20 Years of Crash Simulation at Opel - Experiences for Future Challenge

C.-S. Böttcher, S. Frik, B. Gosolits

Adam Opel AG, ITDC Rüsselsheim, Germany

Abstract:

About 20 years ago, the first full vehicle crash simulations were performed at Opel. Since then, the rapid development of all simulation tools as well as the tremendously increased computer power have established the capability to apply crash and occupant simulations as a main driver of the virtual development for vehicle safety. Especially during the recent years with an increasing economic pressure being present in the automotive industry, there was a strong request to enhance simulation methods as well as their standardized application during the complete vehicle development process. This was done in order to drive the vehicle development process towards an approach combining the strengths of virtual and hardware based development to save costs and time.

Besides the improvements of simulation methods, the paper will also focus on their impact on the change the vehicle development process has undergone during the recent years. It will also cover the achievements that have been made up to now as well as future requirements and challenges.

Despite all efforts and significant progress that has been achieved so far, there is still a high demand for further improvement, especially to achieve the capability to perform fully predictive simulations.

Keywords: Crash simulation, method development, vehicle development, new load-cases

1 First Crash Simulations

At Opel's International Technical Development Center (ITDC), the first crash simulations were performed back in 1985. In the beginning, only the deformation of single parts during the crash impact could be analyzed. Because of limited capabilities of the available pre-processors and the very incomplete availability of 3D surface data, it took about 3 months to generate the body-in-white part of a full vehicle model.

Although the first complete models consisted of only about 20.000 finite elements, they led to computing times of at least 3-4 days for a single crash event. Therefore, most simulations were restricted to prove the feasibility of simulating full vehicle crashes and to increase the correlation with physical tests rather than to give valuable inputs for design decisions.

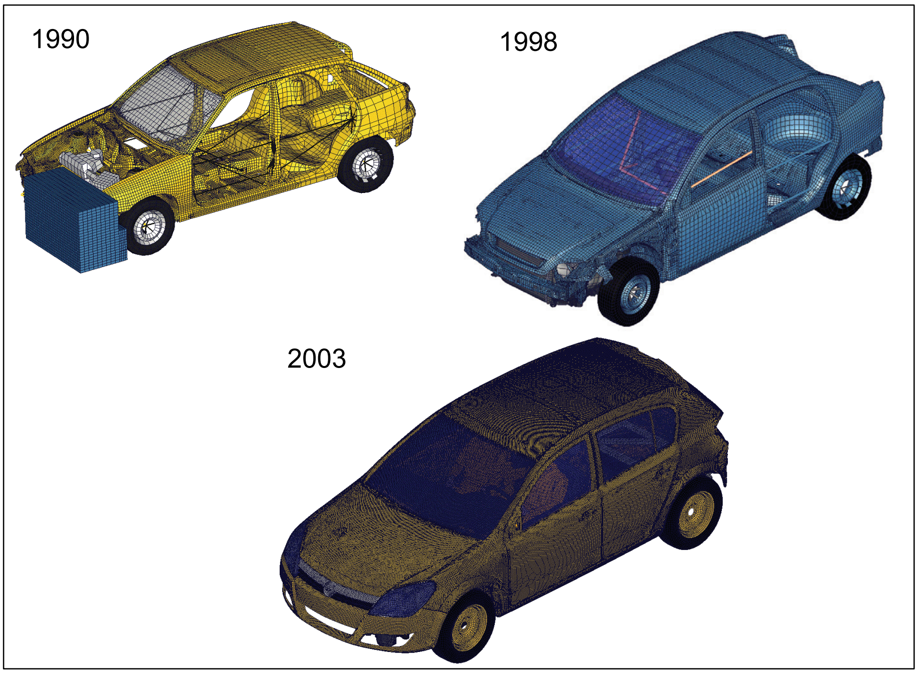

Fig. 1: Model comparison Astra 1990 - 1998 - 2003

The main break-through of the application of simulation techniques for vehicle safety development came in 1990. As the ordinary tests that were performed at that time did not disclose the relevant structural performance for typical accidents, the German car magazine “Auto, Motor und Sport” established a consumer test using a rigid offset barrier. This test led to a significantly increased loading of the vehicle structure. As the Astra project was relatively close to start of production, there was almost no time to develop counter measures by means of hardware tests. Thus, the existing simulation model was used to analyze the structural performance and to assess the individual design proposals. Within a relatively short period of time, it was possible to develop successful measures by means of simulation that could also be confirmed by the following physical hardware tests.

The changed role of crash simulation is also reflected in the organizational structure. In the beginning, the simulation group was part of Advanced Engineering. Today it is an integral part of the Product Engineering organization in order to guarantee the full involvement in the daily development decisions.

2 Improvement of Simulation Capability

2.1 Modeling techniques

In the recent years, the geometric representation of all vehicle components has been improved tremendously. As a main enabler, DMU (Digital Mock-Up) systems were established, providing regularly updated geometry and material information of the complete vehicle. Especially the progress regarding the available computer hardware allows a much finer mesh resolution and thus the wide application of automeshers. However, all parts determining the deformation and energy absorption behavior during the respective crash events must still be meshed with higher care in order to achieve reliable simulation results.

Another big advance in crash modeling that was established a couple of years ago, was the capability to use mesh-independent spotwelds. This feature allows the independent modeling of sheet metal parts and is a key enabler for the parallel and thereby efficient generation of component meshes that can then be assembled almost automatically to full vehicle simulation models. By this means the modeling efforts could be reduced significantly while providing higher geometric mesh fidelity and higher quality meshes.

2.2 Model contents

A few years ago, crash simulations were mainly performed to support the structural development of the body-in-white. Today, crash simulation has to cope with all components that have a direct or indirect impact on passenger or pedestrian safety. As for example, the dummy performance is of high interest, the models have to include the complete restraint system and interior components that might interact with the dummies during the crash event. In order to be able to estimate their performance with the required level of accuracy, all these components must be modeled very thoroughly. Especially door trims that consist of various materials connected by different connector elements are still a challenging task to simulate.

As an example, Fig. 2 shows the level of detail that is captured in the crash simulation models used for the development of the 1998 and 2003 Opel Astra. Besides the interior, significant modeling effort is spent on the engine compartment and the suspensions.

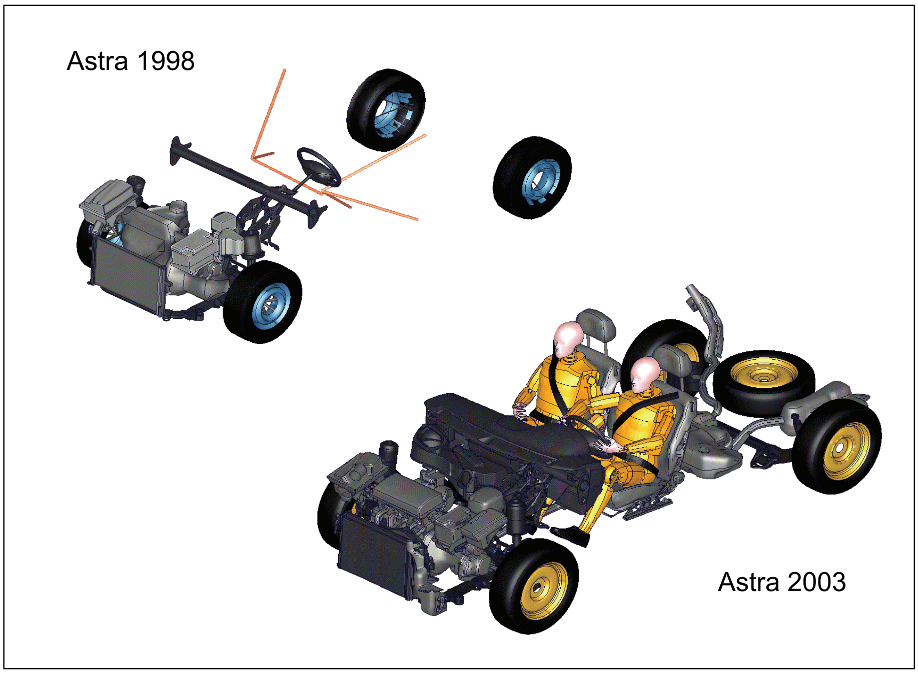

Fig. 2: Comparison of crash model contents for 1998 and 2003 Opel Astra

By adding all those parts to the simulation model, the model size went up from about 120.000 elements for the 1998 Astra up to about 1.400.000 elements for the 2003 Astra.

2.3 Material behavior

In current vehicles, high strength steels are applied widely to achieve the desired structural performance at a reasonable weight. These materials often show a significant work-hardening effect. This means, that the strength will be increased during the manufacturing process. Therefore, an important step to improve the representation of material properties was the implementation of forming data (local thickness and plastic deformation) to all crash simulation models. This measure led to tremendous improvements regarding the prediction of local deformation patterns that could also change the overall crash performance [1].

At ITDC, all components that are part of a load-path for a crash load-case are now provided with forming data on a regular basis. In order to get the required information in time, a particular process was established together with manufacturing engineering to couple die development and crash simulation necessities. As an example, Fig. 3 shows the parts of the current Opel Zafira carrying forming data.

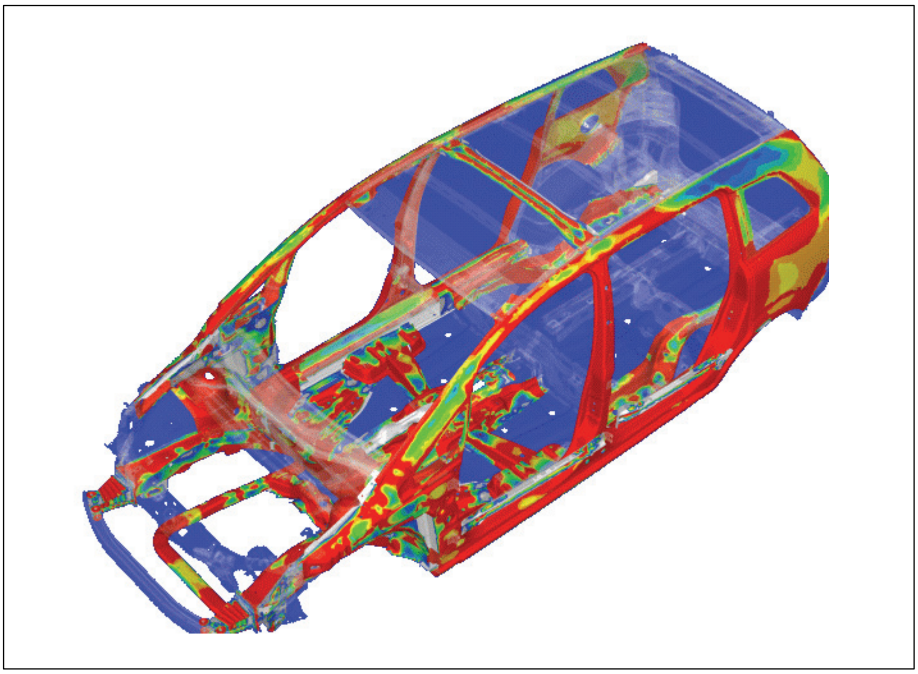

Fig. 3: Application of forming data to full vehicle crash models

In addition to that, significant improvements have been achieved to represent the characteristics of polypropylene, foam, and rubber materials [2]. This led to a much better representation of door trims, bumper foams, and engine mounts, and many other parts.

2.4 Computational resources

Of course, the increased model fidelity and wide application of crash simulation as a daily development tool was only feasible because of the tremendous increase of the available CPU capacity. Fig. 4 shows the normalized CPU capacity that has been available mostly for crash simulation purposes at ITDC.

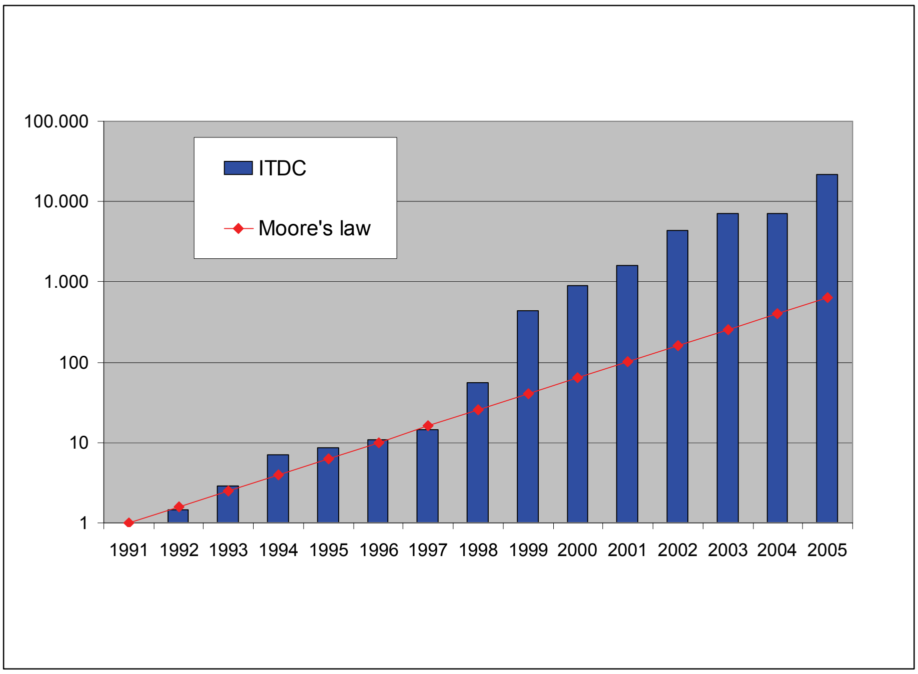

Fig. 4: Available CPU capacity at ITDC

In order to cope with the requirements that are raised from vehicle development the number of CPUs as well as their speed had to be increased significantly. As the computing performance of LS-DYNA does not speed up linearly with the number of applied processors, a trade-off between computing speed and throughput must be set. Therefore, the required speed is mainly driven by the model size whereas the number of CPUs reflects the number of simulation runs that need to be performed during the vehicle development projects.

3 Software

Until 2001, all crash simulations at Opel were performed with Radioss. In order to be able to exchange simulation models and share simulation knowledge within the corporation, it was decided to switch to LS-DYNA, the code that has already been used in other General Motors divisions.

The process took several years from the first tryouts to the final complete migration. There were a couple of issues that had to be overcome step by step. Amongst others, the hardest problem to solve was a much too soft structural response of the LS-DYNA model compared to the respective Radioss model. There even the LS-DYNA experts could not give a quick answer. Only through months of working with the tool, ideas were found to reach a stiffer response, such as:

- Solid spotwelds
- Refined mesh
- Including of mapping information
- Fully integrated elements for main load-paths
- New material laws

After going through those and other improvements we had to rethink the modeling strategy. Many problems we faced were caused by the traditional practice established through Radioss. Having finished the migration, the simulation results had an explicitly better correlation with hardware tests.

4 Impact on the Vehicle Development Process

During the recent years there has been an increased pressure to drive vehicle development from a mainly hardware based approach towards virtual development in order to save both costs and time. For example, it was decided to perform the development of the current Astra without any hardware for the so-called structure car. This was only possible because the simulation capabilities had already reached a level that allowed this step without jeopardizing the complete vehicle project.

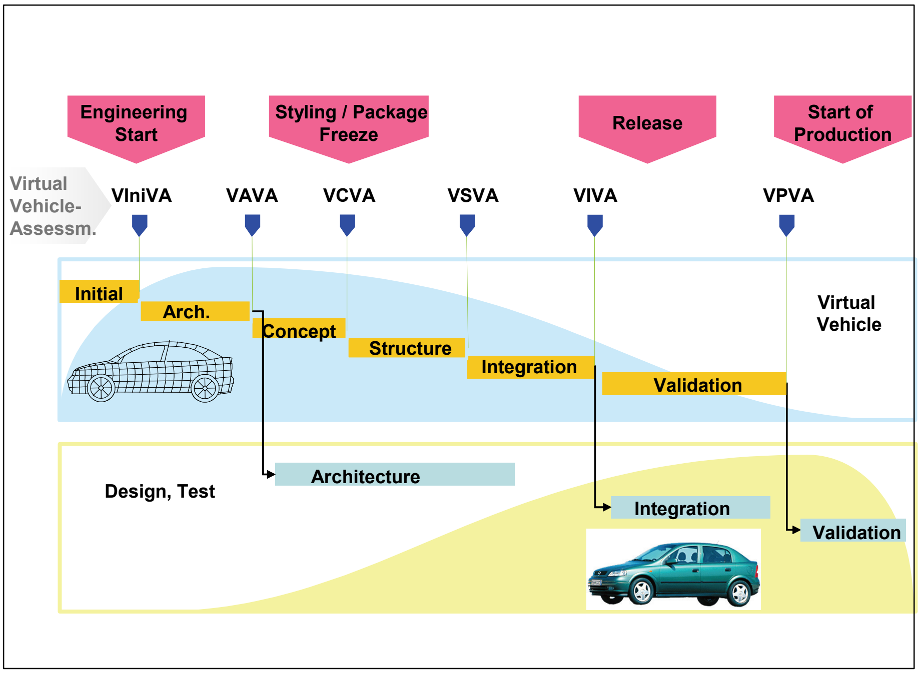

Fig. 5: Interaction of virtual and hardware based vehicle development

This change required the broad application of simulation activities to ensure the maturity of the vehicle concept. In contrast to the past, when simulation activities were mainly performed on single requests, these activities are now following a detailed standardized simulation plan. This plan defines exactly when to simulate which load-cases with which level of detail.

In addition, the role and necessary skills of the simulation engineers altered considerably. A few years ago, solely simulation specialists were required to set up simulation models, perform simulation runs, and analyze the results. Today, simulation engineers take over the role of development engineers so that they also need to have know-how e.g. about manufacturing requirements and the interaction of the respective parts with their environment in the vehicle. This is mandatory to enable them to come up with feasible proposals in order to minimize the number of required iteration loops.

In the meantime, virtual and hardware based development activities are completely integrated. So called virtual milestones were introduced prior to the respective hardware build stages in order to prove that the vehicle concepts fulfill the performance requirements. Without proving the maturity of the virtual vehicle expensive prototype tools would have been released without any chance to pass the subsequent hardware tests successfully.

At Opel, this process was strongly supported by the restructuring program “Olympia”. Part of this program was the analysis of the whole vehicle development process. Therefore, all hardware tests and their deliverables were examined whether they could be supported or replaced by means of simulation. In case of missing simulation capabilities and tools, detailed action plans have been defined to overcome this drawback. These plans cover the improvement of simulation capabilities, the implementation of substitute tests like component tests as well as tests using cheaper hardware. Of course all activities have to ensure, that this strategy does not lead to additional development risks and has no negative impact on product quality or reliability.

Because of the complexity of today's vehicles a significant part of the development work is performed by development or component suppliers. In order to achieve an efficient development process, their activities must be integrated as well. This causes the necessity to exchange simulation models and results throughout the development process. Therefore, so called CAE exchange points have been introduced to make sure that both OEM and suppliers have the most recent component and full vehicle models available to do their part of the virtual development.

Besides this, today's development timings are only feasible, if validated component models are provided by the system supplier so that they can directly integrated into the OEM's full vehicle models. At ITDC this is defined in certain documents, describing when which models need to be delivered. This also includes modeling details, simulation code and the component validation tests that are needed to prove the functionality of the models. By this means, it is assured that the component models can be integrated with comparably low effort. In return, the system suppliers receive full vehicle models in order to do their virtual component confirmation.

5 Simulation applications

5.1 Standard load-cases

Today, the application of crash simulations is an integrated part of standard vehicle development projects. At the beginning of each project it is defined, when each load-case needs to be simulated. This includes all load-cases assessing the passive safety performance like high speed crashes for front, side, and rear impacts as well as occupant and pedestrian protection. As there is an aim conflict of high speed and low speed requirements it was decided, that the crash simulation group at ITDC should also focus on low speed crashes that are mainly performed for insurance classification tests like the AZT test.

5.2 Airbag sensing system development

As the number of physical prototypes for structural development has already been reduced significantly, the considerable amount of vehicles that is still needed for airbag sensing algorithm development has come into the focus. In the past with only central sensing systems being available, the sensing systems mostly relied on high frequent acceleration signals. Thus the application of finite element based results for sensing system development was not possible and it would have caused an extremely high effort to provide the signals with the required accuracy.

This situation has changed with the availability of up-front sensors leading to the opportunity to base the airbag deployment on velocity deviations between up-front and central sensors. As velocity signals can already be provided with the required accuracy, it is possible to apply simulation results to develop the sensing system algorithm [3]. However, the final sensing system calibration still needs to be done based on hardware test results in order to capture the final physical vehicle performance and to cover all kinds of misuse conditions.

As the performance of the vehicle structure during the crash event has a significant impact on the sensing system performance, it is important to keep track of its performance throughout the structural development. Therefore, all simulation runs that are performed during the vehicle development are set up such that they also deliver sensing signals. Structural changes that are unfavorable for the sensing performance can easily identified and avoided. Besides this, the simulation results can also provide important information on the best sensor positions by tracking the signals at all potential locations.

6 Future Trends

In order to cope with the further reduced number of physical prototypes, there is an increased need for capability growth of the applied simulation methods. In case further complete hardware stages should be eliminated, there will be a strong necessity to perform fully predictive crash simulations. On the other side, all hardware tests will need to be performed with more advanced test equipment in order to get as much information as possible out of the remaining tests. In addition, more component tests will be necessary in order to provide the basis for sufficient validation of simulation models.

Additional simulation load-cases caused by upcoming new legal safety requirements (e.g. Pedestrian Protection Phase 2) and consumer tests are to be expected. Besides this, the application of simulation techniques for the development of all airbag sensing systems will also lead to a significant increase in load-cases.

In order to be able to provide all necessary simulation models in time, additional efforts need to be undertaken to improve and accelerate the setup and especially the handling of models and results. Here the meshing of surface data has already been improved significantly, so that it requires much less time than in the past. However, the effort for model assembly and model handling that is required to assess the structural performance for such a large number of load-cases must still be decreased considerably.

First attempts have already been undertaken to apply simulation methods for type approval purposes. As an example, the ECE R21 (interior protection) regulation allows the partial substitution of physical hardware tests by simulations. Simulation results may be used to determine the worst case scenario that is then tested by hardware tests. It ca be expected, that additional regulations will include the same opportunity once the simulation capability is increasing furthermore.

In order to cope with this situation, completely predictive simulations will be necessary. This will require further essential improvements of modeling and simulation techniques, especially in the following areas.

- Material models for <u>all</u> crash relevant components (especially all non-metallic materials) must be available.
- These models must also be capable to predict material failure.
- Improved representation of connector elements, e.g. spot welds, MIG and laser welds, adhesives.
- More robust dummy models showing improved correlation of injury values with respect to hardware tests and additional information about dummy response.

7 Summary

During the last 20 years, the application of crash simulations has undergone tremendous changes. This applies for both modeling techniques as well as for the simulation tools. Today, crash simulation is directly involved in the daily vehicle development process providing the basis for all major design decisions. As the simulation capabilities are evolving more and more components can be simulated and thus be influenced by crash simulation results.

Although the past development has reached a level, where the application of simulation tools is able to provide significant contributions to vehicle development, there is still a lot of room for improvement on the way to a more comprehensive virtual development.

8 Literature

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