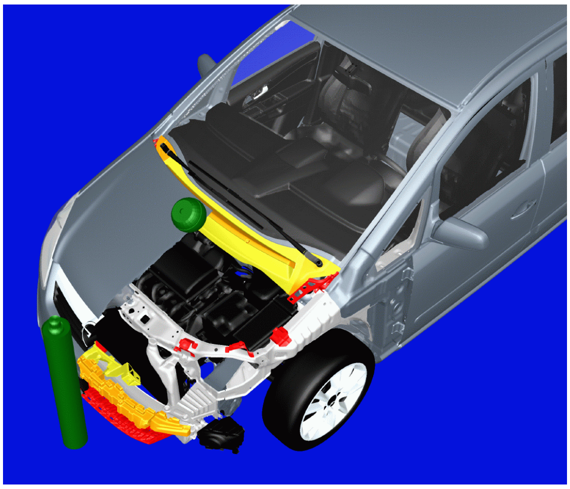

Figure 22. The ZAFIRA CAE Model for Pedestrian Simulation: section through center line. Key components are shown as red.

A large number of different impactor positions were simulated to predict injury values for the legal and EuroNCAP head and lower leg impacts, as well as to develop optimisation measures.

Figure 23 illustrates the number of impact positions for the different pedestrian loadcases:

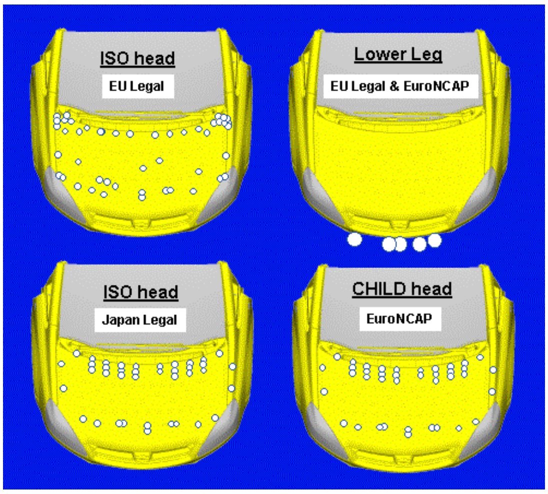

Figure 23. The ZAFIRA II Pedestrian Impact – Key Points (White) Investigated by CAE

The very large number of impact positions necessary to determine the legal and Euro NCAP status at each stage placed very heavy demands on CAE manpower and CPU, as well as on the team performing the hardware tests. The creation of CAD data for all the different impact areas also required considerable CAD experience and detailled understanding of the complex impact area definitions for the different requirements.

Pedestrian CAE validation is difficult and critical hardware tests must be repeated to obtain reliable results.

Therefore, extensive hardware concept confirmation at a number of stages is vital for pedestrian protection development. The critical impact positions for the ZAFIRA II were later validated by hardware tests at 3 stages:

1. Pre-concept studies
2. Architectural Mule Upgrade (to check basic concepts and architecture for pedestrian protection)
3. Integration Car (to confirm production-near concepts)
4. Validation Car (final confirmation before production car and also for Type Approval)

Opel has installed a sophisticated setup including the BIA pedestrian testing equipment, to perform all legal and NCAP pedestrian tests in-house at Ruesselsheim, Germany.

SUMMARY / LESSONS LEARNED DURING ZAFIRA II DEVELOPMENT

The ZAFIRA II has achieved pedestrian compliance in advance of future legislation, while achieving a dynamic vehicle styling. With this, its first vehicle to be compliant with pedestrian Phase 1, General Motors Europe has taken an important step in pedestrian protection and gained considerable knowledge for future vehicle development:

- There are considerable difficulties in the integration of pedestrian protection into a vehicle without sacrificing other normal in-service requirements.
- Pedestrian protection has a significant effect on other loadcases e.g. low-speed insurance, fender stiffness, hinge stiffness, hood slam etc.
- Pedestrian development affects most areas of vehicle development. Hence, an experienced multi-disciplinary team, drawing from many departments, such as the ZAFIRA development team at Opel ITDC, is essential. Of particular importance is the close cooperation between simulation, test, design and styling. Pedestrian protection is very sensitive to styling and package changes.
- The CAE confidence level is insufficient to reliably predict results at all the necessary impact positions. However, CAE is an essential tool in developing pedestrian measures, enabling the development team to understand and analyse the vehicle structural behaviour in detail.
- CAE front-loading avoids late and costly design change.
- Non-metallic materials play a significant role in pedestrian impact behaviour and it is very difficult to obtain sufficient data for CAE, e.g. anisotropic, strain-rate dependent stress-strain curves for plastics´, with fracture criteria.
- Significant pedestrian development without hardware is currently impossible. Due to test variability and CAE limitations, extensive hardware tests (requiring expensive prototype builds) are necessary for concept confirmation, or to indicate non-compliant areas well before starting the production tooling.
- There is often high test variability for pedestrian impact tests; hence tests at critical impact positions must be repeated at least once for reliable results.
- The selection of impact positions must be made separately for the different pedestrian impactors and speeds and must also be updated after each relevant styling or package change. The creation of CAD data for the different impact areas, especially for head impact, is very complicated, requiring detailled knowledge of the different impact area definitions and extensive checking.
- The large number of impact positions and the different pedestrian loadcases for the EU, Japan and Euro NCAP created a tremendous additional volume of work for the CAE and test engineers, which required very substantial

manpower, CPU and hardware resources to complete.

- With simulation front-loading, the ZAFIRA II has been successfully developed to comply with Japan and EU Phase 1 pedestrian requirements, in advance of legislation coming into effect.

REFERENCES

[1] European Directive 2003/102/EC

[2] Japanese Directive TRIAS63

[3] EuroNCAP Protocol

DISCLAIMER

This presentation is solely provided for the purpose of scientific discussion of the main tasks and concepts in order to implement national and international legal requirements related to pedestrian protection efforts in automotive engineering. This presentation explicitly does not cover all and any engineering and design issues around Pedestrian Protection efforts; it is not to be construed to being an engineering manual, to provide any specific or ultimate solution nor to represent a certain engineering decision by Adam Opel AG., its subsidiaries and affiliates and / or any reasons for such decisions.