Parametric Modelling of Simplified Car Models for Assessment of Frontal Impact Compatibility

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ABSTRACT

The aim of the FIMCAR project (co-funded by the European Commission within the 7th Framework Programme) 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 is envisaged. However, car-to-car simulations with models of different car manufacturers are almost impossible because of confidentiality. In addition the detailed models of the car manufacturers are complicated to optimise for different assessment procedures and are consuming considerable computational efforts. In order to overcome these problems, parametric car models were built allowing fast modifications. By simplifying the models, computational efforts are reduced.

Due to the rapid increase of the calculation power the level of detail in car models has reached a very high level. At the same time the number of discretised parts drops and smaller structures are considered in the meshing process. However, only a few structures are mainly responsible for the frontal crash behaviour of the vehicle. A high variability of mounting positions, connections and stiffness of parts of a car's front–end offers a big potential in investigations of frontal impact vehicle structures. However, the modification of these criteria is time consuming, especially the modification of a given FE-mesh or geometry model.

The software SFE CONCEPT^{TM} offers the possibility to establish an implicit parametric car model in an easy and fast way. A variable geometric model is created by the specification of base lines and cross sections for the different parts. The modification of a structure with respect to connected parts is one of the advantages of SFE CONCEPT^{TM}. Through manipulation of the implicit parameters, new structure concepts and /or small variations of a part's dimensions can be established. After all the software is able to mesh the geometry and export the data for different solvers like LS-Dyna.

In that way it is possible to generate a manifold number of structures, in a fast and certain way which is necessary for the investigations of the influence of these structures in frontal impact compatibility. The set up of the FE model is adapted to the export data structure of SFE CONCEPT^{TM}. This way the models can be simulated directly after modification without further post-editing.

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 frontal impact 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.

Preliminary results of the FIMCAR project show that structural alignment including vertical and horizontal load spreading is crucial for the frontal impact behaviour in car-to-car accidents. In addition the compartment strength should at least be maintained at the current level and injuries resulting from high acceleration loading should also be considered.

2 SIMPLIFIED VEHICLE MODELS

One of the main requirements of the models is the lower calculation time compared to detailed OEM models. To comply with this requirement the PCMs (Parametric Car Models) were modelled with several simplifications. E.g., the rigid parts in the engine compartment (e.g. engine, battery, and gearbox) were merged to one part. The focus of the modelling of the PCMs was a realistic crash behaviour during the collision. Especially the following crash characteristics were respected; crash pulses, deformation behaviour of the front-end structures and the interaction of the energy absorbing structures during car-to-car crashes and car-to-barrier crashes. Figure 2.1 shows the front-end structures of the parametric car models.

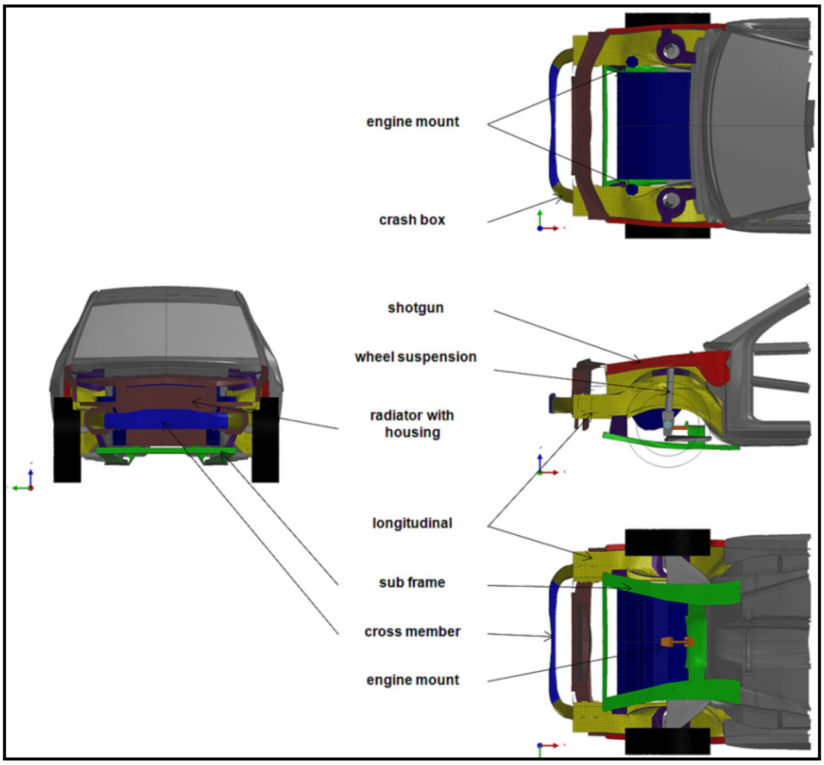


Figure 2.1: Front-end structures of the PCMs

The requirements of the topology of the models derive from the given usage. The PCMs were intended for use in different crash configuration, like crashes against a rigid wall with 100% overlap, offset crashes with deformable barriers and car-to-car- crashes. Each of these configurations requires several conditions:

- Load spreading into the rear car parts
    - The front-end structure consists of three different load paths. The primary load path is created through the longitudinals, the secondary one consists of the shotguns and the sub frame. The tertiary load path is generated through the block construction of the front wheels and the door sill.

- Load spreading into non-impacted structures
    - Cross beam and engine spread loads during offset crashes into non impacted structures of the frame. Furthermore cross beam and engine protect the longitudinals against buckling.

- Influence of the engine
    - The movement of the engine is controlled by typical engine mounts. A pre-located radiator with housing spreads the loads during a collision.

- Intrusions
    - To make a statement about resulting intrusions the bulkhead and the side frame are modelled with elasto-plastic materials.

Another main requirement was to represent the actual European vehicle fleet. Up to now three different vehicle classes were generated on basis of the parametric vehicle model. They were modelled with averaged values (vehicle length and width, wheel base and kerb weight) from four to six top sellers for every vehicle class, Table 2.1.

Table 2.1: 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

Furthermore the following numerical requirements were considered:

- Numerical stability
    - To ensure numerical stability the results of several initial calculations were investigated with respect to stable time steps, energy conservation and added masses. These analysed terms were in bounds of numerical simulation.

- Possibilities to interact with detailed OEM models
    - The setup of the PCMs ensures an easy implementation in the OEM models.

3 PARAMETRIC MODEL

The parametric models were generated with the software SFE CONCEPT^{TM}. This CAD tool offers the possibility to change the geometry of a vehicle through variation of parameters. These parameters can be divided into two groups. The first group is responsible, for the geometry of the several structures. Basically, a cross section in combination with a base line creates the structure. Through modification of the parameters which describes cross sections and base lines (dimensions, radiuses), the structures can be varied, Figure 3.1.

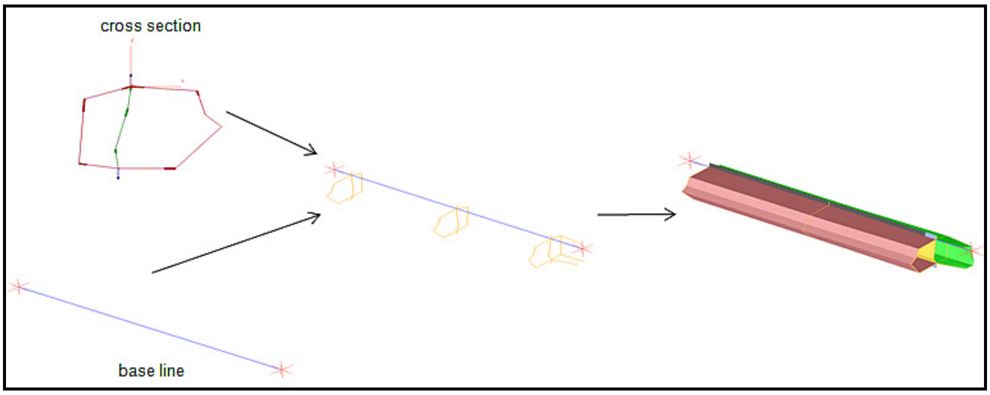


Figure 3.1: Design of variable structures

The second group of parameters is called "hard points". These hard points were defined at specific locations, like the connections of the B-pillar and the door sill, Figure 3.2. By sliding these points along pre-defined lines, it is possible to vary this connection. After that the software calculates automatically the new position and geometry of all influenced structures.

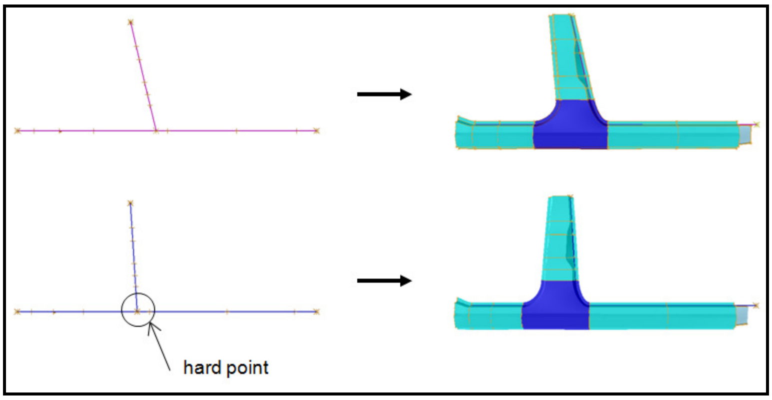


Figure 3.2: Variation of geometry with SFE CONCEPT^{TM}

The whole parametric model consists of 125 hard points. Chosen hard points are shown in Figure 3.3.

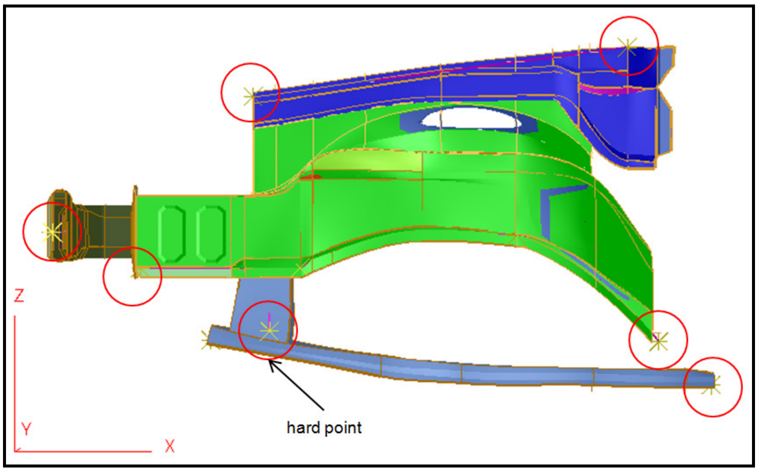


Figure 3.3: Chosen hard points of the front structures

In order to have a large representation of the European fleet, three different vehicle classes were modelled, Figure 3.4.

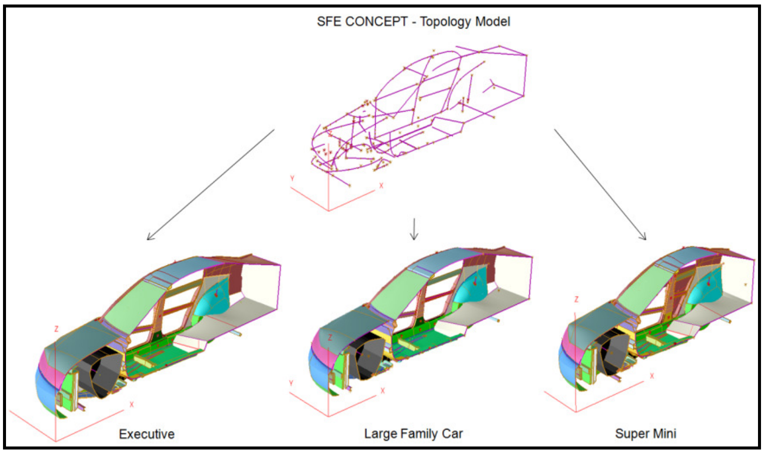


Figure 3.4: Generated vehicle classes

The variation of the different parameter groups has different influences on the vehicle behaviour. The main objective to modify parameters of group one is to change the stiffness of a part. A moved hard point (group two) modifies the topology of multiple structures. In that way it is possible to generate several load path concepts without deleting structures. Although, effects resulting from manipulation of a given structure concept, unexpected interactions of multiple modification is possible. An assessment of the effects cannot be made before a simulation run was done.

After the creation of the new vehicle topologies the software generates surfaces, which are the bases for the final meshing process. The software is able to generate an FE-mesh with respect to several pre-defined connection types, like welding points or joints. Finally this information can be exported in several crash solver specific codes, like LS-Dyna, for the calculation.

Looking at the compatibility issues defined by the FIMCAR project and the aims of the metrics of the different test procedures the following adjustments of the PCM are possible:

- Structural alignment
  - Location of longitudinals, crossbeam and additional load paths can easily be modified in order to study under/override behaviour

- Load spreading
  - Strength of the bumper beam can easily be modified in order to analyse the fork effect
  - Quality of the connection of the bumper beam with the longitudenals can easily be modified in order to analyse the fork effect
  - Width of the bumper beam (does it exceed the area between longitudenals or not) in order to analyse small overlap impacts can easily be modified
  - Z dimension of the bumper beam can easily be modified in order to analyse the load spreading of the structure
  - Additional load pathes can be added or removed and modified in order to analyse the load spreading of the structure

4 FE-MODELS

The setup of the model is adjusted to the content of the export files from SFE CONCEPT^{TM}. Thus, new changes in the geometry can replace the old ones and the model is ready for calculation. Further modifications, like variation of the stiffness of individual parts, can be realised easily, through changes in the part thickness. Just as well, it is possible to replace the materials of these parts.

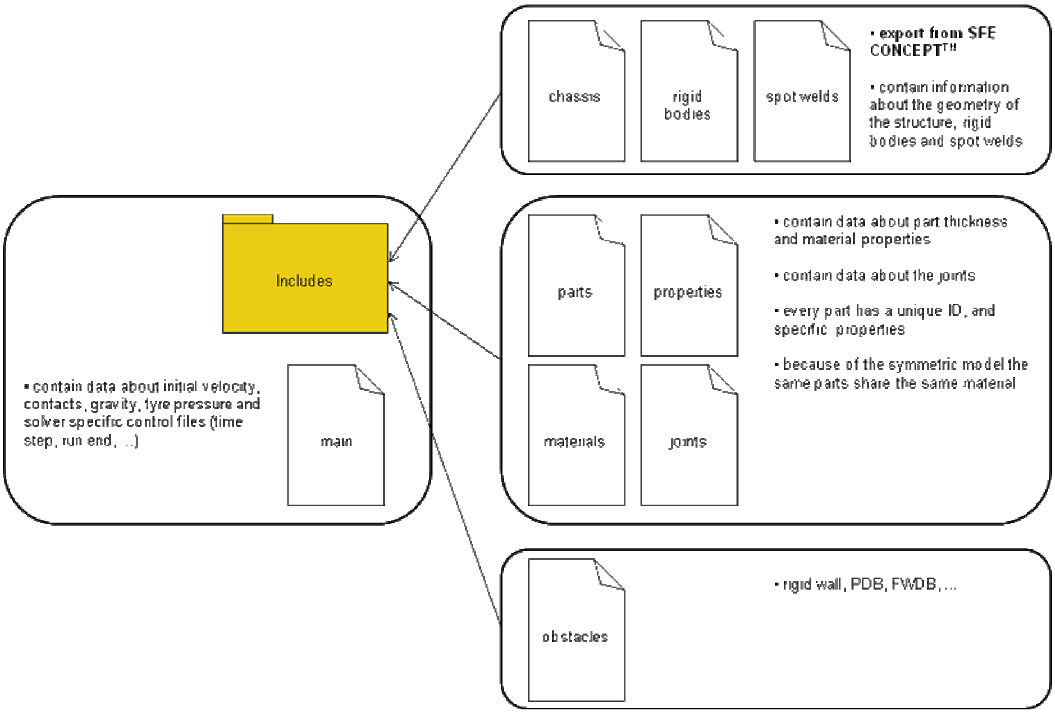
The modelling of the PCMs with respect to the content of the SFE CONCEPT^{TM} output required several simplifications. E.g., the PCMs had to be modelled with relative simple definitions for additional modules of the FE-model, like spot welds or joint definitions.

Due to the trade-off between calculation time and accuracy of the results the maximum edge length of the elements was set to 15 mm. This edge length showed to be a good compromise between level of detail (e.g. radiuses or beads) and the resulting number of elements or nodes, respectively. Furthermore this ensures a stable interaction with other numerical models. With respect to the dimensions of each vehicle class and the theoretical edge length of the FE mesh, the models consist of the following numbers of nodes/elements:

Table 4.1: Number of nodes and elements of the three PCMs

	Nodes	shell elements	spot welds
Super Mini	158,649	154,628	1,924
Large Family Car	181,081	175,910	2,252
Executive	205,317	200,097	2,440

Equally to the model setup the data structure of the models was adjusted to the exported data of SFE CONCEPT^{TM}. The include-file structure is the same for every vehicle class, Figure 4.1.



- **export from SFE CONCEPT^{TM}**
- contain information about the geometry of the structure, rigid bodies and spot welds

- contain data about part thickness and material properties
- contain data about the joints
- every part has a unique ID, and specific properties
- because of the symmetric model the same parts share the same material

- contain data about initial velocity, contacts, gravity, tyre pressure and solver specific control files (time step, run end, ...)

- rigid wall, PDB, FWDB, ...

Figure 4.1: Include-file structure of the PCMs

5 VALIDATION

The PCMs were validated for the collision with 56km/h against a rigid wall and 100% overlap. 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 most important criterion of the validation process was the crash pulse. For this purpose, the crash pulses of the PCMs were compared with corresponding crash pulses of real vehicles (in extracts for the Large Family Car model),Figure 5.1 and Figure 5.2. The focus of the crash pulse validation was, to model a vehicle which is comparable with vehicles of the same class. Due to this target, it was important that the pulses have the same characteristics, like pulse duration and average deceleration levels.

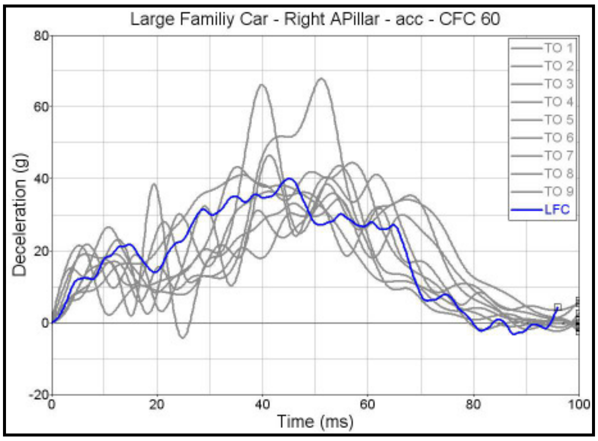


Figure 5.1: Comparison of decelerations for the vehicle class “Large Family Car” of different test objects (TO) with the PCM Large Family Car (LFC)

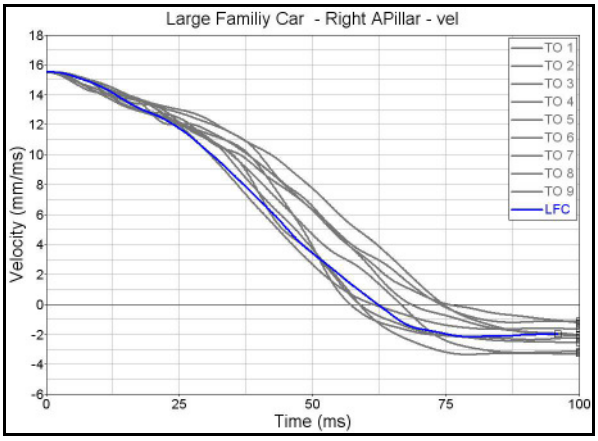


Figure 5.2: Comparison of velocities for the vehicle class “Large Family Car” of different test objects (TO) with the PCM Large Family Car (LFC)

The adjustment of the crash pulses was mainly influenced through the variation of the part stiffness. The geometry of the structures was only changed at the beginning of the validation process.

To assess the passive safety it is intended to use the OLC (Occupant Load Criterion). This criterion offers the possibility to rate the generated crash pulse with respect to generalised occupant decelerations. The generalised dummy forward displacement is considered to be 65 mm without deceleration and 235 mm engaged to the restraint system. After engaging to the restraint system the deceleration is constant until the overall forward displacement of 300 mm is reached. This constant deceleration is the OLC.

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.

6 SUMMARY

The presented model characteristics combine two different approaches. With the approach to simplify vehicle models to the relevant crash structures it is possible to simulate different crash scenarios in an economic manner. The conservation of the energy absorbing structures allows it to check all investigations in car-to-car crashes. Furthermore these simplifications are the basis for a parametric design of the whole vehicle model. With easy and fast modifications it is possible to generate a large number of different model variations. That offers the possibility to run sensitivity studies and to isolate specific influence values, e.g. for the frontal impact behaviour.

7 ACKNOWLEDGMENTS

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