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SEVENTH FRAMEWORK
PROGRAMME

FIMCAR
IV – FIMCAR Models

FIMCAR
frontal impact and compatibility assessment research

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CONTENT

EXECUTIVE SUMMARY

The aim of the FIMCAR project is to develop and validate a frontal impact assessment approach that considers self and partner protection. In order to assess the influence of different test procedures and metrics on car-to-car compatibility a huge simulation programme was executed. However, car-to-car simulations with models of different car manufacturers are almost impossible to obtain because of confidentiality.

In order to overcome these problems, parametric car models (PCM) were built, allowing fast modifications and more detailed generic car models (GCM) were developed for structural interaction analysis.

Three different PCM representing a super mini, a large family car and an executive car were developed. By simplifying the models, computational efforts are reduced. Due to the parametric design it is possible to modify the models in an easy and fast way. The models are delivered in three crash codes (LS-DYNA, PAM-CRASH and RADIOSS) in order to be usable at all FIMCAR OEMs.

The Generic Car Models (GCM) model virtual cars which represent an average real car of the respective category (super mini, small family car, executive car) in a comparable way to the OEM models. All together five different models were generated (2 super minis, 2 small family cars and one executive), again delivered in three different FE codes (LS-DYNA, PAM-CRASH and RADIOSS). The models can be used to evaluate the behaviour of the crash structure (e.g., crash pulse, deformation characteristics and intrusions). For supermini and small family categories, two models were generated in each class in order to describe the two main architectural/structural car variants that can usually be found on the road, i.e. with and without a lower load path in the frontal frame (structural elements below the main rails); the availability of both structural solutions in the GCMs is in fact important for the study of compatibility issues.

1 INTRODUCTION

1.1 FIMCAR Project

For the real life assessment of vehicle safety in frontal collisions the compatibility (described by the self-protection level and the structural interaction) between the opponents is crucial. Although compatibility has been analysed worldwide for years, no final assessment approach was defined. Taking into account the EEVC WG15 and the FP5 VC-COMPAT project activities, two test approaches are the most important candidates for the assessment of compatibility. Both are composed of an off-set and a full overlap test procedure. However, no final decision was taken. In addition another procedure (tests with a moving deformable barrier) is getting more and more in the focus of today's research programmes.

Within this project different off-set, full overlap and MDB test procedures will be analysed to be able to propose a compatibility assessment approach, which will be accepted by a majority of the involved industry and research organisations.

The development work will be accompanied by harmonisation activities to include research results from outside the consortium and to early disseminate the project results taking into account recent GRSP activities on ECE R94, Euro NCAP etc.

The FIMCAR project is organised in six different RTD work packages. Work package 1 (Accident and Cost Benefit Analysis) and Work Package 5 (Numerical Simulation) are supporting activities for WP2 (Offset Test Procedure), WP3 (Full Overlap Test Procedure) and WP4 (MDB Test Procedure). Work Package 6 (Synthesis of the Assessment Methods) gathers the results of WP1 – WP5 and combines them with car-to-car testing results in order to define an approach for frontal impact and compatibility assessment.

1.2 Objective of this Section

In real world car-to-car crashes the interaction of the colliding partners is crucial. Thereby the interaction is controlled by the following three main parameters: vehicle mass, stiffness and geometry of the front structures. Together these parameters are the most important aspects for partner protection. With respect to the results of former research projects like VC-Compat the self-protection has still to be taken into account. The main objective of the ongoing research project FIMCAR (Frontal Impact and Compatibility Project) is to develop a proposal for a compatibility test procedure that addresses both: self and partner-protection. FIMCAR started in October 2009 and is co-founded by the European Commission within the 7th Framework Program. To achieve the main objective FIMCAR is mainly build on the results of VC-Compat. On this occasion FIMCAR improved the understanding of structural interaction and the capability of different test configurations (off-set and full width configurations) to assess frontal impact compatibility. To answer the open questions a large test program was executed that is divided into physical and virtual testing.

Besides the car models described in this section the following numerical models were developed or improved within FIMCAR project:

- Barrier models (PDB model, MPDB model, FWDB model)
- Multi body fleet models

Furthermore commercial models and in-house models of various barriers were used.

2 MODELLING APPROACHES

Within the FIMCAR project two different modelling approaches for the development of FE car models were used. The GCM (Generic Car Models) were developed by CRF (Centro Ricerche FIAT S.C.p.A.) and the PCM (Parametric Car Models) were developed by TUB (Technische Universität Berlin). The two types of models are available for three different crash solvers: LS-DYNA, PAM-CRASH and RADIOSS. In this way it is possible to include the detailed car models of the OEMs (which are partners of the consortium) into the virtual test program.

2.1 GCM - Generic Car Models

The GCMs used in FIMCAR were derived from the GCMs developed by CRF within the research project APROSYS [APROSYS 2005], through the implementation of huge modifications and improvements. In total five different models of three different vehicle classes (super mini, small family car and executive) were generated, Figure 2.1. Two additional variants, with respect to the original architectures of super mini and small family car, were in fact introduced by the addition (super mini) or removal (small family car) of a lower load path. The availability of such structural variants on the GCMs was an important and necessary element for the study and the understanding of compatibility issues within the project.

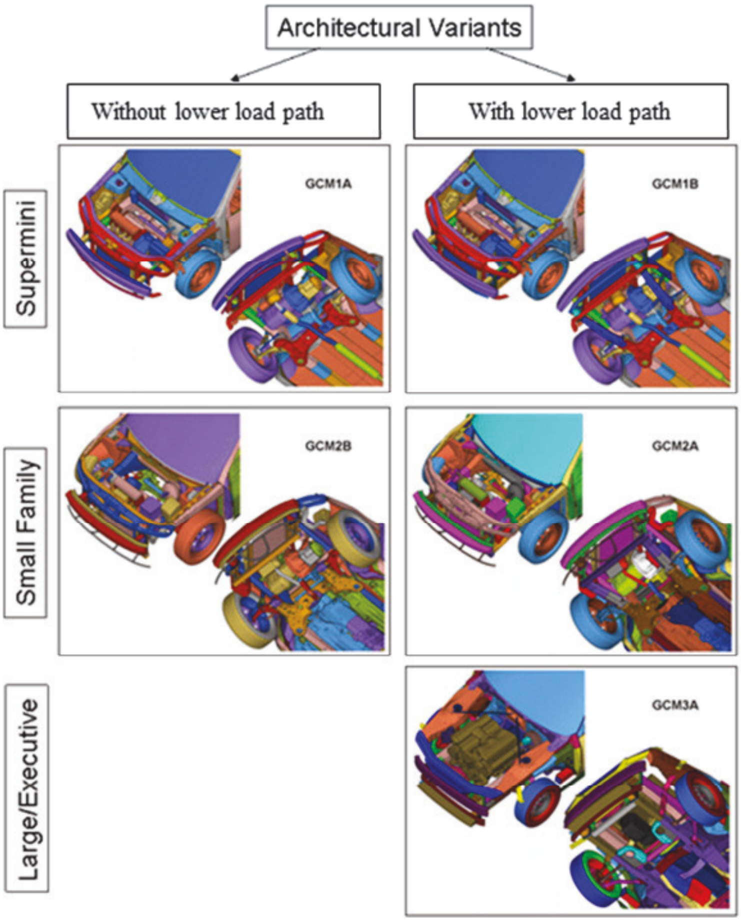
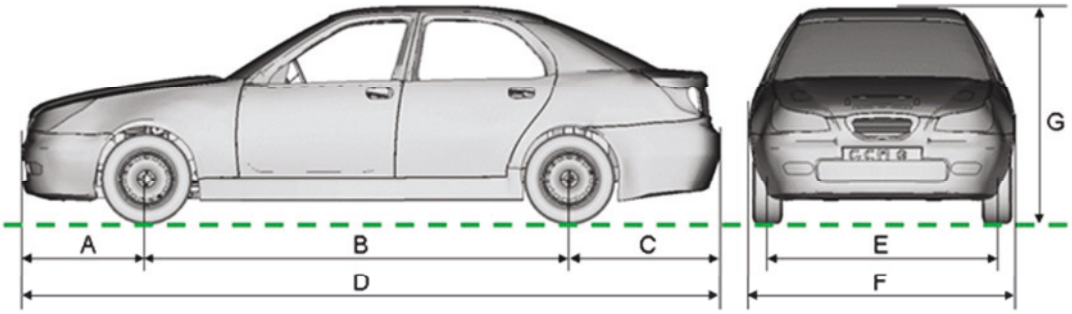


Figure 2.2: Architectural variants of GCMs.

A main requirement for the GCMs was to represent typical vehicles of the actual European vehicle fleet. Other than for the architectural solutions described before, this requirement was applied to the external dimensions and weights of the models, too.

Figure 2.3 gives an overview of the main external dimensions and weights of GCMs.



		GCM1A	GCM1B	GCM2A	GCM2B	GCM3A
A	*Front Overhang [mm]*	845		855		851
B	*Wheel base [mm]*	2464		2620		2887
C	*Rear Overhang [mm]*	603		742		1028
D	*Max Lenght [mm]*	3912		4217		4766
E	*Wheel track [mm]*	1507		1577		1578
F	*Max Width [mm]*	1720		1822		1828
G	*Max height [mm]*	1547		1485		1490
	Kerb Weight [kg]	983	988	1186	1180	1732

Figure 2.3: Dimensions and weights of GCMs.

Another important requirement taken into account during the GCMs development was to have frontal structures with main rails (or PEAS, Primary Energy Absorbing Structures) presenting cross sections with an adequate vertical overlap w.r.t. the "part 581 common interaction zone" (located between 16 and 20 inches from the ground), according to the TWG Voluntary Agreement Option 1 that is considered and applied in USA with the aim to improve the compatibility between SUVs/Pick-ups and traditional passenger cars. All GCMs comply indeed with this voluntary technical specification, as highlighted in Figure 2.4 (recalling graphically the rules behind the option and showing the GCMs positioning w.r.t. the part 581 zone).

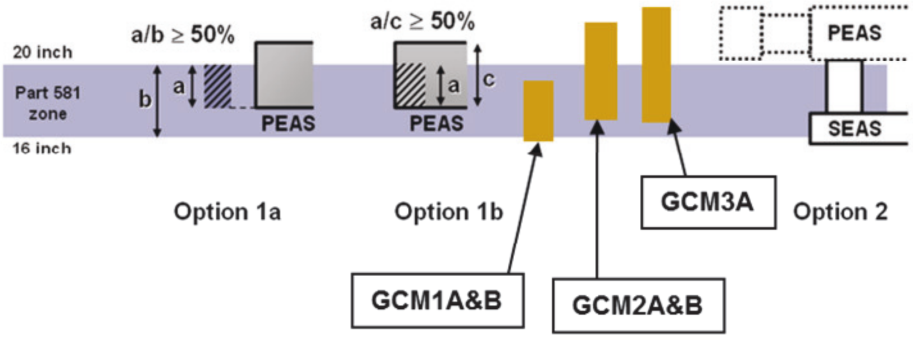


Figure 2.4: GCMs compliancy w.r.t. TWG Voluntary Agreement Option 1 (both 1a and 1b to be satisfied.

The modelling was controlled by the following two main parameters: high level of detail (comparable to models of OEMs) and a generic topology of structures and parts of typical vehicles that can be found on the roads of the corresponding vehicle class. To fulfil the first requirement especially the front structures of the GCMs were modelled with fine mesh. Thus the models consist of about 600,000 elements. Although the structures are generic ones they are modelled to ensure realistic crash behaviour with respect to crash pulse, intrusion behaviour, energy absorption management and collapse modes.

The development of the GCMs was performed by adopting the US NCAP (rigid wall, 56km/h, 100% overlap) and old AMuS (rigid wall, 55km/h, 50% overlap, 15° wall inclination; former test procedure of the German automotive magazine “auto motor und sport”) configurations as reference frontal impact conditions, see Figure 2.5.

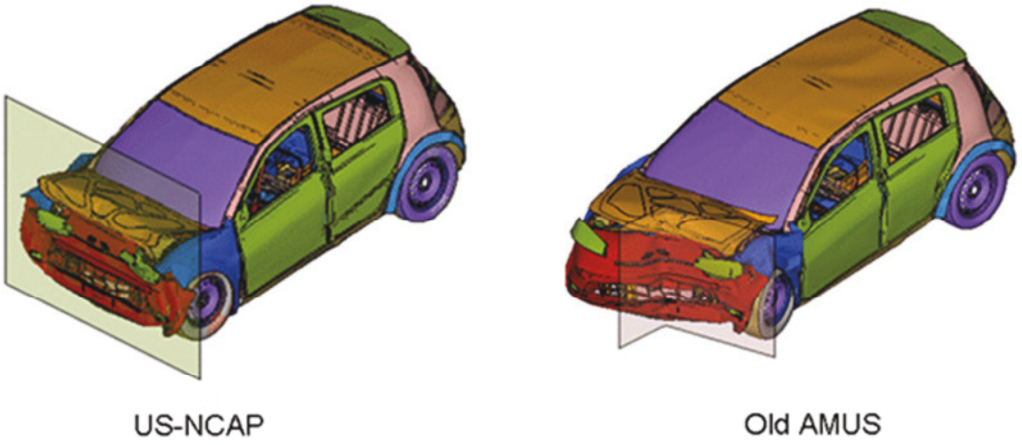


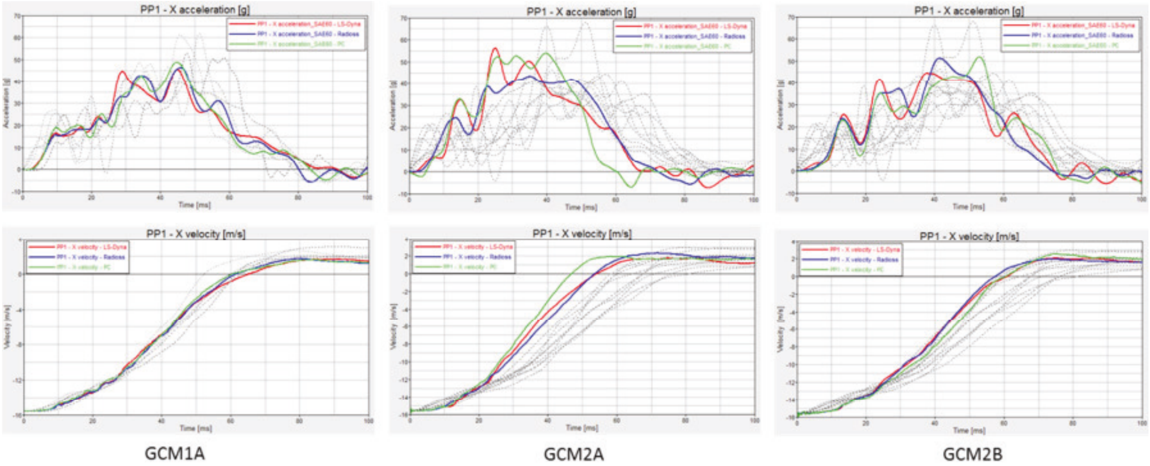
Figure 2.5: Frontal impact crash configurations considered for GCMs development.

The use of fixed rigid obstacle was decided in order to simplify the comparison of results between same GCM variant in different code environments, then avoiding the introduction of such an additional source of differences represented by the model of a deformable barrier.

In fact, all the GCM variants were initially developed/engineered within one of the three numerical codes (i.e. LS-DYNA); when the model variants behaviour reached the appropriate level of realism in the reference crash configurations, the translation to the other codes (RADIOSS and PAM-CRASH) was operated and the levels of correlation between code versions was verified.

A classical (or pure) validation phase (comparison between numerical and experimental results) cannot be strictly performed for these models, simply because corresponding physical models of GCMs do not exist; GCMs behave in a “realistic” manner; this “realistic” behaviour is indeed the target that guided their development work and that represents at the end their “validation”.

However, due to the fact that US NCAP data are available to the public and that the collision at 56 km/h against a rigid wall and 100% overlap represents one of the two development and verification virtual testing set-up used for the GCMs, a numerical-to-experimental comparison for this configuration was possible and done, on acceleration pulses, in order to better illustrate the level of “equivalence” between GCMs virtual results and the ones of similar state-of-the-art real vehicles. In Figure 2.6, the crash pulses obtained from the 3 numerical model code versions (red, blue and green curves) are compared with real (experimental) crash pulses of vehicles belonging to the same categories (grey dotted lines), for some of the GCM developed variants.



GCM1A GCM2A GCM2B

Figure 2.6: Comparison of crash pulses of some GCMs w.r.t. different code versions and real test results (US NCAP frontal impact at 56 km/h).

On each GCM model the user can find several measurement points from which acceleration pulses and/or displacements/intrusions can be extracted; the locations of these points correspond to the common positions typically adopted, on experimentally tested vehicles, for the accelerometers and the several markers; moreover, some sections of the vehicle structure are monitored on the models, so that the forces passing through them during the impact can be extracted for the analysis. Figure 2.7 shows the location of such monitoring points on GCM models.

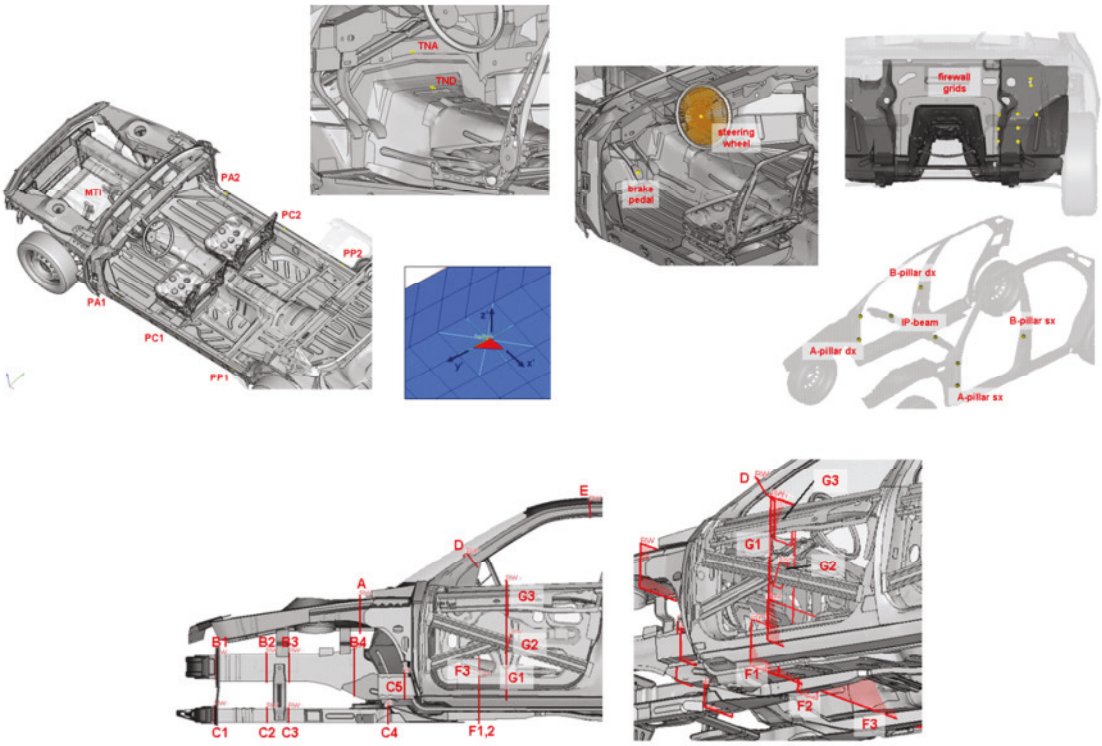
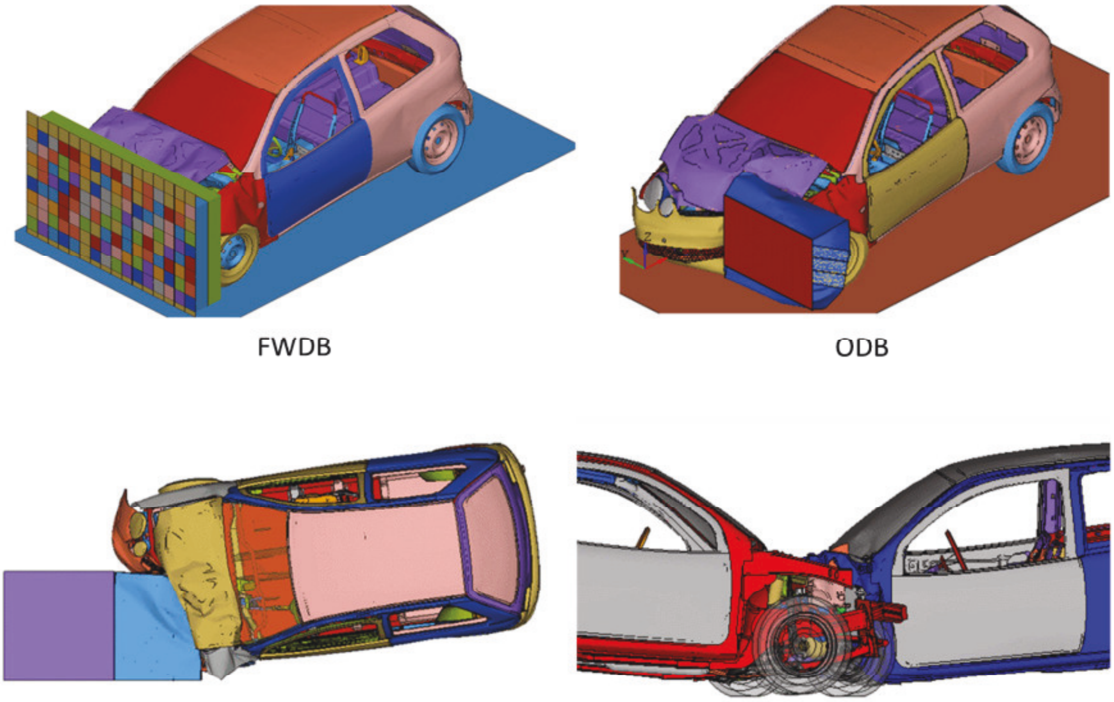


Figure 2.7: Typical locations of accelerometers, markers and cross sections available on GCM models.

The main tasks of the GCMs within FIMCAR are to analyse the crash behaviour in the different frontal impact test configurations, to compare these results with responses from car-to-car crash simulations and to serve as common bullet vehicles against the OEM models.

In Figure 2.8 the main crash configurations considered during the project are recalled.



FWDB

ODB

PDB

CAR-TO-CAR

Figure 2.8: Main frontal impact configurations considered within FIMCAR.

2.2 PCM – Parametric Car Models

To investigate the influence of different front structure topologies and the impact of the assessment metrics to the front structures, the PCMs were developed to overcome the aims of structural interaction. Usually the modification of the structure of a finalised FE model is a complicated and time consuming exercise. Morphing tools or manual transformations of the mesh is time consuming and can cause numerical instability. To avoid these problems, the PCMs approach uses an implicit parametric design of a CAD model that allows fast modifications of the structure. Therefore position, shape and size of the most important crash structures can be changed in an efficient way. Finally an automated mesh algorithm generates meshes and additional FE information needed to create computable FE models without further pre-processing [Stein 2011].

In contrast to the GCMs one of the main requirements of the PCMs was the lower calculation time. To comply with this, the PCMs were simplified. E.g. many parts of the power train were merged to one rigid part, and crash relevant parts like cross beam, longitudinals and sub frame were modelled with respect to realistic crash behaviour, Figure ***2.9***.

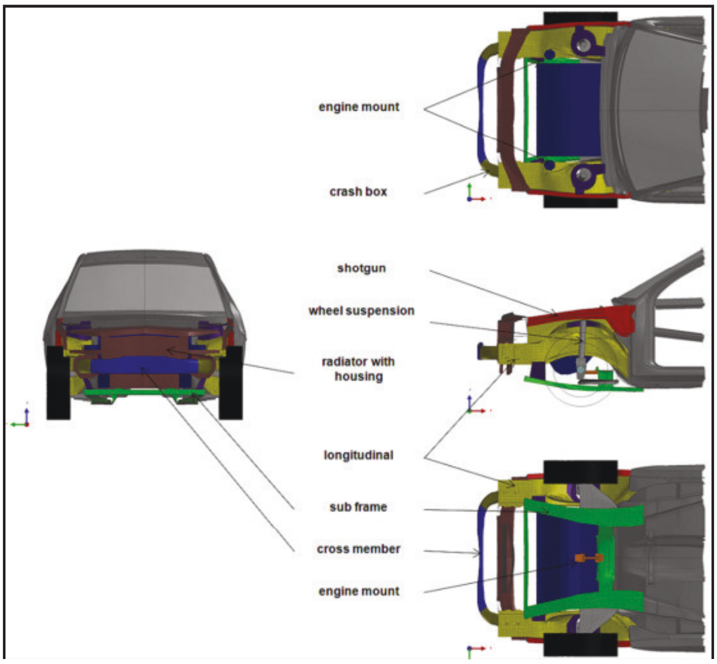


Figure 2.9: Front end structures of the PCMs.

During the first part of the FIMCAR project three different vehicle classes (super mini, large family car and executive) were modelled. To reduce the computational effort, the mesh size was set to an average edge length of 15mm. The final number of elements is about 200,000 for each vehicle model. One of the main requirements, when setting up the models was to represent the actual European vehicle fleet. Therefore averaged values for the most crucial design parameters (vehicle length and width, wheel base and kerb weight) were investigated by using the values of four to six top sellers for every vehicle class, see Table 1.

Table 1: Target values for the geometry of the PCMs.

	length [mm]	width [mm]	wheel base [mm]	kerb weigth [kg]
Super Mini	3,800	1,670	2,400	843
Large Family Car	4,600	1,820	2,800	1,568
Executive	5,100	1,910	3,030	1,899

The topology of the structures, especially in the front end of the vehicle, is based on the construction methods of real vehicles. In combination with the specific stiffness (material and part thickness, shape of the cross section) the vehicles behave during the crash in a realistic way. However the models are not able to represent failure of materials or welding points.

The priority of the behaviour of the structures and the interaction increases in car-to-car collisions. To make a statement about compatibility issues, it is important that the models have the ability to produce several phenomena, like over- and under riding. Modifications which finally lead to a validated status of the PCMs were always done with respect to these criteria.

The models were validated for the US NCAP configuration (rigid wall, 56km/h, 100% overlap). The crash pulse of the compartment was the main criteria in the validation process. The pulses were compared (duration, peak and average deceleration) with real crash pulses of cars of the corresponding vehicle class. Therefore the FIMCAR database and other public available databases were used to find a range of pulses for the different car types. The number of test objects ("TO" in Figure 2.10) that could be found differs for the three models.

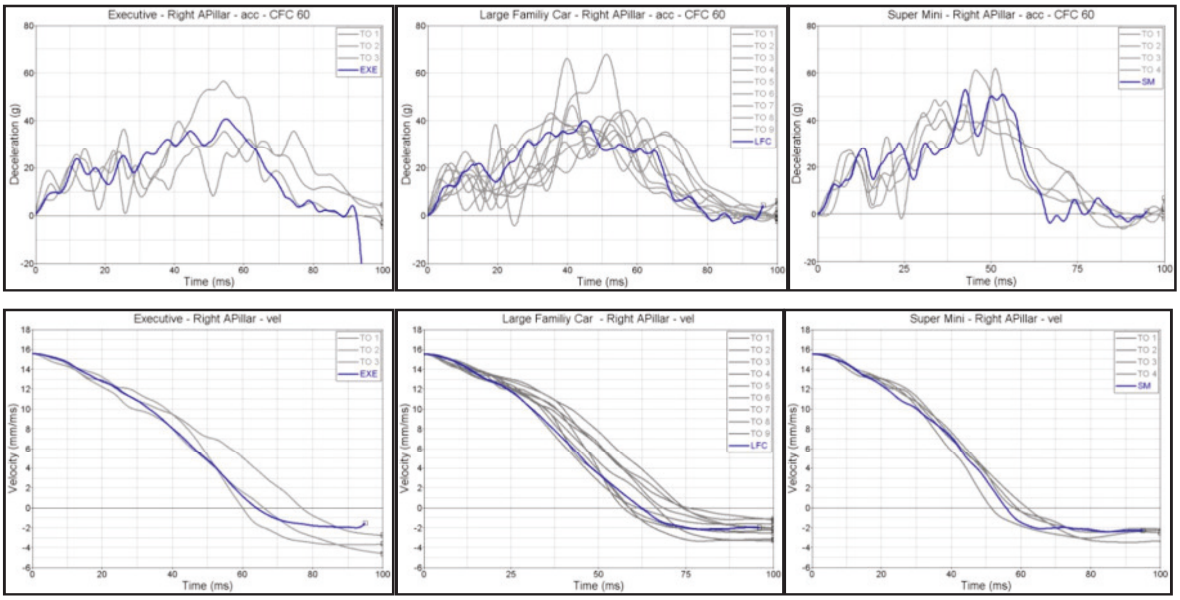


Figure 2.11: Comparison PCMs vs. European cars.

Furthermore the pulses of the different crash codes were compared and validated in order to assure, that the models can be used for the same investigation at OEMs that use different crash codes. The comparison is shown in Figure 2.10.

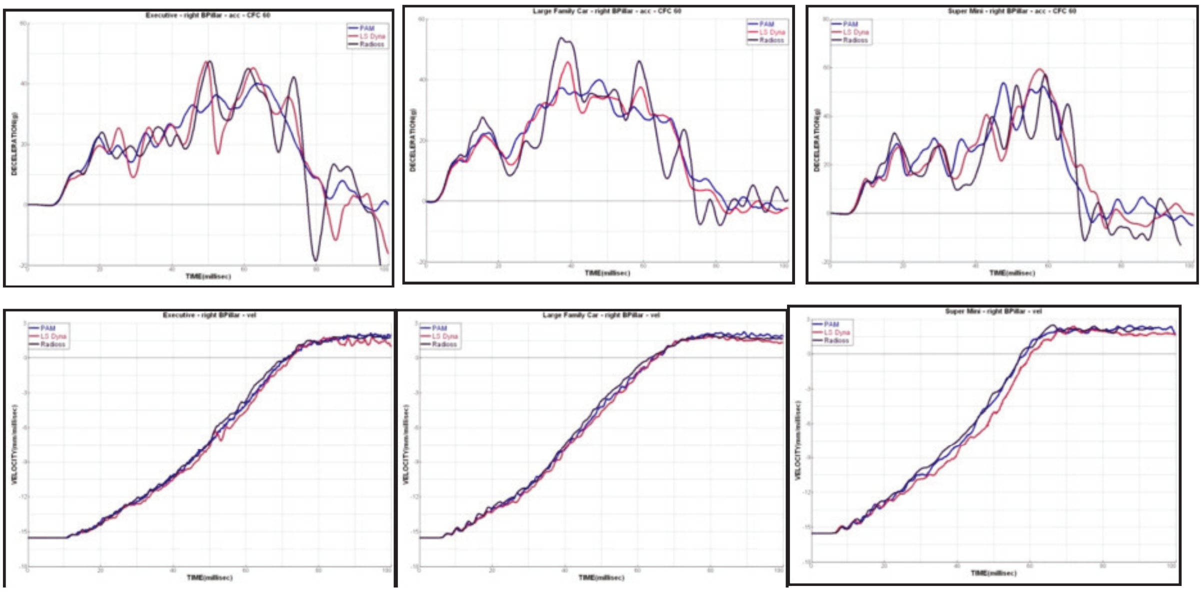


Figure 2.12: Comparison of the different crash codes for the PCMs.

The PCMs offer several ways to measure intrusions. All relevant structures, like bulkhead, floor pan, or the side frame structure, are modelled with deformable material characteristics. Due to the simplifications of the model it was not possible to represent a detailed passenger compartment (e.g. no steering wheel or foot pedals were modelled). During the validation the intrusions were used to adjust the force levels in the front end structure and the passenger compartment. The aim was to prevent the collapse of the passenger compartment.

The main tasks of the PCMs within FIMCAR are sensitivity analyses of the topology of structures in car-to-car crashes and robustness analyses of the test configurations and their corresponding assessment metrics.

2.3 Assessment of Occupant Loading

The main intension of both model approaches is to analyse the influence of the front structures in different crash scenarios. Due to the modifications of these structures the crash behaviour changes. Because normally the characteristic of a restraint system (trigger times, load levels etc.) is designed for a specific crash behaviour of the vehicle, the restraint system has to be adjusted after each modification of the structure to ensure an optimal safety level. For that reason the models are not equipped with restraint systems and do not offer the possibility to include crash test dummies to measure the loads that are applied to the occupant during the crashes.

However, an assessment of the occupant loading is crucial. To overcome this problem, different methodologies were used within FIMCAR to analyse the loading of the occupant.
In the full width test configurations the OLC (Occupant Load Criterion) was used to correlate the deceleration of the cabin to the loading of a belted occupant [Kübler 2008]. The OLC is a mathematical algorithm that simulates an artificial restraint system. This restraint system has a belt slack causing 65mm free forward displacement relative to the vehicle. After that a constant deceleration of the occupant is assumed on the remaining 235mm forward displacement. The constant deceleration is the OLC and corresponds with the injury severity level of the occupant.

In the offset test configuration the analyses of intrusions (firewall and a-pillar) into the cabin provides information of the loading of the occupant. Assessments of the injury severity level caused by intrusions are supported by analysing the loads monitored in relevant cross sections of the structures.

3 FIELD OF APPLICATIONS

At this point chosen applications of the two types of models are presented. Depending on the aims of each investigation both model approaches were used at the same time or the analysis based on one or the other. To assess the capability of the two test candidates for the full width test configurations (full width rigid barrier – FWRB and full width deformable barrier - FWDB) all investigations were performed for both configurations.

3.1 Possibilities of Influencing the FWB Criteria in Full Width Tests

In principle test procedures must meet a lot of technical requirements like reproducibility and repeatability. Furthermore the assessment metrics shall bring benefits e.g. shall improve the safety level. In terms of FIMCAR the full width tests focus on improving the structural interaction of colliding cars in frontal impacts. The assessment metrics analyse the forces applied to the load cell walls (LCW) which are generated by different structures of the front end of the car. To ensure that these forces were applied by structures that help to improve the structural interaction of cars in frontal impact an analysis was performed to investigate the influence of hard points (like towing eyes or the towing eye attachment) to the force criteria.

3.1.1 PCM - Towing Eye in FWRB and FWDB

In a first step a PCM was equipped with a towing hook mounted at two different positions (upper and lower side) of the right longitudinal, see Figure 3.1. The towing eye was simplified and designed by several assumptions (e.g. mass of towed vehicle 1500kg, safety factor 2, material steel, only normal stress). The towing eyes were in alignment with Row 5 (mounted on upper side) and Row 3 (mounted on lower side) of the LCW.

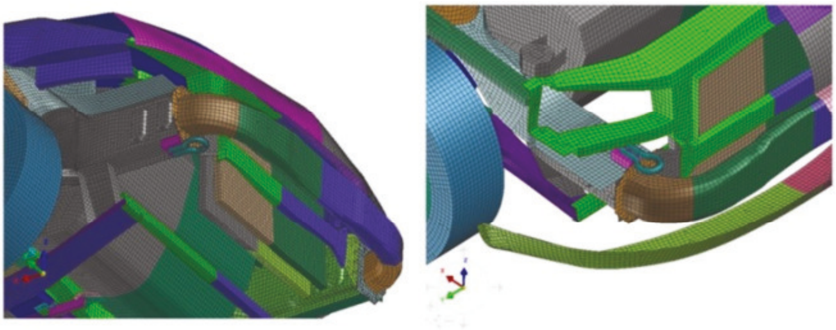


Figure 3.1: Mounting positions of the towing eye on right longitudinal (left figure – below longitudinal; right figure - above longitudinal).

In the FWRB test configuration the unfiltered sum forces of the Rows 3 and 5 showed a high peak (red circles) at the time of impact of the towing eye with the wall, see Figure 3.2. Due to the recommended filtering of LCW data with a CFC60 filter this peak disappears.

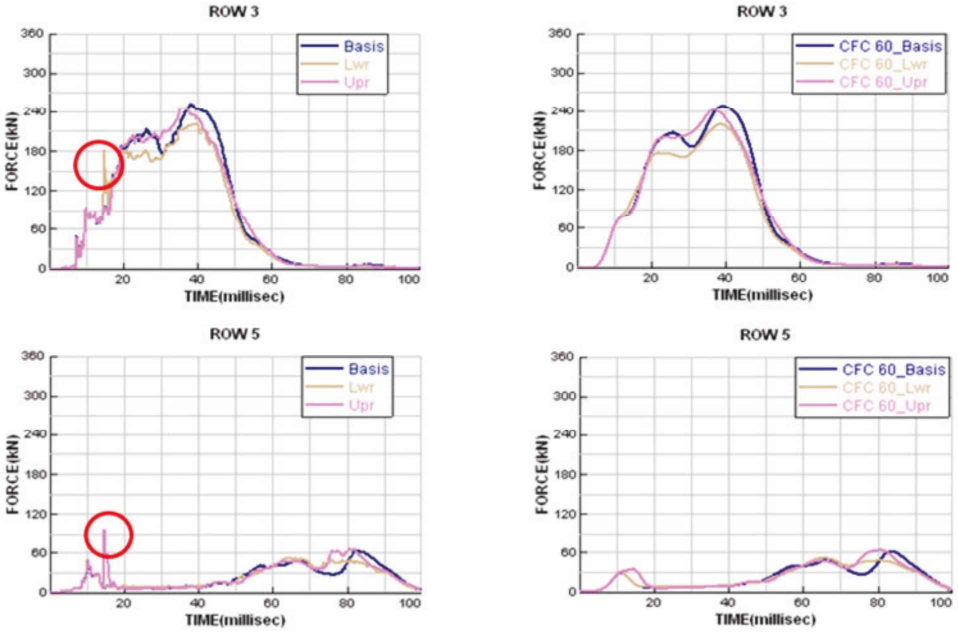


Figure 3.2: FWRB – LCW forces of Row 3 and 5 (left side unfiltered, right side filtered with CFC60) applied by PCM with towing eye.

In general it could be shown that hard points like the towing eye apply heavy loads to the LCW. But the effect disappears after filtering the data. In that way the assessment criteria of the FWRB were not influenced by hard points.

The same simulations were conducted for the FWDB test configuration. In contrast to the FWRB the towing eye influenced the criteria of the FWDB. The applied forces did not disappear after filtering, see Figure 3.3.

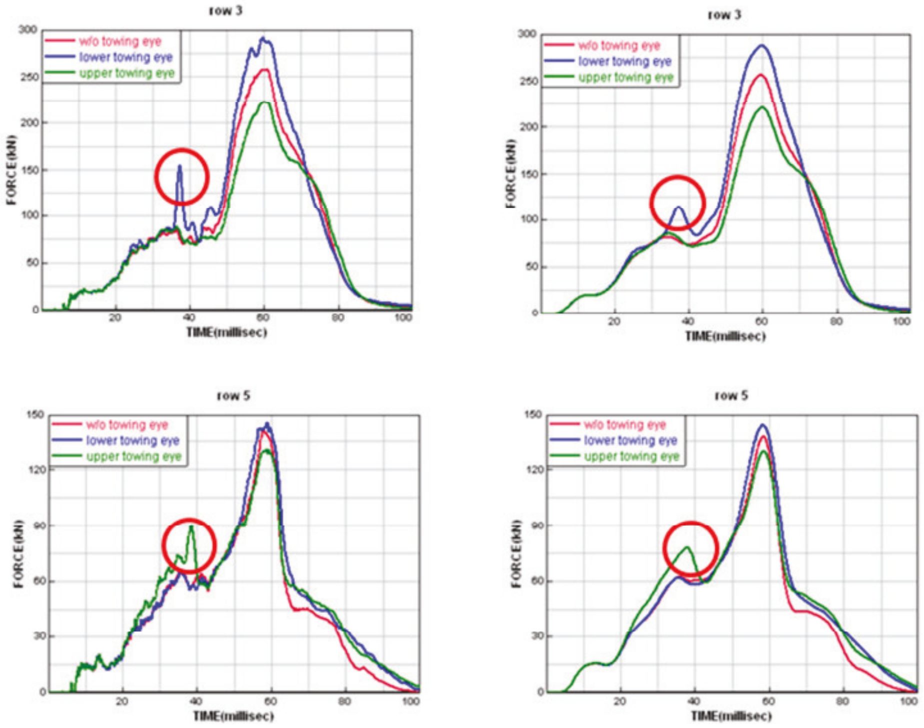


Figure 3.3: FWDB – LCW forces of Row 3 and 5 (left side unfiltered, right side filtered with CFC60) applied by PCM with towing eye.

In the crash against the FWDB the relatively stiff towing eye showed another deformation behaviour due to the deformable element in front of the LCW. In that way the towing eye itself bended (lower towing eye) or the longitudinal bended (upper towing eye) and applied significant forces to the LCW, see Figure 3.4.

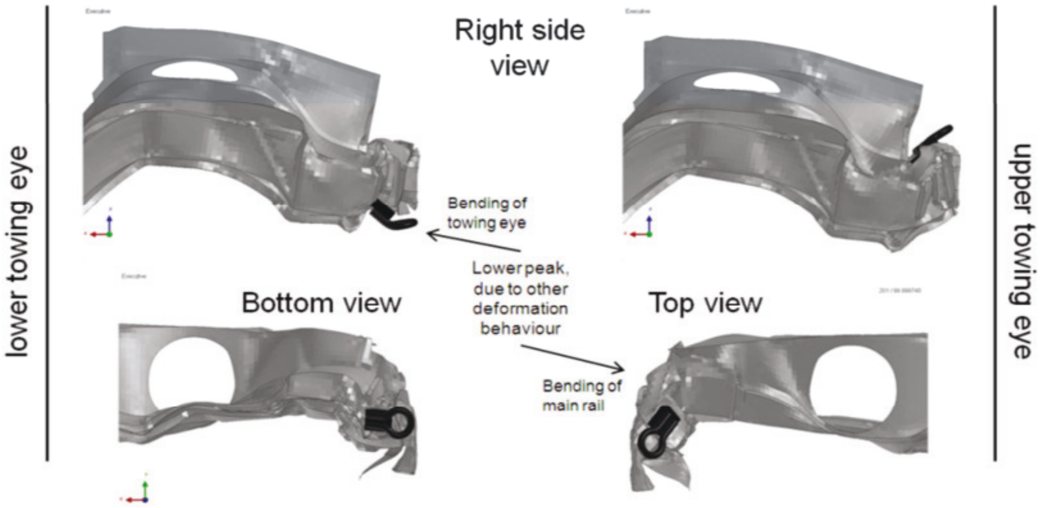


Figure 3.4: FWDB – change of deformation mode of longitudinal for towing eye mounted on lower side and upper side of longitudinal.

3.1.2 PCM - Towing Eye Attachment in FWRB and FWDB

Due to styling aspects and increased requirements on pedestrian safety today vehicles are only equipped with a screw thread to attach the towing eye to the car. Following this the PCM were equipped with such an attachment at two different locations, Figure 3.5.

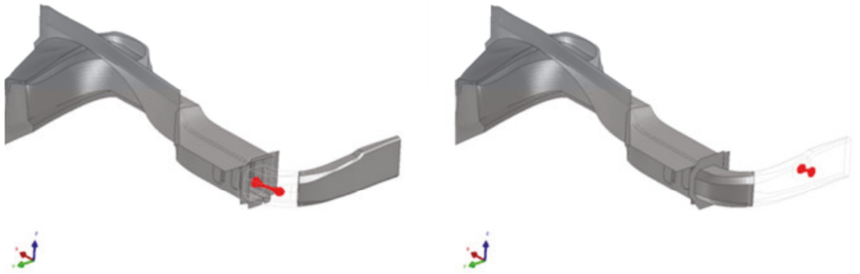


Figure 3.5: Screw thread attachment (left figure – in front of longitudinal; right figure – on the right half of the cross beam).

Both configurations were crashed against the FWB test configurations. Compared to the analysis of the LCW of the FWRB the data showed hardly any differences in the forces applied to the wall. In the FWDB configuration the criteria were influenced by the screw thread.

Finally the simulations showed that the deformation behaviour of the front end structures and therefor the force distribution to the wall is different in the two test procedures. Furthermore it could be shown that a high local stiffness lead to different deformation behaviours in the two configurations. This changed deformation mode has no influence on the FWRB criteria but they influence the FWDB criteria.

3.1.3 GCM – Towing Eye Attachment in FWRB and FWDB

To improve the understanding of the influence of a towing eye attachment the GCM were used to repeat the conducted simulations. The GCM is equipped with a rigid screw thread located inside of the crash box and mounted on the frontal flange of this crash box, see Figure 3.6.

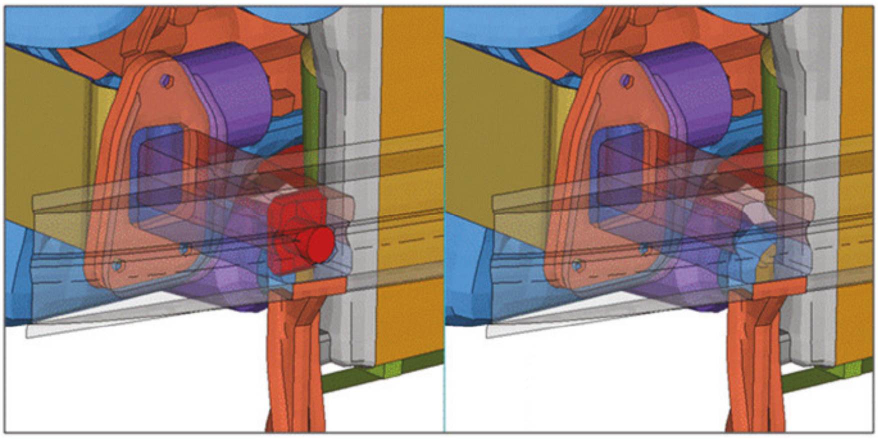


Figure 3.6: GCM1A – Right front crash box with (left figure) and without (right figure) screw thread attachment.

The GCMs were crashed against FWRB and FWDB with and without screw thread attachment. In the FWRB configuration the LCW data showed no differences between the GCM with and without screw thread, see Figure 3.7.

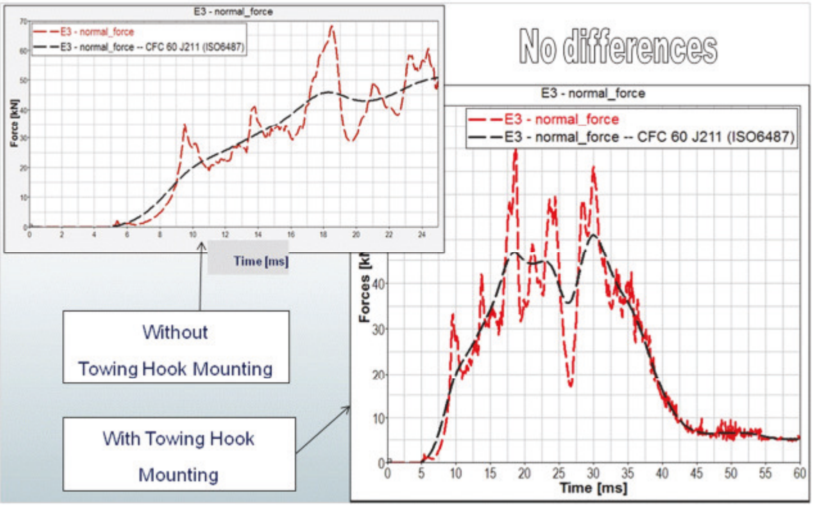


Figure 3.7: FWRB - force applied to directly impacted load cell (left side without, right side with towing eye attachment).

In the FWDB test the deformable element caused only very slight differences in the deformations of the crash box depending on the existence of the attachment. Without the attachment, the crash box still bends downwards (instead of collapsing axially with folding like against the FWRB, with just a different fold detectable on its side wall, see Figure 3.8 (red circles). This initial slight difference on the crash box induces also a subsequent slightly different collapse fold on the main rail side wall (white circles)

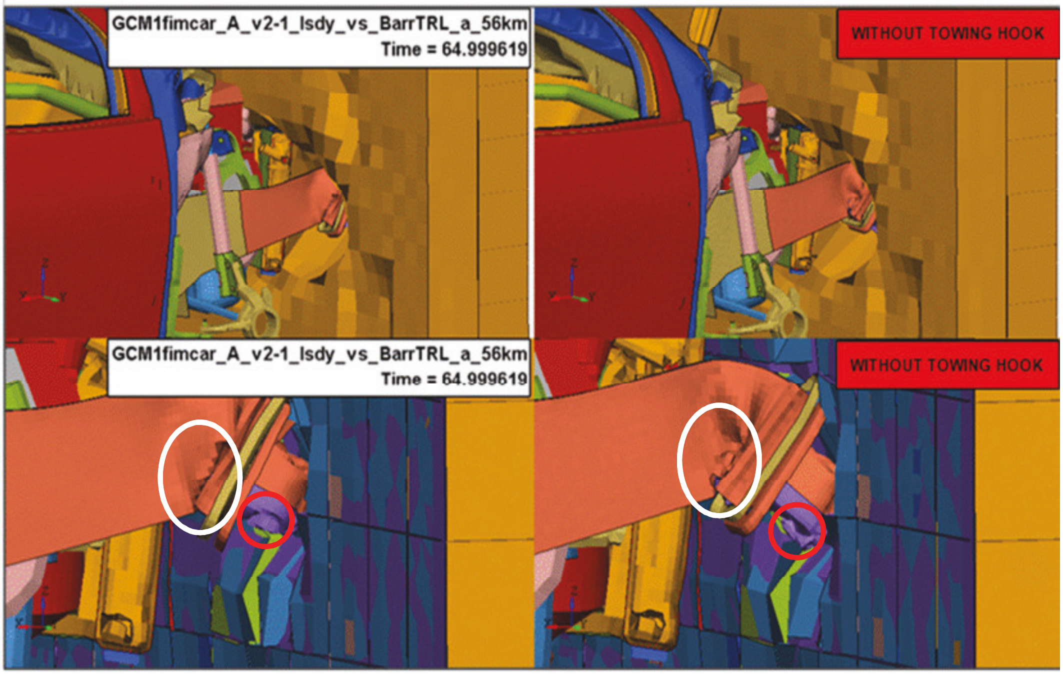


Figure 3.8: FWDB - GCM1A with and without screw thread attachment.

The above mentioned differences in the deformation mode slightly influence the forces applied to the LCW. Figure 3.9 shows the total wall force and the sum forces of Row 3 and Row 4 of the GCM with (dotted lines) and without (solid lines) towing eye attachment. In comparison the forces applied by the GCM with a screw thread are a little bit lower than without the screw thread especially in the range up to 40ms (time range of the FWDB criteria). However the differences had no influence to the assessment criteria.

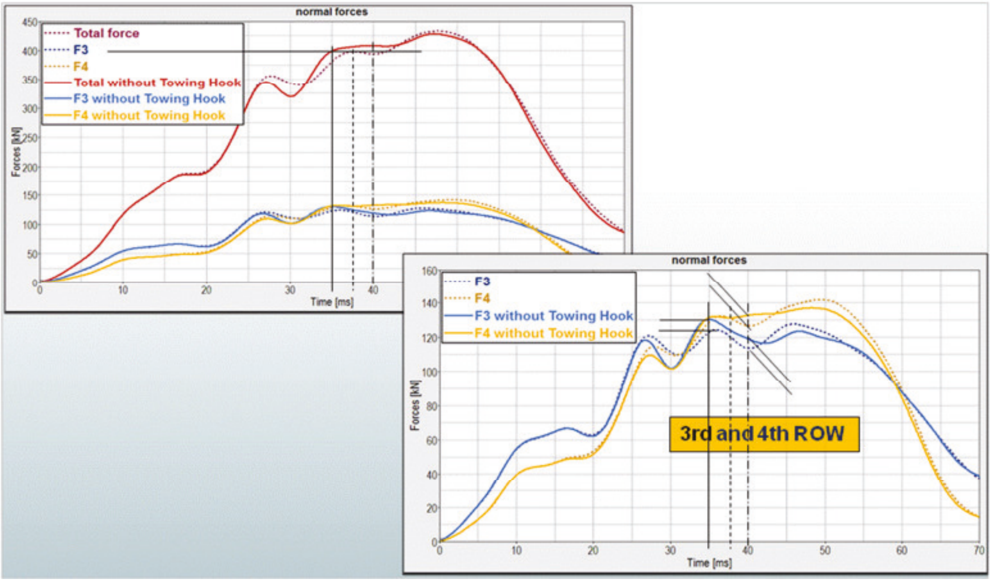


Figure 3.9: FWDB – total wall force and Row 3 and Row 4 forces applied to LCW by GCM1A with and without towing eye attachment.

3.1.4 Conclusions Possibilities of Influencing the FWB Criteria in Full Width Tests

The conducted simulations showed that the deformation of structures differs depending on the test procedure. The deformable element of the FWDB causes the structures to other deformation modes. W.r.t. the main objective of this analyses it could be shown that parts with a high stiffness attached very far forward to the vehicle front can have an influence to the force criteria depending on the test procedure. In the FWRB the effects disappears after the filtering whereas the criteria of FWDB detects this local high stiffness. However in case of the towing eye it could be shown that the todays commonly used attachment does not influence the criteria of both test procedures. Furthermore it was shown that the presence of towing eyes may influence the deformation pattern of the car. Following that it is natural that the load forces may be different.

3.2 Cross Beam Height and Position Relative to Longitudinal

In general the topology of the crash energy absorbing structures is similar across all cars. As a result the topology of the primary energy absorbing structures (PEAS) is in almost every case as the following: crossbeam connected with crash boxes to the longitudinals. However there are cars that have other topologies of the PEAS (e.g. HONDA CRV has its cross beam below the longitudinal). The main objective of this study was to investigate the behaviour of those designs and to decide if those PEAS are appropriate in car-to-car crashes.

3.2.1 Modifications

Additionally to the basis configuration of the PCM (executive) five modifications were modelled. The modifications followed the goal of this study to investigate a PEAS topology where cross beam and longitudinals were not in vertical alignment. Table 2 lists the modifications and Figure 3.10 gives an overview about the different designs.

Table 2: PCM structural modifications

Modification (abbreviation)	Description
mod_1	Increase the vertical position of the longitudinals and cross beam until the vehicle fails the metric
mod_2	Lowered cross beam and variations of connections and stiffness of the structures (cross beam below and within main rails)
mod_3(_1/2)	Cross beam below main rails, but in front of them, different connection stiffness
mod_4	Lowered cross beam (misalignment of structures)
mod_5	Same configuration like mod_4, but placed as far forward as possible

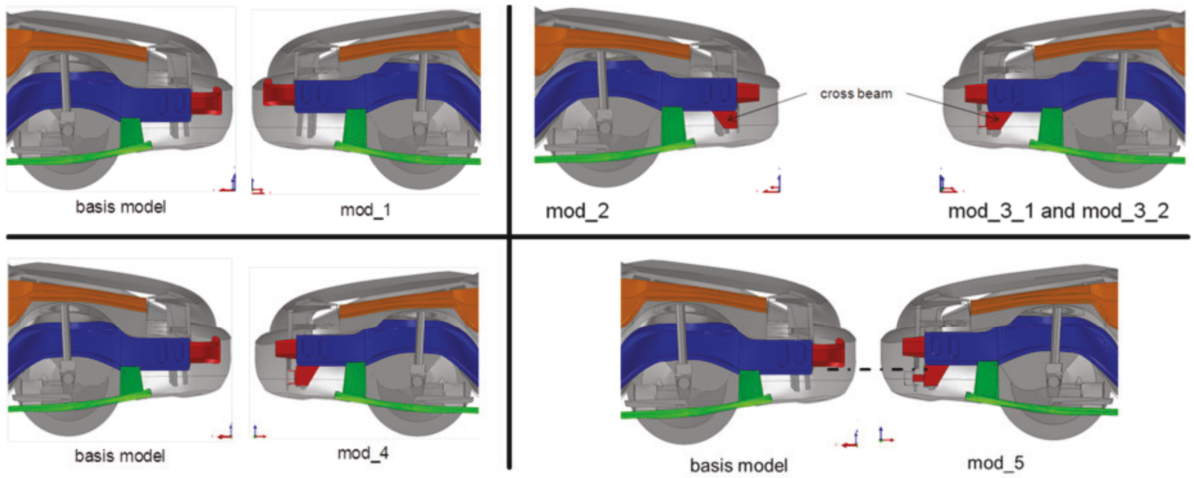


Figure 3.10: PCM structural modifications.

With respect to the LCW the different heights of the energy absorbing structures in combination with the alignment with the part 581 zone (common interaction zone) is shown in Figure 3.11.

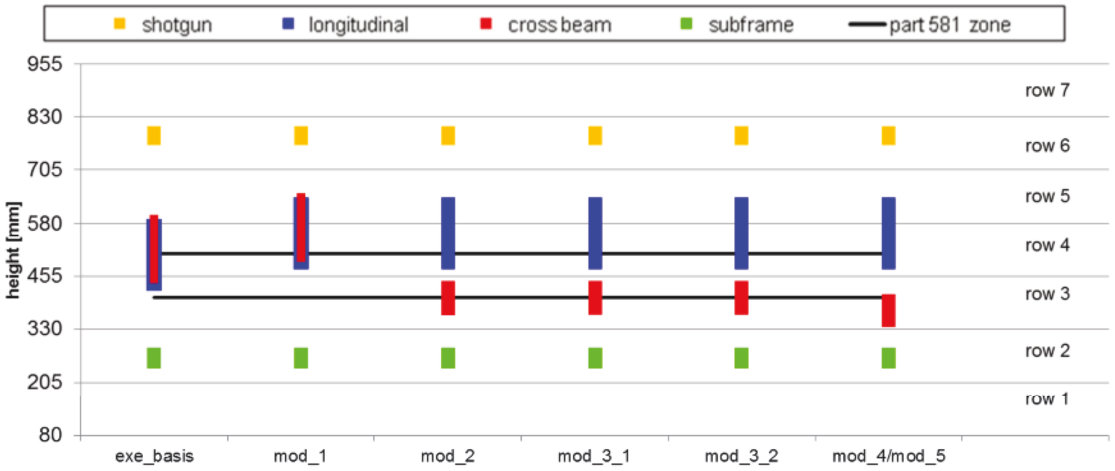


Figure 3.11: PCM – Height of energy absorbing structures.

3.2.2 Results

All described modifications were crashed against the FWRB and the FWDB. Different observations were made after the analysis of the both force criteria:

FWRB:

- The total wall force of 200kN was reached later (10ms ➔ 17ms) for the modifications compared to the basis model
- Modification 3 (compared to modification 2 the cross beam was placed in front of the longitudinals) could apply enough forces to pass the criteria, however the values were borderline between pass and fail
- Modification 4 as well as modification 5 could not apply enough forces to the LCW to pass the metrics

FWDB:

- The wall force limit of 400kN was reached later (37ms ➔ 44ms) and no engine dump occurred
- Only the basis model passed all proposed metrics, modification 2 only failed the force depended metric but passed the time depended ones (final metric proposal)

Comparing the results of the two analysis differences were identified in the deformation behaviour of the primary energy absorbing structures (PEAS). The deformable element forces the structures to deform earlier in the crash. Different bending modes and thus other reaction forces on the wall are the result.

Concluding the results of this analysis it was found that different structural designs were assessed by the two test procedures in different ways. While the FWRB assessed the weak structures as good enough to pass the metric the FWDB detected these design as not being appropriate. The main reason for that assessment was the honeycomb structure in front of the wall in the FWDB test configuration.

3.3 Step Effects

The objective of the FIMCAR full-width assessment procedures is to assess the car's safety performance with respect to structural alignment. For robust metrics the influence of impact alignment shall not result in step effects, i.e., small changes in the ride height causes large differences in the metric results. Here step effect means that the metrics shall reflect the cars structural topology in particular the PEAS. Furthermore the criteria shall correlate well with those structures and should let vehicles pass respectively fail the metrics depending on their performance in car to car crashes. The goal of this analysis was to investigate the robustness of the metrics in terms of step effects and to ensure the correct assessment of the metrics.

3.3.1 Methodology

The PCM large family car was used for this analysis and in a first step crashed against the FWRB and the FWDB. Therefore different ride heights were simulated by vertical translation of the barriers. Figure 3.12 shows the initial structural alignment with the LCW and gives an overview about the overlap of Row 4 (71%) and Row 3 (54%). A step size of 20mm was chosen.

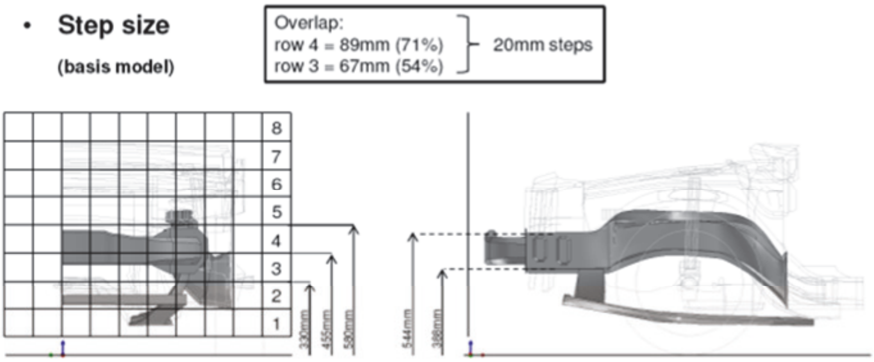


Figure 3.12: PCM – initial structural alignment with the LCW.

3.3.2 Results of FWB Tests

The results of the FWRB crashes can be seen in Figure 3.13. On the left side the figure shows the ratio of the Row 4 force to the sum of the forces in Row 3 and Row 4 (F4/(F3+F4)) and the overlap of the PEAS with the corresponding rows. The figure on the right side shows the individual row forces (Row 3 and Row 4) related to the geometry of the cars. A good correlation between the applied wall forces and the corresponding structural alignment with the loaded rows can be observed (left figure). Furthermore no strong step effects could be identified. The right figure shows the forces (e.g. force of Row 4 is zero if there is no overlap with a structure) depending on the overlap of the PEAS with Row 3 and Row 4.

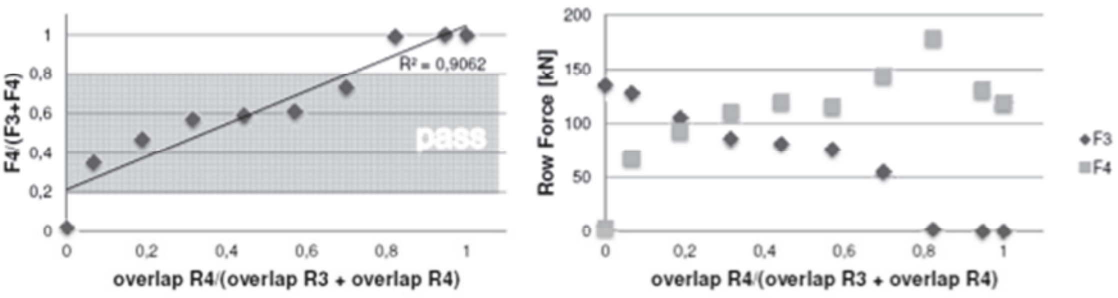


Figure 3.13: FWRB – Influence of ride height on forces in Row 3 and Row 4;), left picture shows the relation of Row 3 and 4 from the FWRB metric, right graph shows the individual forces of Row 3 and 4.

The results of the FWDB simulations are shown in Figure 3.14. With respect to the different metrics the figure on the left side shows the individual forces (Row 3 and Row 4) up to a total wall force of 400kN and the figure on the right side up to 40ms. Due to numerical problems of the FWDB barrier model the simulation with the PCM raised by 40mm terminated before 40ms. Thus no assessment by the time dependent metric could be made for this run. Both criteria show no step effects and a good correlation to the structural topology. However load spreading due to the deformable element could be observed.

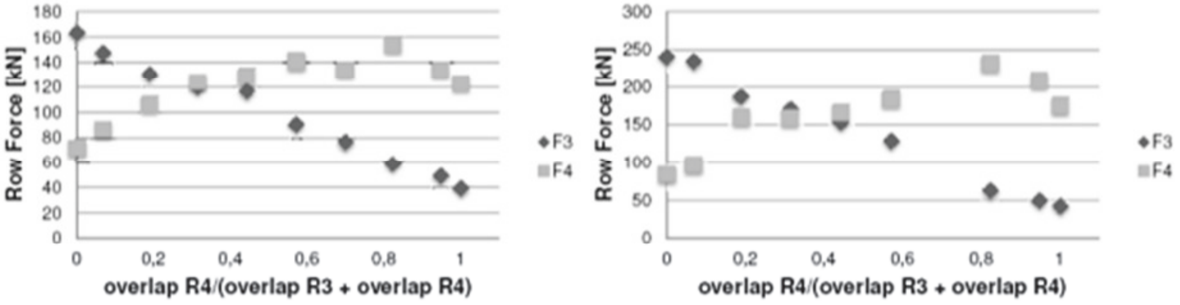


Figure 3.14: FWDB – Influence of ride heights on forces in Row 3 and Row 4; left graph shows the row forces up to LCW force 400 kN, right graph shows the row forces up to 40 ms.

3.3.3 Car-to-car Crashes

To compare the ratings of the metrics car to car crashes were conducted with respect to the test results of the FWRB. The following three configurations were simulated:

- Lowered vehicle that fails the metric against basis model → vertical offset -40mm
- Raised vehicle that fails the metric against basis model → vertical offset +60mm
- Borderline (lowered and raised) vehicles that passes the metric → vertical offset 100mm

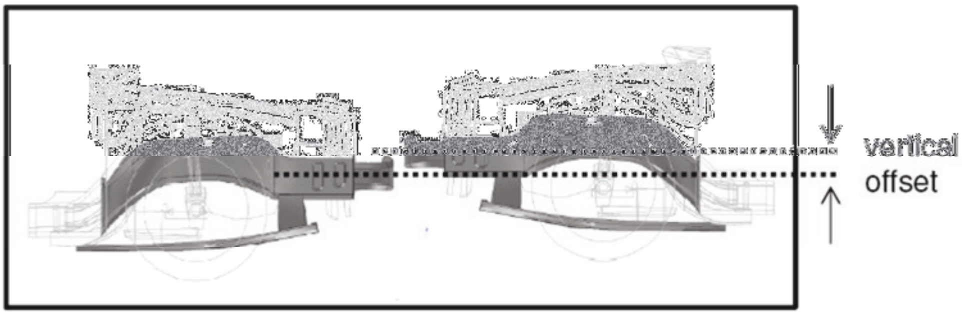


Figure 3.15: car to car crashes – definition of vertical offset.

The tests were conducted with 50% and 100% horizontal overlap and a closing speed of 112km/h (each vehicle with 56km/h).

The results of the full overlap simulations were that the overriding car had lower peak values for the deceleration of the cabin and the intrusions of the firewall increases of the underridden car. These trends could be validated by increasing the vertical misalignment of the PEAS. The more the misalignment increases the more increases the incompatibility.

For the 50% overlap simulations there were hardly any differences for the deceleration detected. No trends could be observed for the firewall intrusions. A comparison of the a-pillar intrusion showed higher displacements for the underridden car then for the opposing car.

3.3.4 Conclusions Step Effects

The robustness analysis of the FWB assessment metrics showed good results. Although the resolution of the LCW is limited (125mm x 125mm) no step effects could be observed within the given range. A good correlation of the measured forces and the structural alignment with the rows of the LCW could be verified. The car to car simulations indicate that cars that fail the metrics also perform worse in car to car crashes compared to those that pass the metrics. The identified thresholds of the different metrics seemed to work well.

3.4 Test Severity

As shown in the accident analysis of FIMCAR [Johannsen 2011] the main injury risk (MAIS2+) in frontal impact with more than 75% overlap occurs with a delta-v up to 52 km/h taking into account the exposure and the individual risk. Following this the capability of the FWB tests procedures in particular the FWDB was analysed regarding different test speeds. The main objectives of this study were to check if the metrics results are independent from the test speed within a given range.

3.4.1 Methodology

For this study the GCMs (GCM1B, GCM2A and GCM3A) and PCM (large family car) were crashed against the FWRB with 56km/h and FWDB with 40km/h, 50km/h and 56km/h.

3.4.2 Results

A final analysis of the assessment metrics showed that all proposed FWDB metrics worked well for different test velocities. However for the time dependent criteria with fixed limits were borderline due to the fact that the wall forces increase slower due to the lower test speed.

3.4.3 Conclusions Step Effects

The results of this analysis showed that the selected assessment metrics for the FWDB test procedure are independent from test speed in a range from 40km/h to 56km/h. A reduction of the test speed for the FWDB test to address the higher risk of MAIS2+ injuries seemed to be possible.

3.5 Other Use Cases for the FIMCAR Car Models

The models were used for several other applications in the project such as sensitivity analysis of different PDB metrics, PDB test severity analysis, assessment of lower load path designs etc. These investigations are reported in detail in the FIMCAR Deliverables D2.1 [Lazaro 2013/1], D2.2 [Lazaro 2013/2], D3.1 [Adolph 2013/1], D3.2 [Adolph 2013/2], D4.2 [Versmissen 2013].

4 SUMMARY

This section gives an overview about the two main car FE modelling approaches used within FIMCAR to investigate car-to-car frontal impact and corresponding test procedures that allow assessing self and partner protection. On the one hand the Generic Car Models (GCMs) were used, these models were developed originally within APROSYS by CRF and subjected to huge modifications and improvements for the goals within FIMCAR. The GCMs represent cars of three different vehicle classes with a generic structure and topology of the most common parts of the front end of modern cars. The level of detail is comparable with those of OEM models used for the product development process. On the other hand the Parametric Car Models (PCMs), developed by TUB, were used. These models are simplified models of three different vehicle classes. One of the main results of the simplification process was the separation of the energy absorbing structures of the front end. Due to the parametric design of the CAD model fast changes in the topology of the structures are possible.

Five chosen investigations were presented demonstrating a large field of applications of the both models. The first example shows the usage of the both models to investigate the influence of specific structures like the towing eye respectively its attachment to the full-width barrier metrics to avoid a wrong assessment by the developed metrics.

Different designs of the primary energy absorbing structures could be analysed by the PCMs. Structural modifications were crashed in full-width barrier tests and analysed with respect to their capability in car-to-car crashes.

The third and the fourth example show how the numerical models helped to develop the test procedures. The metrics were analysed regarding robustness to avoid step effects and to check the identified pass and fail thresholds. Furthermore the test severity was analysed with respect to a reduction of the test velocity and the effects to the assessment metrics.

The final example shows a sensitivity analyse of the vehicle parameters like mass, test speed and topology of specific structures for the PDB test procedure. 45 simulations were conducted to investigate the influence to the assessment metrics.

5 CONCLUSIONS AND OUTLOOK

Within the FIMCAR project a large test program was executed that was divided into physical and virtual testing. Two different FE model approaches were used to support the investigations. Depending on the approach different tasks were performed to answer open questions and improve the understanding of frontal impact. It could be shown that today the quality of the results of the virtual models is on such a high level that it could be used for research purposes. In that way the number of physical tests and therefore costs could be reduced.

The intension of different approaches follows the need of different levels of details. On the one hand simplified models like the PCMs can be used for the identification of the influence of different EAS topologies. Due to the relatively low number of elements they are suitable for high numbers of simulation runs. They are offering the possibility of optimising the structures for car-to-car crashes and for the assessment metrics. In that way the PCMs offer the potential to identify the best structural concept to improve frontal impact compatibility.

On the other hand the GCMs are closer to real cars and the level of complexity allows detailed analyses of the structural interaction of all parts of the front end. For the future the generic design offers the option to serve as bullet cars within the product development process by using them to improve the vehicle safety or in terms of virtual testing for homologation replacing the homogenous honeycomb barriers.

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