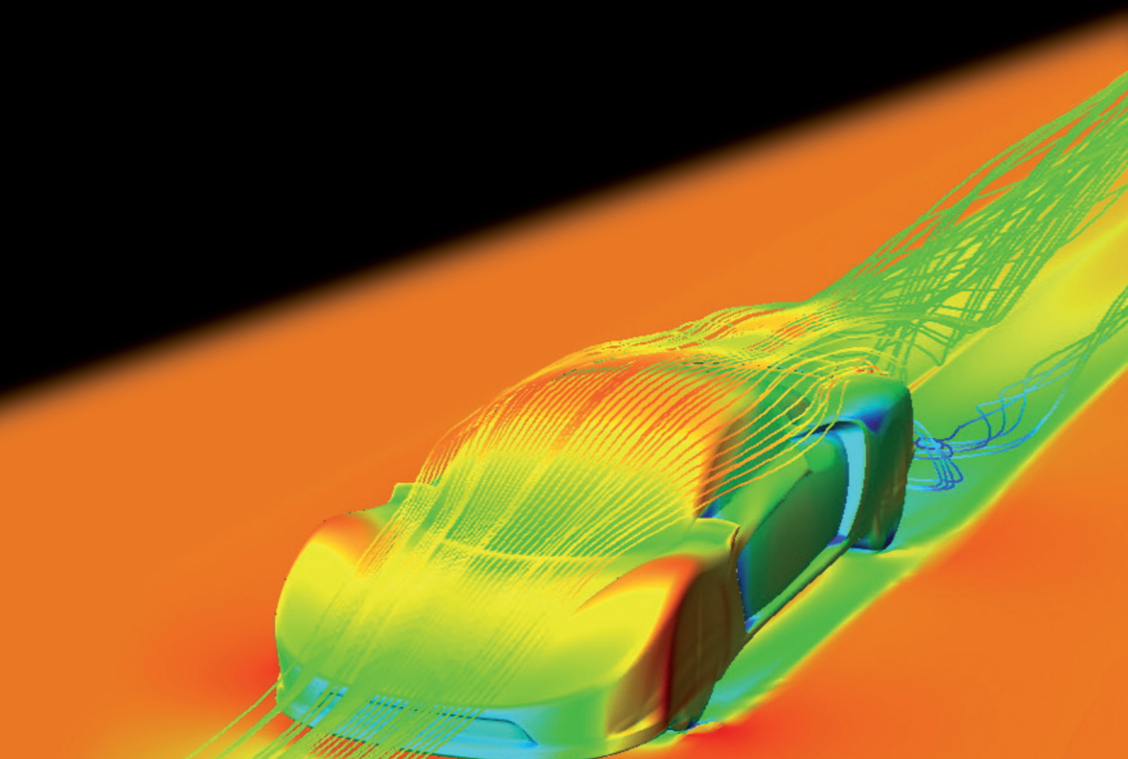
autosim

Current & Future Technologies in Automotive Engineering Simulation (CAE)



SIXTH FRAMEWORK PROGRAMME
PRIORITY [6.2]
[SUSTAINABLE SURFACE TRANSPORT]
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NAFEMS
a NAFEMS Project

Current & Future Technologies in Automotive Engineering Simulation (CAE)

Developed by the AUTOSIM Consortium

www.autosim.org
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Managed by NAFEMS and CAEvolution

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And the Technology Leaders:

Jean-Marc Crepel	Renault
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CAEvolution	*EnginSoft*	*Fundación LABEIN*
Herbertus	*NAFEMS*	*P&Z Engineering*
Renault	*TRL*	*VIF*

The other Consortium Member Companies were:

ABAQUS Europe	*Arsenal Research*
CADFEM	*COMAU*
Componenta Pistons	*CD-adapco*
DYNAmore	*EASi Engineering*
Faurecia	*IMAMOTER*
INPROSIM	*LMS International*
MECAS ESI	*MICADO*
MSC.Software	*Pankl Drivetrain Systems*
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TWT	*University of Manchester*
Volvo	

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Contents

Executive Summary

Thirty-two of Europe's leading automotive companies joined forces to launch the AUTOSIM project. This project, funded by the European Commission, cost 600.000 Euros, and lasted three years (September 2005–August 2008). It was managed by NAFEMS and CAEvolution.

The intent of AUTOSIM was to provide conceptual contributions that will enable the entire European automotive industry to make more effective use of engineering simulation techniques, particularly in structural analysis and computational fluid dynamics.

The project consortium included OEMs, Tier 1 and Tier 2 suppliers, consultants, researchers, and software developers. AUTOSIM had two complementary aims: firstly, to develop Best Practice, and secondly, to identify the most promising potential Breakthrough Technology (please review appendix 1—Glossary of Terms).

These aims and objectives have been examined under three following key technology areas:

- **Integration of simulation into the development process**
- **Materials characterisation**
- **Improved confidence in the use of simulation**

During the project, the members of the **AUTOSIM** consortium reviewed the current analytical procedures and research strategies and developed a preliminary set of guidelines for Best Practice and Breakthrough Technology. They consulted with the wider automotive industry worldwide to gain feedback on the preliminary documents in order to produce final findings. These findings will be disseminated internationally throughout the automotive industry.

The general objectives of **AUTOSIM** were as follows:

- **Facilitate the use of advanced simulation and data management and its integration into the design process.**
- **Improve the quality, confidence level, and robustness of modelling and simulation.**
- **Investigate the use of different, relatively new materials for different applications.**
- **Investigate material laws and material data in different design stages.**

- **Improve technology and the transfer of knowledge (training programs and education).**
- **Identify technology gaps and areas where further research is needed.**

With these aims in mind, **AUTOSIM** should make a substantial contribution toward advancing design techniques by increasing the efficiency and quality of simulation.

This report makes continued references to the strong interrelationship among the three key technology areas because:

- Quality of **material data** affects **confidence.**
- Effects of **material law selection** impacts **integration.**
- Model sizes must be balanced within accuracy, predictability, and cost, bridging the gap between **integration** and **confidence**.

1. Introduction

Today more than ever, the automotive industry has to cope with the following obligations (Ref. [1]):

- **To push innovative technologies**
- **To reduce development times**
- **To reduce costs**

These obligations must attend to and provide improvements in the following:

- **Safety (e.g. pedestrian protection and occupant safety)**
- **Environmental Protection (e.g. reducing CO_2 emission)**
- **Handling and Comfort (e.g. vehicle dynamics, vibration comfort, and acoustic properties)**

Computer Aided Engineering (CAE) tools play a key role in creating an improved design by simulating and analysing new vehicle concepts intended to fulfil these requirements. They enable optimum use to be made of information in the various design phases, from the conceptual design phase to the detailed series-development phase.

Although the design and validation process differs from company to company, the importance of early functional coverage is universal. In the early development phase, there is an emphasis on fast evaluation of different concepts. Quickly and accurately understanding relative trends is most important. In this design phase there are frequently no CAD models available. By the detailed series-development phase, CAE models used for prognosis must be highly accurate because, in this phase, relative results are no longer sufficient. Results must be absolute.

Therefore, in 2005 NAFEMS (www.nafems.org) proposed and initiated a project with the aim of reviewing the current use of CAE and studying ways to improve its use.

This was the start of the AUTOSIM project (AUTOmobile industry SIMulation), which began on 1 September 2005. 32 companies across Europe — including Renault, Peugeot, Volvo, Bosch, and P&Z—joined the project consortium (see www.autosim.org).

The aim of AUTOSIM was to focus on three topics. These were as follows:

- **Integrating Simulation into the Development Process**
- **Materials Characterisation**
- **Improving Confidence in the Use of Simulation**

The overall goal was to identify **Best Practice (BP)** and **Breakthrough Technology (BT).** Because designers may have different interpretations of these terms, the consortium suggested the following definitions:

- **Best Practice (BP):** How we currently make the best use of available technologies and procedures to tackle engineering problems.
- **Breakthrough Technology (BT):** Novel or revolutionary technologies and procedures needed to solve engineering problems successfully in our vision of the future.

During the AUTOSIM project a series of workshops were held in which speakers were invited to present on BPs and BTs in the three AUTOSIM discussion areas of Integration, Materials and Confidence. The agenda for these workshops is presented in Chapter 6 of this report and further details on some of the presentations given at the workshops can be found at www.autosim.org/meetings

2. Awareness Statement

The participants of the Autosim project recognize and acknowledge the importance of other topics, which could not be covered within the Autosim project due to limited project time and funds. Example of topics not covered include:

Performance

Grid Computing with Cluster Computers will help to support the trend to more CAE simulations in the coming years. Therefore any improvement in computer performance is highly welcome.

Human Factor

The envisaged paradigm shift from a CAD-centric to a CAE-centric product development process will have an effect on the people involved in that process. It is of vital importance for a successful implementation of required changes to the product development process and associated methodologies that people affected by the change will be involved and will buy-in as early as possible.

Mechatronics

Mechatronics is the synergistic combination of mechanical engineering, electronics, control engineering, and computers, all integrated through the design process. The increasing number of mechatronic systems will strongly affect the application of suitable simulation methods and their integration into the design process.

Computational Electromagnetics

Computational electromagnetics, computational electrodynamics or electromagnetic modeling refers to the process of modeling the interaction of electromagnetic fields with physical objects and the environment. The importance of electromagnetic simulation in the automotive industry is increasing as the communication demands become more varied and complex.

3. CAE at Different Stages in Product Development

(Ref. [1], [2], [3], [4], [5], [6], [7])

A wide range of technologies are used during different design phases in simulation driven product development, including structural finite element analysis, acoustics, crash analysis, fatigue and failure analysis, and computational fluid dynamics. When CAD geometry is available during design refinement and function evaluation (Fig. 3.1), it is used to validate simulation results against tested physical prototypes.

However, this process (create the geometry, then analyze and compare the simulation with a test), is much too slow and costly for concept design. Competing manufacturers now need to apply simulation at the concept stage so that they can explore design alternatives, detect design flaws, and optimize product performance before detailed designs or physical prototypes are created.

During this phase, designers have more freedom to make design changes than they do during later design stages—and changes can be made at a lower cost. CAE tools can help to expand product knowledge significantly. Design alternatives can be assessed, verified and/or validated more easily. Risk assessment—allowing for the robustness of design concepts—can therefore be alleviated. Often simple models bearing little resemblance to the final CAD model can provide more insight in a shorter period of time than can a more complex and highly detailed solution.

Of course some design changes will still occur during physical testing, but the number of costly and time consuming changes can be reduced by orders of magnitude. This is also reflected by the “rule of ten” which states that the cost of fixing a problem that designers should have corrected in the planning and concept phase increases10 times if the company discovers it in the testing phase, 100 times if it finds the problem in the production phase, and 1000 times if the customer discovers it.

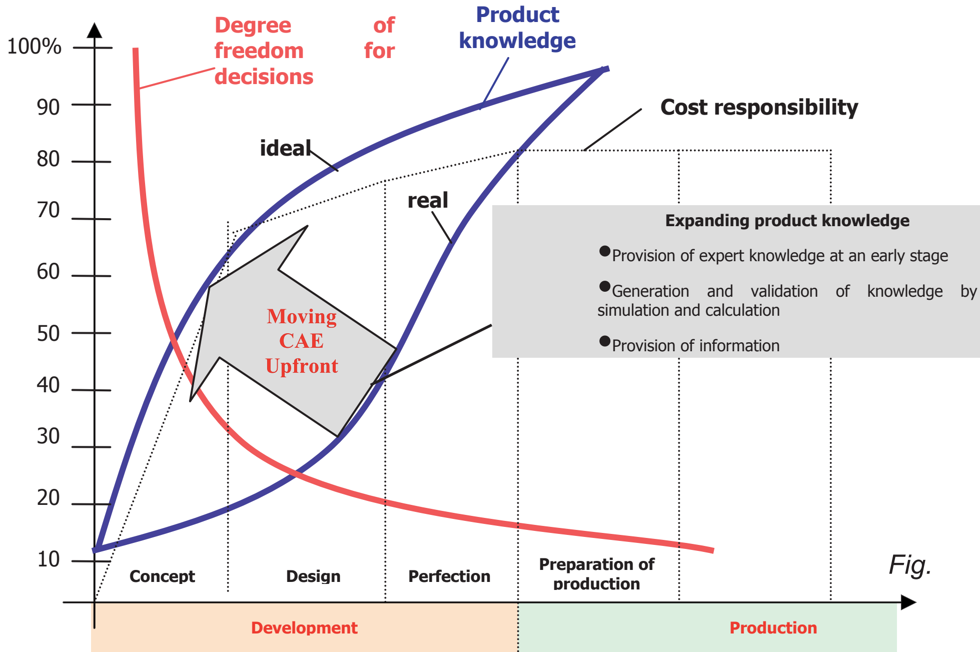


Fig. 3.1: The value of applying CAE methods early in the design process (courtesy of SFE GmbH; Ref. [2])

Currently, by the end of the initial development stages (Concept Design) around 70 percent of the final product cost has been committed, whereas product performance knowledge is still limited to approximately 20 percent. Furthermore, a product that is six months late to market, even if on budget, will generate an average of 33 percent less revenue during a five-year period than it would if the company had introduced it on time. So whatever can be done to improve product knowledge early in the design process will help companies to cut cost, reduce time-to-market, and increase quality.

Although the design, verification, and validation process differs from manufacturer to manufacturer, the importance of proving a concept at the earliest possible stage is becoming crucial. The need for early CAE in concept design inevitably changes the traditional design and drafting process, leading to a paradigm shift.

Geometric models must be flexible enough to adapt to dynamically changing functional requirements. It is crucial to generate and modify models, without CAD availability, quickly. This could be achieved by using implicitly parameterized models. Morphing is not sufficient.

These functional requirements are determined by many complex factors. Multiple disciplines, such as crash and NVH (Noise Vibration Harshness), must be considered to resolve target conflicts. Meanwhile, tools are available to allow Process Integration and multi-disciplinary simulation and/or Optimization (PIDO) and Multi-Objective Optimization during the concept phase.

4. The AUTOSIM project (Ref. [8])

4.1 The Three Selected Key Technology Areas Within the AUTOSIM Project: their Interdependencies and Overlap.

AUTOSIM was initiated based on the findings of the EC funded project FENet (Ref. [9]). Based on this project, three key topics were identified to be considered in more detail.

These topics were:

- **Integration of Simulation into the Development Process**
- **Materials Characterisation**
- **Improving Confidence in the Use of Simulation**

Although Integration, Materials, and Confidence are very important by themselves, they cannot be considered as stand-alone items because they exhibit a strong interrelationship and interaction (Fig. 4.1.1).

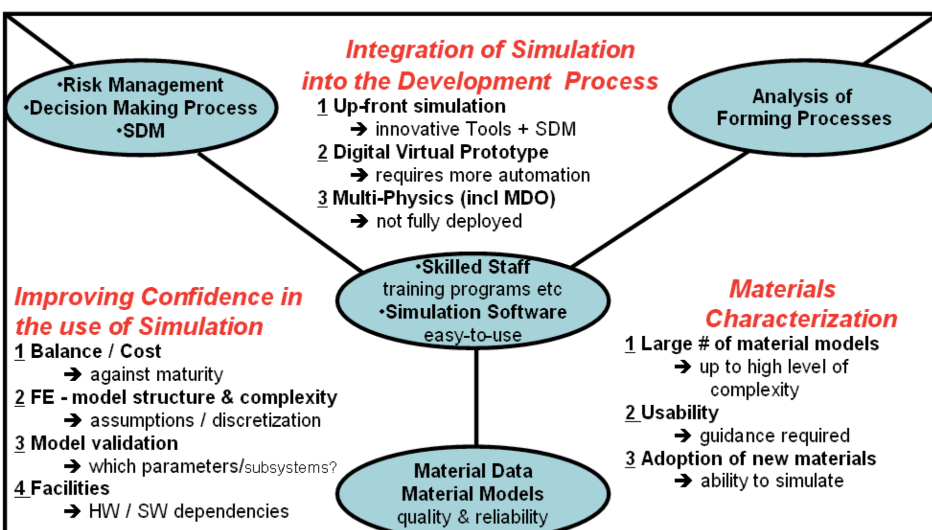


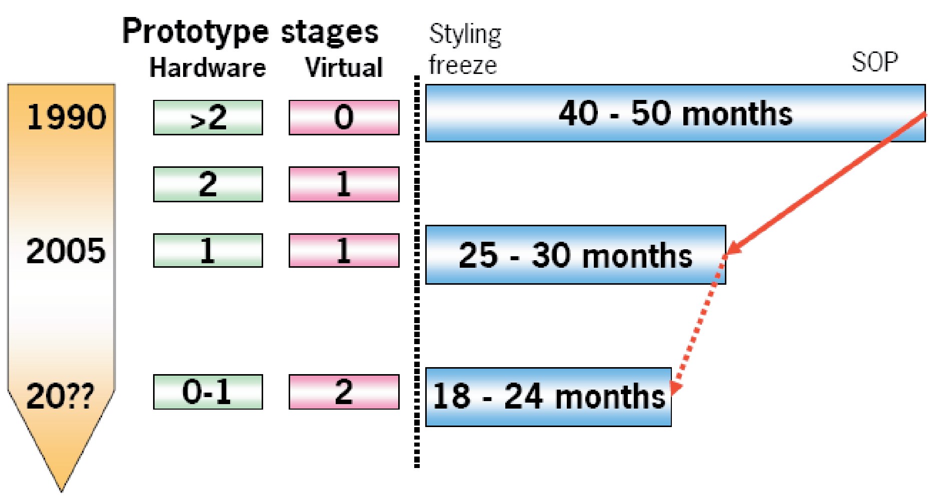
Fig. 4.1.1: The interrelationship of the three selected Key Technology Areas—Integration, Confidence, and Materials—on which AUTOSIM is focused.

The subsequent sections, 4.2–4.4, describe Best Practices and Breakthrough Technologies within these three selected Key Technology Areas.

Of course there are many other important topics that could be covered and investigated, but because of the limitations which inevitably arise from the project's fixed duration and available funding, the AUTOSIM consortium concentrated on a subset of items agreed to during the preliminary workshops.

4.2 Integration of Simulation into the Development Process

The AUTOSIM project considers integration to be a high-level objective. Its purpose is to identify simulation technologies, methods, and methodologies that have the potential to support the European automotive industry in its goal of reducing the product development cycle from the current time span of 25–30 months to a target goal of 18–24 months (Fig. 4.2.1).



Source: AUTOSIM (2006) with Extension from Prof. Schelkle (Porsche AG).

Fig. 4.2.1: Reduction of product development cycle

The members of the AUTOSIM project consider Up-Front Simulation (Fig. 4.2.2) and a CAE-centric product development process (deriving design from analysis) as key enabling methodologies.

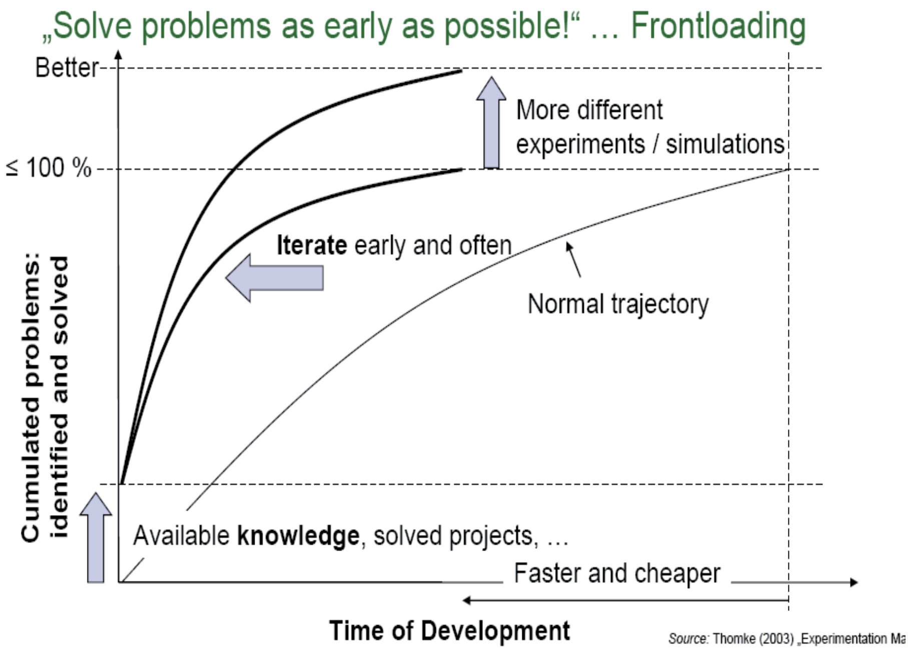


Fig. 4.2.2: The frontloading concept of Up-Front Simulation

Up-Front Simulation is a key driving force behind today's paradigm shift in new product development (Fig. 4.2.3). Conventional product development methods are costly, time consuming, and too inefficient for manufacturers who need to be competitive. Typically, organizations rush to create a design so that physical prototypes can be built and tested, then rebuilt and retested.

Fig. 4.2.3: Up-Front Simulation and related paradigm shift

The new simulation-driven approach represents a significant cultural change—a paradigm shift. Today, leading organizations perform simulations at the concept stage to explore alternatives, detect flaws, and optimize product performance before a detailed design or a single physical prototype is created. This process allows key decisions on functionality, geometry, and materials to be made at an early stage of development by utilizing computer-generated models for testing.

Regarding concept development, AUTOSIM's aim is to encourage the use of CAE methods (Up-Front CAE) for the basic layout work needed to obtain management support of decisions made during the early phases of a project. Currently, a lack of suitable methods and tools cause bottlenecks in concept development.

In series-vehicle development, complex function-validation models and standard CAE methods help to answer detailed questions. Automatic model generation could break up current bottlenecks in series development and increase the speed of development.

At any given development stage, designers need simulation models appropriate to specific design phases with the highest possible forecast quality and shortest response time.

4.2.1 Best Practice Topics Covered Within Working Area Integration

- **CAD-Integrated CAE Tools**
  A broad range of CAD-integrated CAE tools have been developed and delivered to the market in recent years. CAD-integrated CAE works especially well (time reduction) on a component level and for certain analysis types (commodity).

  It should be noted that the CAD-integrated software created for initial testing simulations does not always provide the fully accurate picture which can only be obtained from detailed simulation. Nor can all the constraints be considered, causing a bottleneck. A strategy of simulation-driven concept design, as described in Section 4.2 above, is considered a viable solution for overcoming this problem.

- **Simulation Data Management / Product Data Management (SDM/PDM)**
  The role of SDM is to capture and manage data, process, and methods, which differentiates it from existing Product Data Management (PDM) solutions. Best Practice today is to use PDM and SDM systems in parallel. PDM systems of today manage (frozen) data for the product, whereas SDM systems manage data (geometry, model, result) history and process to accommodate virtual product development. A bi-directional link between PDM and SDM is important, as product meta-data are held in PDM. The basis for this link could be a hierarchical product documentation covering PDM as well as SDM systems, combined with corresponding hierarchical data mining models. It is expected that today's PDM and SDM systems will be consolidated into one system in the future (Breakthrough Technology).

  One approach for this consolidation is provided by the ProSTEP project group „SimPDM" with the project „Integration of Simulation and Computation in a PDM Environment ". (www.prostep.org/en/projektgruppen/simpdm/). This group has the objective of developing a specification in order to integrate CAE-Systems into a PDM-Environment (Fig. 4.2.1.1).

  The standardized, generic meta data model for simulation and computation data can be integrated into any PDM-System. Therefore simulation and computation data are managed within the existing PDM system. Another advantage is the parameter synchronization between product structure and CAE model structure. The benefits of this synchronous, automated parameter synchronization are:

- ⇨ Change management and version control
- ⇨ Acceleration of processes
- ⇨ Simulation always takes place on the current development status

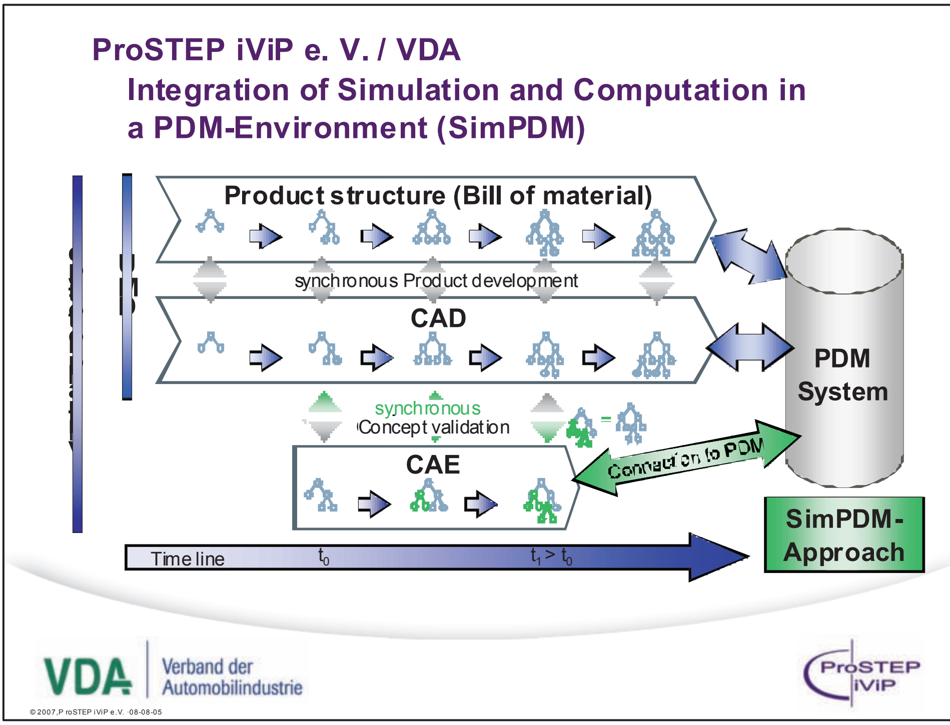


Fig 4.2.1.1: The Integration of Simulation and Computation in a SDM Environment

- **Data Integration (CAD/CAE/CAM/CAT)**
  A bi-directional communication between CAD and CAE applications is considered to be essential. Bi-directional communication between CAD and CAE is inherently given for CAD-integrated CAE solutions. Otherwise best practice communication is mainly unidirectional from CAD to CAE. The importance of integrating CAM and CAT data has been recognized, but has not been considered within the AUTOSIM project.

- **Collaborative Product Development**
  Because suppliers to OEMs must be integrated into the system to make it work efficiently, SDM must be a part of the link. There must be common understanding and cooperation beyond the CAD-CAE interface. This is already practised and also further elaborated, amongst others, based on VR technology adding significant benefit for collaborative working groups (e.g. Ref. [22]).

4.2.2 Breakthrough Technology Topics Covered Within Working Area Integration

- **Conceptual Simulation Models**
  New and/or enhanced technology models are needed for applications such as symbolic CAE, design languages, and parametrics. Appropriate design languages should have the potential to improve and accelerate concept design. However, the automotive industry does not yet use design languages in production. It will probably take up to ten years to integrate design languages into concept design. Pilot projects in the automotive industry will be needed to prove the concept. During the next few years, symbolic CAE tools have the potential to become increasingly useful in the automotive development process.

  Identified needs:
    - New technologies such as symbolic CAE, design languages, and parametric models
    - Combination with optimization tools
    - Efficient data exchange between new and traditional CAE technologies
    - Fast new tools for simulation of functional performance
    - Geometry generated and modified quickly and easily. This will be quite complex during the concept stage.

- **CAE to CAD Data Integration**
  Today's CAD/CAE data communication is mainly unidirectional from CAD to CAE. CAE to CAD data communication technologies are required in support of a simulation-driven product development process.

- **Knowledge Data Mining And Assessment Of Data**
  An important purpose of knowledge data mining is to derive a "(near) optimal" design from solution clouds obtained for the current design and predecessor designs. It seems to be important that in the future more knowledge data mining is included in process

management tools. First successfully applied solutions in this area cover, for instance, knowledge integration in innovative design processes based on templates, with the need to transfer the template designer's knowledge to the template users.

- **Automatic Model Generation**
  Automatic simulation model generation is essential during both the conceptual and series product development stages.

  Identified needs:
  - The ability to add and remove features
  - Meshing features (feature based meshing)
  - Automatic model assembly (mesh and geometry based)
  - Batch meshing (linked with optimization)
  - For solid models tetrahedral meshing is now widely accepted due to better element formulations and hardware performance. For surface models, triangular meshing has not yet reached a similar state.

- **Homogenous vs. Heterogeneous Model Environment**
  A characteristic of many technical systems is their heterogeneity. Heterogeneous systems are characterised by cooperating subsystems from different domains.

  Most existing modelling methodologies were developed for a special field of activity. They therefore have specific characteristics that support modelling and simulation of systems from this domain particularly well. The main advantage of heterogeneous modelling represents the possibility of being able to describe each subsystem with the best available modelling methodology.

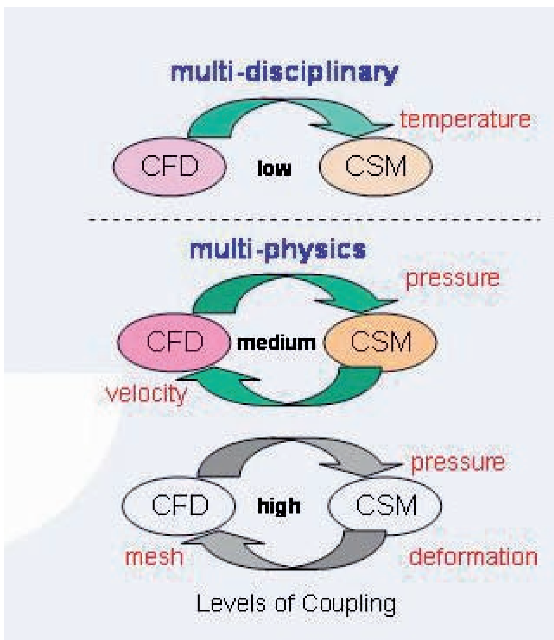
  If a system model is homogeneous in design, then only one modelling methodology is needed to describe different subsystems of a heterogeneous system. This offers the advantage of needing only one simulation tool to execute system simulations, and avoids the problems of a coupled simulation.

- **Multi-physics Simulation**
  Multi-physics simulation is already partly established in the automobile product development process. An example is the coupled thermal protection analysis process described in (Ref. [23]) enabling a more detailed and therefore more precise thermal computation of thermally loaded components. However, the

application fields of multi-physics as well as MDO have to be widened and applied to a greater variety of fields.

Multi-physics simulation may be categorized according to the level of coupling (Fig. 4.2.2.1), as an example shown here between CFD (Computational Fluid Dyanmics) and CSM (Computational Structural Mechanics):

- Low level coupling (unidirectional = multi-disciplinary simulation))
- Medium level coupling (bi-directional, iterative)
- High level coupling (equations)



Source: FENet EC project with modifications from Prof. E. Schelkle (Porsche AG)

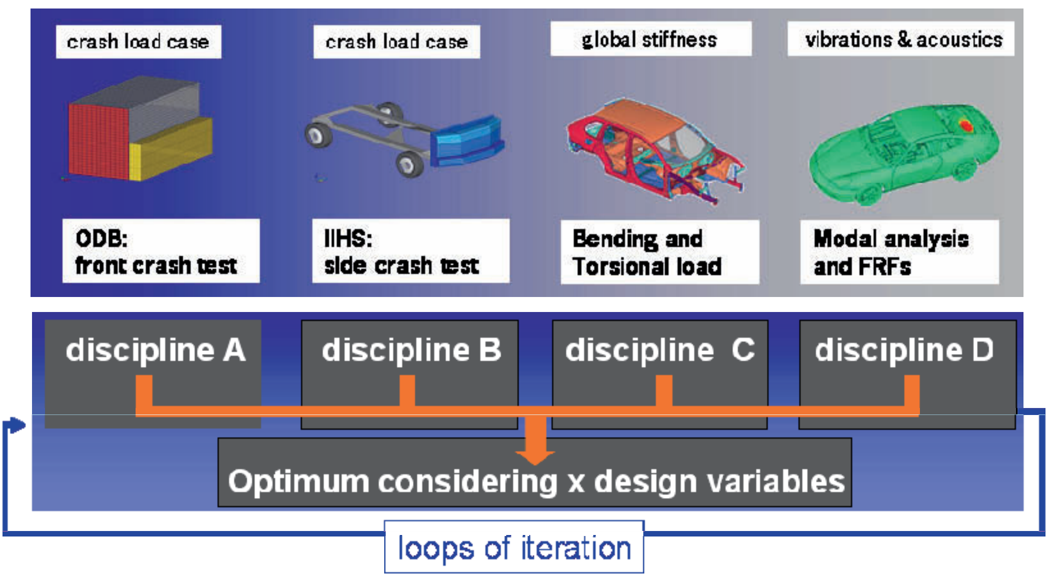
Fig.4.2.2.1: Levels of physical coupling

Technologies for certain applications are available for all three levels. Further developments are required. For example, one need which was identified is the need for a fully coupled aerodynamics-structure solution.

- **Multi-disciplinary Optimization (MDO)**
  For complex systems or subsystems in the automotive industry (see Fig.4.2.2.2), the design process is a very complex optimisation task involving multi-disciplines, multi objectives, and computationally intensive processes for product simulation.

  Complex systems require more than one optimisation loop to arrive at an optimum. Therefore it is of particular importance that multi-disciplinary optimization can be used in the concept design stage to identify early on the substantial tendencies for design optimization.

  There have been a series of excellent presentations on multi-disciplinary optimization during AUTOSIM workshops which are available to download from www.autosim.org/meetings.



Source: Prof. Schelkle (Porsche AG) & carhs training gmbh

Fig. 4.2.2.2: Multi-disciplinary Optimization in Vehicle Design

4.3 Materials Characterisation

Materials Characterisation is potentially a large subject if all forms of materials and their modelling methods in different analysis codes are to be considered. Therefore, we have attempted to establish the topics most important to today's automotive engineers. Some topics have been discussed because of specific gaps identified under the Integration and Confidence themes. Clearly, inferior material characterisation will undermine other efforts to improve automotive CAE.

The overall objective is to establish a methodology that can address the key points required to ensure best practice in Materials Characterisation for automotive CAE, and that can also highlight key technological areas where breakthroughs are required.

4.3.1 Initial Topics

A number of topics were initially put forward for consideration. These were based in part on the findings of the earlier FENet project (Ref. [9]). The initial topics were as follows:

- New materials—such as composites, foams, advanced high strength steels, non-ferrous metals
- Choice of constitutive models and the required input data
- Modelling connections
- Fracture, damage, and failure
- Effects of manufacturing and assembly on final material properties

It has been clear from the outset that there is much uncertainty as to how best to deal with these issues; moreover, we believe that engineers may not be applying novel material technologies in vehicle design because of uncertainty about how to model them correctly.

4.3.2 Refinement of Topics—Questionnaire and Materials Matrices

In order to gauge the industry's highest priorities, a questionnaire was circulated that set out the initial topics and asked for participants to rank these to indicate Technological Maturity, State of Practice, and Priority Level. However, the results eliminated only a small number of topics, indicating a broad range of interests amongst the participants and a high level of importance attached to most topics relating to Materials Characterisation.

Further refinement of the subject was carried out using a set of matrices indicating the importance of key topics regarding the materials of interest to automotive engineers (mild to ultra high strength steels, non-ferrous metals, plastics, composites, foams, and elastomerics). This was further refined by considering four different load cases typically addressed in automotive design (static, transient short term, transient long term, and cyclic).

Analysis of the matrices confirmed that many topics still need more development in order to move automotive CAE forward. The following topics were distilled from the results:

- New ultra **High Strength Steels** require new constitutive models
- **Strain Rate Sensitivity** for all materials (short duration transient loading)
- **Composites** (all load cases) for material properties, modes, failure or damage, connections, and even the effects of forming
- **Failure/Fracture/Damage** involving most materials across all load cases; understanding the differences and how to best model them in CAE
- **Effects of Forming** for all materials for short duration loading and non-metals for other cases; effect of assembly also highlighted, particularly for metals.
- Choice of **Constitutive Models** for non-metals—complexity vs. ease of use
- **Modelling Connections** for all materials and most load cases

Several of the presentations to the Technical Workshops have explored one or more of these topics; please see the AUTOSIM web site for details (Ref. [8]).

4.3.3 Best Practice—Is it already in use?

To supplement the circulated questionnaire and matrices, an analysis of the automotive development process was carried out. The result was a more detailed view of the material models used in specific areas of virtual car development and the identification of important issues mentioned by CAE engineers in their daily work. These issues were assessed by comparison with other simulation topics, such as model creation, quality of geometrical data, etc. Clearly this analysis is not complete and might vary for each car manufacturer. However, discussions at the Technical Workshops suggest that the findings are valid for most OEMs.

If we take a look at the present simulation process used in the car development process, we find several kinds of material models in use. The chart below (Fig. 4.3.3.1) shows the distribution of material models used by 120 CAE engineers working primarily for premium car manufacturers.

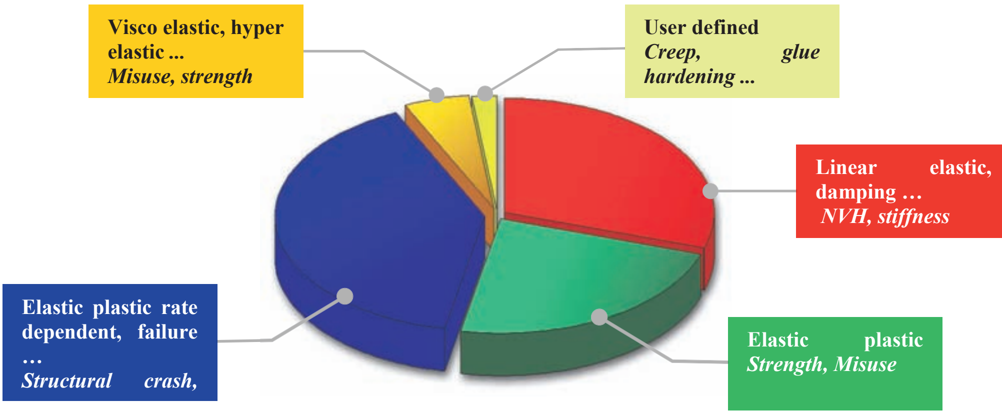


Fig.4.3.3.1: Distribution of material models in current use (courtesy of P&Z)

The evaluation shows that common, well-known material models (linear-elastic or elasto-plastic) are used for most development work, whereas more sophisticated, complex models are only occasionally applied. The reasons relate to the value attributed to the complex material models and the cost of using them. If we consider the quality of the common methods and their current application, we find many shortcomings noted by CAE engineers showing that in daily work there is a significant difference between the material models used and the available best practice.

The decision to apply best practice methods depends on the following considerations:

- Can the product be improved by improving the material model?
- Is the cost of developing an improved material model affordable?
- Does the improvement affect the established development process?
- Is the change in the development process acceptable to others?
- Is the experimental input to use the improved material characterisation available?
- Does the improved method improve the quality of the performance prediction?

In addition to the material models used other topics, such as model creation and quality of measured properties, may affect the choice made. If we list the issues raised by CAE engineers we find a general need for improvement in current practice for materials characterisation as follows:

- For modelling plastics, foams, and reinforced plastics, best practice is rarely used.
- The influence of the production process is not sufficiently taken into account.
- CAE engineers need better training to use best practice materials characterisation.
- For many best practice methods, input data relevant to material models are missing.
- Along with material issues, other demands seem to have just as important an influence on the product quality or development process.

4.3.4 Best Practice—When to use it?

An important topic that has been discussed intensely is the impact of a defined best practice on the time taken during development to apply it. The main problems with using best practice materials characterisation in the complete development process are as follows:

- Relevant test data is not available.
- In the early phase, decisions about which material to use have not been made.
- Geometry data is insufficient and inaccurate in the early development phase.
- Working with characteristic curves for concept evaluation is faster.
- Rapid geometry changes dominate the early development phase.

The chart below (Fig. 4.3.4.1) illustrates the potential benefit of applying best practice materials characterisation in relation to the phases in the development process.

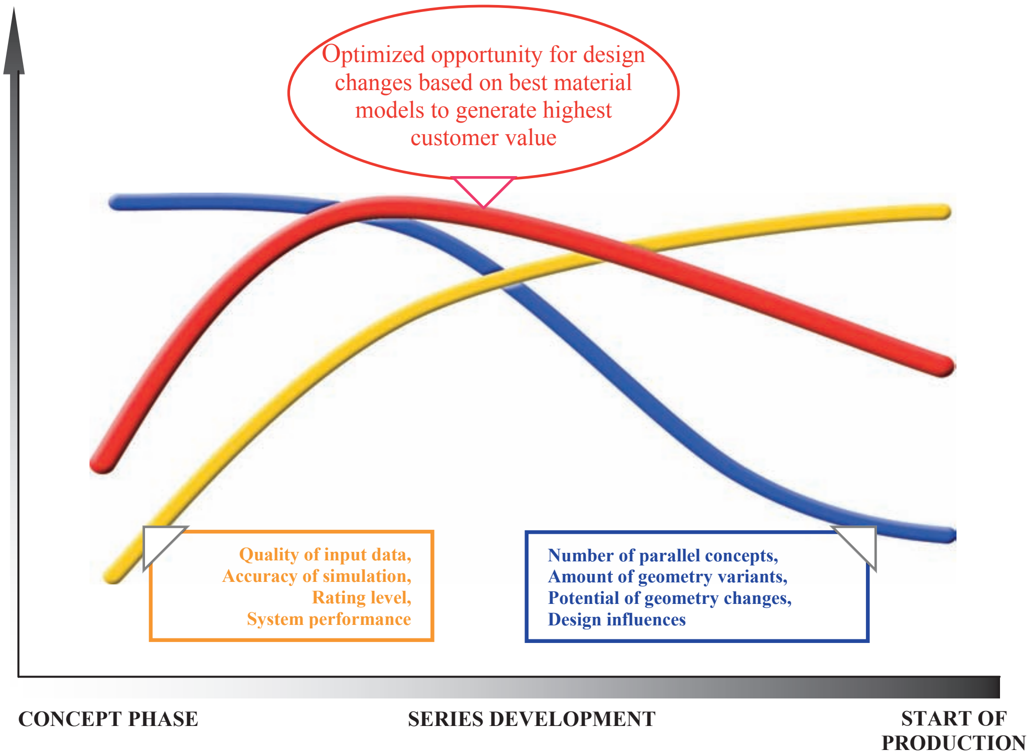


Fig. 4.3.4.1: Benefit of Best Practice Materials Characterisation vs. Development Stage (courtesy of P&Z)

The graph shows the following:

- The influence of the quality of materials characterisation on the performance prediction (yellow curve) increases as development proceeds. This is due to the fact that other issues such as geometry or choice of material are dominant in the early phase of development. As soon as these topics are clarified quality of materials characterisation dominates the quality of performance prediction.
- The size and rate of geometry changes decreases with time (blue curve).

From this, a further trend has been generated (red curve) showing the time period offering the best return of investment for use of sophisticated materials characterisation. In other words, there appears to be a point around one-third into the development process when use of best practice has the most positive influence on the final product design. This time may vary individually for different OEMs due to different development processes.

However, it could also be argued that in some cases, e.g., crashworthiness analysis, it is essential to use best practice materials characterisation as early as possible in the development process. For example, strain rate sensitivity of certain materials may be critical to the design; simple models omitting these effects may give a false impression. Including the effects of the manufacturing process may also be significant. In particular, the use of the best material model available is very important in every development phase for system responses that are likely to show bifurcations in response.

Similarly, use of “generic” data rather than data specific to a material for a particular supplier may not allow the correct design choices to be made – the involvement of the supplier at the earliest stage may be crucial. These are important considerations in the move towards “up front” simulation (see Section 4.2).

Modelling cost must also be acknowledged here as many decisions on materials characterisation are necessarily cost constrained. Cost comprises many aspects including data generation (testing and data capture), material model development, model pre-processing effort and solver processing time.

4.3.5 Breakthrough Technologies—How to identify them?

The discussion of best practice in materials characterisation (and the related cost constraints) leads to the question of what constitutes a breakthrough technology.

European research programmes on materials for automotive applications, such us EuMaT (European Technology Platform for Advanced Engineering Materials and Technologies), STEP (European Steel Technology Platform) and ERTRAC (European Road Transport Research Advisory Council) all identify material modelling as a strategic tool for the development of high added value components with improved performance and tailored properties, that can be used to strengthen the competitiveness of the automotive industry. To achieve this, we propose not only conventional, but also new materials (developed with the aid of modelling methods). These new materials could combine classical properties with new ones, such as self-healing the damage caused by abrasion and wear, variable strength, etc. Such materials may even be able to self-adapt their properties, depending on requirements.

Taking into account material type and functionality and the new trends in automotive materials (not only giving reduced vehicle weight but also producing a high added value product) Table 4.3.5.1 below summarises how breakthrough technologies may arise:

	Current materials (metals, polymers, composites,…)	**New materials (nanomaterials, multilayers, …)**
Current functions/load cases	**Best practice exists Breakthrough technologies (short term)**	**Breakthrough technologies (medium term)**
New functions/load cases or multifunctional applications	**Breakthrough technologies (medium term)**	**Breakthrough technologies (long term)**

Table 4.3.5.1: Relationship between Materials and Functions for Breakthrough Technologies (courtesy of LABEIN)

Consider first the upper left field. Depending on the material and function, either best practice already exists or a short-term breakthrough technology is needed. Two scenarios can be proposed:

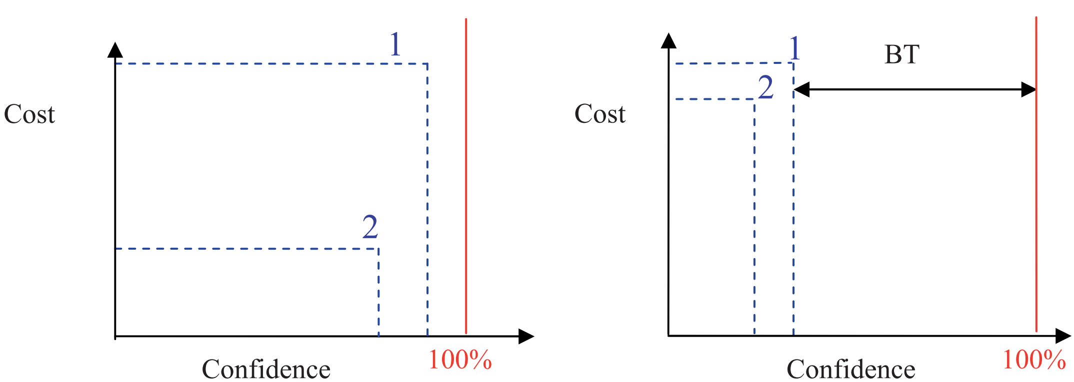


Fig.4.3.5.2: Relationship between Cost and Confidence in Material Modelling (courtesy of LABEIN)

The left hand graph in Fig. 4.3.5.2 represents a case in which a complex model (1) gives a high degree of confidence, but at high cost; model (2) gives only a slight reduction in confidence, but at a much reduced cost. These are key considerations for the CAE engineer when defining best practice, as has been already noted – indeed, there may be cases whether model (2) should be considered Best Practice as a simpler approach can save time, cost and avoid mistakes.

The right hand graph (Fig.4.3.5.2) shows a case in which both models (1) and (2) are relatively high-cost, yet both provide low confidence, hence identifying the need for a breakthrough technology.

Returning to Table 4.3.5.1, the lower right field of the table indicates that long-term research is needed, and in some cases the modelling requirements are not yet established. For example, one trend in material development that clearly requires a significant modelling development is nano-materials. Material characterisation, design methods, and simulation techniques are essential to better understand key phenomena—in particular the structure-property relationships at different scales—to improve reliability and to extend the modelling capability for design and application of these new materials.

Other specific Breakthrough Technologies topics for material modelling could include:

- Modelling of micro-structural evolution in materials processing and under loading
- Modelling of multi-material behaviour
- Modelling of joining/bonding/adhesive behaviour under loading conditions
- Multi-Physics approach (coupled analysis)

4.3.6 Development of a Methodology for Materials Characterisation

Clearly the time and resources available within the AUTOSIM project do not permit detailed analysis of all possible aspects of material modelling. Nevertheless, a number of useful papers on particular topics have been presented at the technical workshops (see Section 6). These have identified Best Practice in a number of specific fields and highlight where Breakthrough Technologies are needed.

Overall, the project has prompted the development of a methodology for systematic consideration of what is required for successful Materials Characterisation. In relation to this, papers have been presented at several workshops discussing the development of an ISO Standard for engineering properties. This is based on an extension of the existing STEP approach to incorporate not only geometry but also material properties (and how they were derived) and the manufacturing process. This would appear to be highly relevant to the AUTOSIM project objectives.

Once a material has been proposed for a component for a new vehicle programme we would propose that a methodology for successful Materials Characterisation would address aspects including:

- Source of material data
    - E.g., existing database, supplier data, test, etc.
- Test methods used to create the required data
- Data variability
    - Robustness of data, inclusion of error bands, etc.
- Choice of material model (may be load case specific)
- Method to fit test data to the selected model
- Inclusion of the effects of manufacturing
    - Effects of forming on material properties, importance of connection/joining processes, etc
- Cost considerations (in different development phases)
    - Costs associated with data generation, model fitting, simulation method, etc.
- Assessment of overall accuracy achieved
    - Test method modelling, component level, system level
- Quality Assurance
    - Data validation, model verification, traceability of data, etc
- Identification of requirements for Breakthrough Technology, considering the limitations of the current method

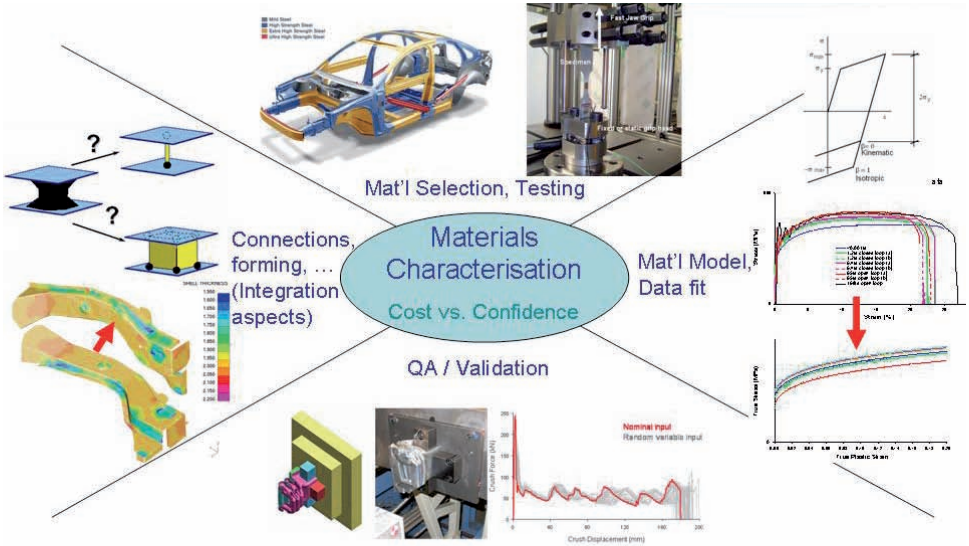


Fig. 4.3.6.1: Key Aspects of Materials Characterisation (courtesy of Dr Paul Wood, University of Warwick)

4.4 Improving Confidence in the Use of Simulation

4.4.1 Introduction

Confidence has a considerable influence on the uptake and use of CAE models. It is reliant on good material information and is necessary for the successful integration of CAE within the design and engineering process. Without confidence a model has no obvious benefit or value.

Six principal factors that contribute to the development of a successful CAE model, which is capable of guiding engineering research and design decisions, are highlighted in Fig.4.4.1.1. These factors affect model confidence and cover a broad range of topics as follows:

- ***The Physical model*** - Subjective and rational validation, integration of the modelling with test departments, standardisation of models to ensure the repeatability and reliability of test data/test corridors.
- ***Human resources and organisation*** - Quality control and capitalisation, detection of modelling errors, staff training and existing staff skills.
- ***Data validity*** - Reliability/confidence in experiments, availability of geometrical and material data.

- ***Digital model*** - Choice of elements and element formulation, discretisation of the model/mesh density and quality.
- ***Mathematical model*** – Variety and accuracy of available material models and model assumptions.
- ***Facilities*** - Hardware, processor and software dependencies.

It is evident from the above list that CAE confidence is influenced by a broad variety of topics. Part of the objective of the AUTOSIM project was to identify the principal topics influencing CAE confidence and to establish the Current/Best Practices and Breakthrough Technologies in these principal topic areas.

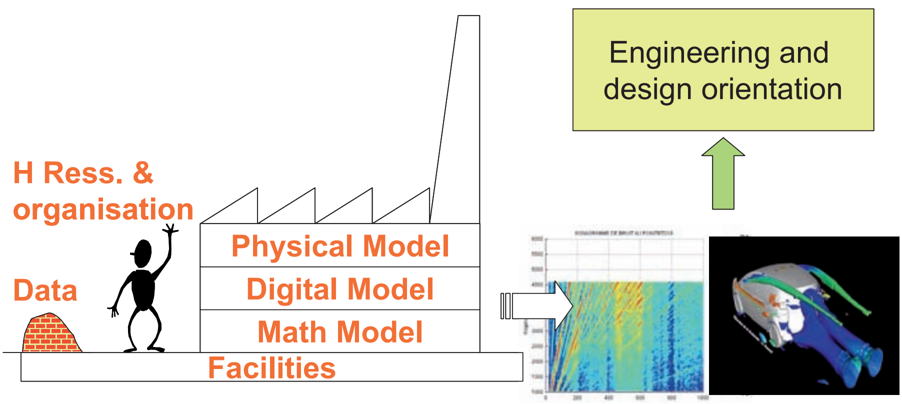


Fig. 4.4.1.1: Foundations of CAE confidence (courtesy of Renault)

4.4.2 Current engineering perceptions and concerns with CAE confidence

Enhancements in CAE confidence will encourage greater use of CAE in design, development and research activities, with the prospect of it being applied in broader and newer areas of interest; e.g. coupled fluid-structure interaction investigations. The benefits that could be expected with improvements in CAE confidence include:

- Reducing the number of required physical prototypes
- Less testing
- Improvements in the quality and robustness of engineering designs
- Virtual testing and certification
- Better understanding of physical phenomena

Further to the benefits it is important to consider that CAE confidence is highly dependent on the time and resources available for developing CAE models. As indicated in Fig.4.4.2.1 the return on invested time and cost to improve model confidence diminishes as the level of model confidence increases. Model confidence is therefore a balance between the available time and resources to develop a model against the eventual application of the model and the relevance and value of its predictions.

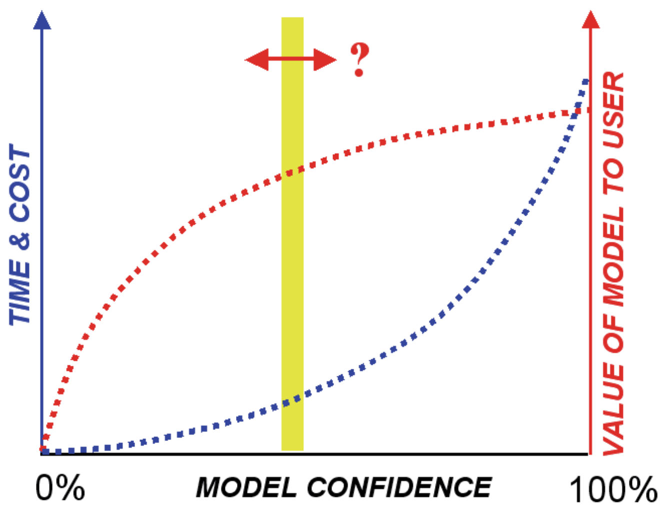


Fig. 4.4.2.1: "Cost of confidence"(Ref. [10])

4.4.3 Outcomes from the AUTOSIM project concerning CAE confidence

Based on the results of a questionnaire conducted in the early stages of the AUTOSIM project the principal factors registered as priority areas in terms of improving CAE confidence included:

- The physical model
- Human resources and organisation
- Data validity
- Digital model

Further to the results of the questionnaire it was determined, in the AUTOSIM workshops, that of the CAE confidence topics discussed the following four attracted the greatest level of interest in terms of their influence on CAE confidence.

- Validation (Physical model);
- Staff training (Human resources and organisation);
- Material data (Data validity);
- Mesh discretisation (Digital model).

Details of the principal points raised concerning the Current/Best Practices and Breakthrough Technologies in these four topic areas are covered in the following sections.

4.4.4 Validation (Physical model)

4.4.4.1 Validation - definition

Prior to discussing the influence of validation on CAE confidence it is important to draw a clear understanding as to the process that this term covers. Terms such as evaluation, verification and calibration of CAE models are often used in the same context as model validation. However, it is important to note that there are clear differences in the meaning behind these terms as follows:

- Evaluation – defines the process of assessing the influence that the characteristics of the model have on its predictions; for example the influence that mesh density, mesh type, the chosen material model and solver type affect the predictions from a model.
- Verification - is the process of determining that the fundamental behaviour of a simulation is consistent with the fundamental laws of motion, energy conservation and momentum. Verification of a model establishes that the physics of the simulation are correct.
- Validation[1] - describes the process of determining the accuracy that the simulation matches the behaviour of the structure or process under investigation. As discussed in Section 4.4.4.2 the accuracy of CAE models are influenced by a variety of factors.
- Calibration – Involves altering model inputs to achieve a better fit of the model's predictions to experimental data. Calibration describes "reverse engineering" of a model by altering its structure in order to optimise its behaviour to match that of the structure or process that it has been built to represent.

[1] In respect of this report it is important to emphasise that the validation being discussed here concentrates on the validation of the numerical model rather than on the validation of simulation software or computer hardware.

4.4.4.2 Validation – Influencing factors

Model validation was a principal point of discussion attracting the greatest level of interest and debate in the confidence sessions of the AUTOSIM project. It was considered that in terms of validation, confidence in a model's predictions is influenced by:

i. The accuracy of the model to predict the physical response;
ii. The number and variety of measurements and tests that the model is compared against.

Effectively, the greater the model accuracy and the more tests and data that a model's predictions are compared against, the more confidence there will be in the predictions from a model. Consequently, the initial questions that arose in the AUTOSIM project concerning validation included:

i. What level of accuracy does a model need to have to be considered validated? Within 5, 10 or 20% of the measured response?
ii. What parameters should a model be validated against to be considered validated? e.g. stress, strain, pressure, flow, acceleration, force etc.
iii. How many measures or data points should a model be validated against to be considered validated? E.g. time histories, location of measures etc.
iv. How many and what varieties of test results should a model be validated against to be considered validated?

It was initially considered that answering the above questions would provide a useful guide on how to validate and improve confidence in the predictions from a model. However, based on the discussions held in the project it was realised that because of the variety of factors that can influence the validation process it is not possible to set out a generic set of procedures to follow in order to ensure that a model is validated.

Ultimately the level and extent of validation that is carried out to improve model confidence will be limited by the available resources and time to carry out the validation process. Greater costs are inevitably incurred by increasing the number and complexity of the measures and tests that are carried out in order to validate the predictions of a model. As implied in Section 4.4.2 the intention of the validation process should be to balance the need for a correct answer against a 'good answer' i.e. one that has the required return for least input. In respect of what constitutes a 'good answer' will be affected by a variety of issues that include the following:

- Industry sector – Industry sectors may demand varying levels of model accuracy and confidence in the predictions from their models because of:

    - Fine tolerances or demands that their products are being built to (e.g. Motorsport).
    - The risks to society posed by their products (e.g. Nuclear, construction or aviation).
- Stage in the product development cycle – At the conceptual stage where subjective understanding of a product’s behaviour may be acceptable, relatively low levels of model accuracy may be required. Later on in the product development cycle a more quantitative understanding of the product’s behaviour may be required and greater accuracy and confidence may be required in the model’s predictions.
- Tolerances in the structure or process that is being modelled - It is not practical to expect a model to have a predictive accuracy lower than the tolerances of the physical structure or process that is being modelled. For instance, if the material properties of a physical structure have a tolerance of ±10% then the accuracy of the model to predict the behaviour of the structure cannot be expected to be lower than ±10 %.
- Tolerances of the test conditions and measures – It is not practical to expect a model to have a predictive accuracy lower than the tolerance of the test conditions and measures made in validation tests. For instance, if a measure made in a test has a possible tolerance of ±5% then the accuracy of the model to predict the measured response cannot be expected to be lower than ±5%.
- Analysis type (FE, CFD, linear, non-linear, static, dynamic) – Relatively immature analysis methods and models of high complexity are likely to have a lower level of accuracy and confidence than their mature and lower complexity counterparts, e.g. a dynamic impact analysis of a vehicle possessing composite structures compared with a linear static elastic bending analysis of a steel beam.
- Knowledge availability – The more knowledge that is available in terms of for instance the physics of the problem and the material behaviour, will lead to the development of a model with greater accuracy and confidence. E.g. the linear analysis of a simple steel structure is likely to be more accurate than an analysis of a complex composite structure under non-linear loading.

Because of the various factors that affect the accuracy of models and the confidence in their predictions it is difficult to define regimented procedures that should be followed to ensure that a model is validated and that confidence in its behaviour is optimised. As such it is effectively up to the individual analyst or organisation to develop their own validation procedures and to decide on the depth and level of validation required for their particular needs. An example of a validation process that may be adopted is provided in Section 4.4.4.3. An understanding of the current/best practices that may be adopted in the validation process to improve model confidence are covered in Section 4.4.4.4.

4.4.4.3 Validation – Process

The conventional process of validating models involves comparing the predictions from the model against the results from tests carried out on the structure or process that is being modelled. However, in a drive to cut lead times and cost in product development the opportunities to develop prototypes and carry out tests in order to directly validate a model's behaviour may need to be sacrificed. To develop confidence in the validation of a model in this more streamlined regime will rely more on historical capitalisation to validate and develop confidence in the predictions from a model. A conceptual understanding of how the process of validating models by historical capitalisation might work is provided in Fig. 4.4.4.3.1. This shows that new modelling approaches are devised based on the validation of earlier models against a product that has already been released to market. This new modelling approach is standardised and validated before being used in the application of the next development project that results in the next product development. Validation of the model against the latest product is then used to guide and validate future modelling studies and develop confidence in model predictions in order to reduce the number of physical prototypes and tests that need to be carried out. Ultimately this validation approach relies more on the predictions from models to guide decisions on the final setup of the developed structure or process.

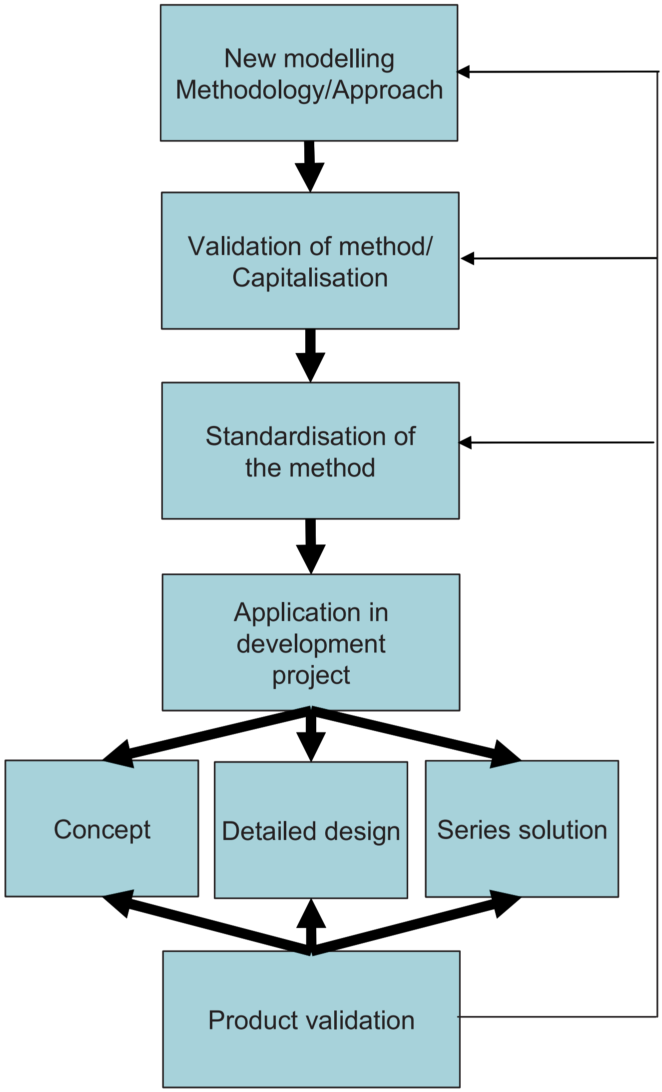


Fig.4.4.4.3.1: Example structure of validation that relies on model capitalisation.

4.4.4.4 Validation – Current/Best Practices

Typically the practice of assessing the accuracy of a model relies on subjective comparisons of a model's predictions against test results. This practice relies on the analyst or model developer providing a subjective assessment on the confidence of the models accuracy based on their understanding of the model's structure and the inherent assumptions made in the development of the model possess. As such this practice of assessing a model's accuracy is open to interpretation, can be misleading and does not provide any direct means of comparing the accuracy of one model's predictions against another.

Objective methods of validating the predictions from models would provide a more consistent understanding of a model's predictive accuracy and a relative appreciation on the accuracy of one model compared with that of another. Examples of subjective methods of comparing model predictions against test results have been developed (e.g. MODEVAL and MAC). However, so far it is understood that these are generally only applicable for validating models under specific loading conditions and they can also provide misleading results. The current understanding is that further work is needed to develop robust objective validation practices.

Uncertainties in the structure and assumptions made in the development of a model can have an influence on its accuracy and the confidence that can be placed in its behaviour. Parametric and sensitivity studies can be used as a best practice to explore the uncertainties and assumptions in the model's construction in order to develop confidence in its behaviour. Similarly stochastic modelling studies can be carried out to assess the robustness of a model's behaviour by comparing the spread of data produced from stochastic studies against comparable sets of test data. An outcome of parametric or stochastic modelling studies could be to define specific loading conditions under which a model can and cannot be applied or they could be used to help define confidence limits for the model's predictions. In practice, restrictions on the available time and resources to carry out test and modelling work limits the amount of parametric, sensitivity or stochastic modelling work that is carried out to validate the robustness of model predictions.

Confidence in the accuracy and behaviour of models can be developed through the gradual building and validation of a model's complexity. For instance, the models of individual components that form an assembly should be developed and validated in isolation prior to their inclusion in a complete model of the assembly. As such there will be greater confidence in the behaviour of the assembly model because of this gradual and methodical approach in its development.

A limitation identified in current practices of validating models is the poor integration between analysts and the staff of test departments. It appears to be normal for the analyst's integration with the test department to be limited to test commissioning and data transfer. Best practice should involve better integration of analysts with the test department to promote the development of better designed validation tests and to develop a better understanding of the setup and limitations of the tests. This will provide essential understanding when it comes to setting up the model for the validation runs and the comparison of the model's predictions against test results.

4.4.4.5 Validation – Breakthrough Technologies

It is considered inevitable that technological developments will bring about both improvements and reductions in the accuracy and confidence in models. For instance, advances in measuring techniques and data logging will help to record data in tests that could not previously be used to validate models, such as the use of thermal imaging to validate the predictions from thermal analyses. Furthermore, developments in material data, modelling methods, processor speed and historical capitalisation will all contribute to developing more rigorous validation methods and more accurate models, which in turn will result in greater model confidence. Conversely, advances in technology could initially compromise the accuracy and level of confidence in models. For instance, as model complexity continues to increase and new materials are developed and applied in CAE models, then, until such time as the maturity of these new modelling techniques has developed, there will be limited confidence in their application.

In the immediate future breakthrough technologies are needed that can automatically and subjectively compare large amounts of model predictions against test data in order to better manage the process of validating models and the output from stochastic and robustness modelling studies. Better techniques are also needed to compare and assess the accuracy of model predictions. To meet this challenge further work is needed to develop robust subjective evaluation criteria and tools.

4.4.5 Staff training (Human resources and organisation)

4.4.5.1 Staff training – Current/Best Practice

The training of numerical analysts is an important aspect to develop confidence in the behaviour of a model. This is especially true considering that it is very easy to produce misleading results from a poorly developed model. As such the competences and experience of the numerical analyst are an important part of developing and applying models that can add value in an industrial context.

In terms of carrying out numerical simulation work it is considered that analysts need to understand the physics of the problem at hand and have a basic understanding of the mathematics of the code that they are using. The most likely approach by which analysts develop this knowledge is laid out in Fig. 4.4.5.1.

At a fundamental level Fig. 4.4.5.1 illustrates that the training of numerical analysts should be a healthy mixture of ‘on-the-job’ training, learning from peers and attendance at external meetings and courses in order to avoid insular practices and the development of poor/erroneous working practices. At the initial stage training for the numerical analyst should involve developing an understanding of mechanics, material science and numerical methods, which can be achieved through a university degree. Following their introduction into industry the analyst then needs to develop an understanding of the software tools that they are using and an understanding of the physics of the problem that they are being required to investigate in order to fill a ‘knowledge gap’. The opportunities for filling this ‘knowledge gap’ typically consist of on the job training, attendance on software specific training courses and attendance on non-software specific training courses covering issues such as non-linear numerical methods and structural impact. There is also the possibility of attending focused training in a CAE discipline such as vehicle safety. This form of training is geared to the particular requirements of the organisation that the analyst is working for and as such can provide a more accelerated route developing the competencies of the CAE analyst. Once established as a CAE analyst training continues in order to keep abreast of the latest technological developments, through interactions with peers, colleagues or competitors, attendance at conferences and workshops and by researching the published literature.

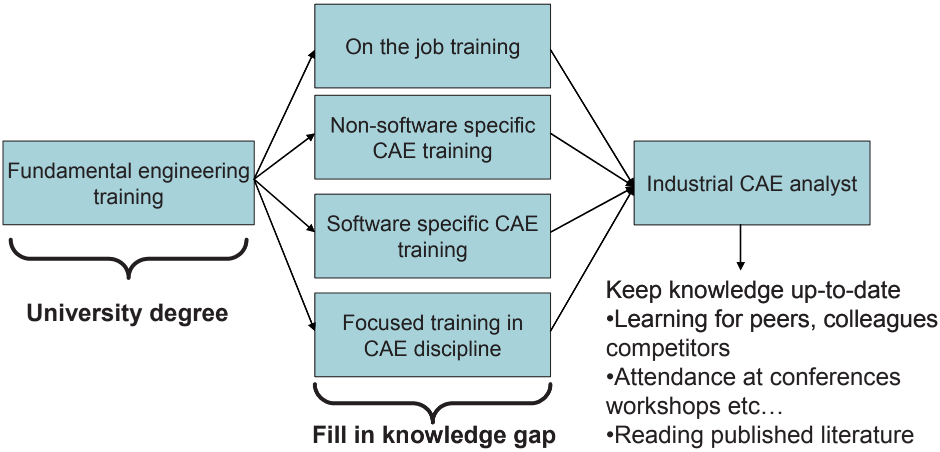


Fig. 4.4.5.1: Conceptual overview of training for CAE analysts.

It is apparent that the demand for trained and competent CAE analysts is increasing. To meet this demand employers are looking towards India and other parts of Asia to fill these positions with the prospect of employing highly educated individuals to fill these roles. The universities could also play a part in gearing the focus of their courses to the demands of what industry wants from their employees. Constructive feedback of the requirements of industry to universities would help in defining the future educational requirements. Forums such as the NAFEMS working groups provide one such platform where this kind of information exchange can take place as these groups are typically attended by both academic staff and industrial personnel.

4.4.5.2 Staff training – Breakthrough Technologies

It was identified in the AUTOSIM discussions that a limitation of an analyst's training is that there are no means of qualifying their experience or competencies, which would be useful in terms of making recruitment decisions and/or evaluating the skills of existing staff. It is known that NAFEMS does run a Registered Analyst Scheme (RA Scheme) in which analysts are ranked at three progressive levels against their specific CAE competence e.g. CFD, Structural analysis, etc. The RA scheme does provide a means of grading the skills of numerical analysts but it would appear that the scheme is largely unheard of around Europe and is not recognised within industry. Future promotion of this scheme may help to establish it as a staff training best practice.

Often analysts encounter barriers in attending courses because of the time and resources that this involves. This problem is partly attributed to the fact that the value of training and attendance on courses is not fully appreciated by managers and decision makers within organisations. It is important that personnel within organisations that have authority to sign off the resources for training and course attendance have a better appreciation of the return in value that this will provide. Also in the future greater use should be made of the internet/web to deliver courses and training which would help to alleviate the resources and time typically involved in attending courses and training programmes. This is a concept which appears to be gaining momentum with organisations such as NAFEMS regularly holding webinars in order to communicate knowledge and training to a larger global audience.

The concept of ‘up-front’ simulation has been discussed at length in the Key Technology area of Integration in the AUTOSIM project. One interpretation of this concept is that FEM tools embedded in CAD systems are used to analyse and optimise designs at earlier stages of the design process. In view of the extensive training that numerical analysts receive in order to develop competent skills it appears impractical, because of other work commitments, that designers could be trained to a competent level to carry out numerical analysis studies. It is envisaged that a more practical approach to resolving this particular aspect of upfront simulation is more of an organisational than a training issue. The proposed approach is that designers should have a basic understanding of numerical methods, but competent trained analysts should be used to support them in carrying out numerical studies. Even today’s software tools are equipped with features such as process automation, rules for meshing and material databases that could be used to support designers in carrying out correct CAE analysis studies.

4.4.6 Material Data (Data validity)

4.4.6.1 Material Data – Current/Best Practices

The accuracy and detail of available material data has an important influence on the accuracy of the predictions that are obtained from a numerical model. In terms of the practical application of material data it is understood that it is often necessary to estimate coefficients for material models because of the limited availability of good quality material data. The decisions for these estimates are typically based on engineering experience and knowledge. However, this practice will still affect the accuracy of the predictions obtained from the model and the confidence that can be placed in the behaviour of the model. By using estimates of material properties in models a considerable reliance is placed on the analyst to interpret and add confidence to the model's predictions based on their understanding as to how the model has been constructed.

Although best practice for material data would be to carry out purpose designed tests of material responses, limitations in available resources and time often mean that tests to develop material data cannot be carried out. The general impression from discussions in the AUTOSIM project is that limited testing is carried out to develop material data that can be applied in CAE models. Some organisations have developed their own material databases for the purposes of their own CAE modelling needs. However, it is more common to use historical test results or search for appropriate data in the published literature or on the web.

4.4.6.2 Material Data – Breakthrough Technologies

In terms of breakthrough technologies the ideal scenario for the numerical analyst would be the creation of a comprehensive central materials database that analysts can freely access in order to select the most appropriate material properties for their models. The benefit of a central database is that it would potentially improve the accuracy and so confidence in model predictions, could help in the transfer of models between organisations and would help to harmonise understanding on the accuracy of the predictions obtained from models developed by different organisations. Although there are obvious benefits to the creation of a central database it is considered impractical to believe that a database of this nature will be constructed, principally because of questions over who would fund such a large scale project and mange and administrate this over the long term future. Without any obvious means of coordinating the creation of a central database the situation will remain that analysts will continue to acquire contrasting material properties from licensed sources or from the published literature.

An aspect of material data that should be tackled by breakthrough technologies is providing provision to adequately reference and catalogue sources of material data, providing details on how this was developed or obtained. Quality procedures have been developed for managing this type of information and this could be embedded into software codes in order to provide options to control this type of model data input. The quality procedures could also be used to catalogue other assumptions that have been made in the development of the model. The benefit offered by cataloguing this information is that details that are important to the interpretation of a model's predictions are not lost and are preserved for future modelling studies (i.e. historical capitalisation).

4.4.7 Mesh Discretisation (Digital model)

4.4.7.1 Mesh Discretisation - Current/Best Practices

It is evident that the size and complexity of material models is continually increasing with mesh sizes ranging between, but not limited to, 10,000 and 10 Million elements. An issue raised in the AUTOSIM discussions is that model sizes can be limited according to the available computer resources on which to run and post-process model predictions. This situation will be more applicable to small scale businesses operations that do not have the necessary resources or justification for purchasing large scale computer resources. However, options do exist for contracting out large model runs to organisations that do possess extensive hardware facilities. This may be an attractive option for small scale industries to adopt if they want to develop and run large scale models but do not have the necessary in house resources to run large scale models within practical or project timeframes.

As a Best Practice model evaluations should be carried out to assess the impact that mesh densities have on the predictions from a model. Feedback from the AUTOSIM discussions indicates that there is neither the available time nor resources on projects to carry out an evaluation of the mesh density's influence on a model's predictions. Typically the mesh density used in models is based on past experience and/or an anticipated understanding of how the model will respond when loaded i.e. increasing mesh densities in areas where stresses are likely to be highest. Tools are available in Pre-processing software to carryout automatic objective checks of mesh quality and structure and the use of these should be considered a best practice in terms of developing model meshes.

4.4.7.2 Mesh Discretisation – Breakthrough Technologies

The principle of a pre-processing software tool was proposed that includes features to personalise and store a variety of mesh quality check templates according to the solving method, customer type or analysis field for which the model is being developed. It was considered that such a tool could be used to help in the development of consistent mesh types according to specific requirements. Along similar lines it was registered in the discussions that software vendors are already working on the development of mesh dependent solvers, which adapt solver methods according to mesh types and structures in order to optimise model run times.

Because of the lack of mesh optimisation that is carried out it is expected that a way forward to resolve this issue would be the development of intelligent mesh adaptation tools that are able to evaluate mesh discretisation errors and automatically improve critical mesh areas based on past predictions.

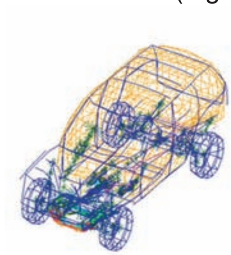
Improved pre-processing tools are also considered necessary for automatically identifying bolts, joints and contacts in CAD data in order to streamline the process of developing CAE models. In this respect there are already indications that the automatic detection of contact areas, is already a feature of some commercially available pre-processing software and will inevitably become best practice in the near future.

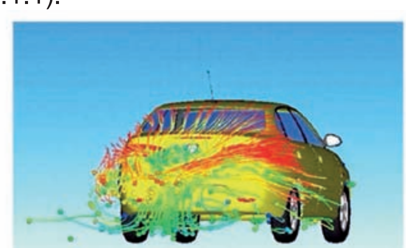
4.5 How To Move On

As discussed in the earlier sections, the conventional product development methods of repeated ***design-analyze-build-and-test*** are too costly, time-consuming, and inefficient for today's competitive environment. A new simulation driven approach must be implemented to explore design alternatives, spot flaws, and optimize product performance at the concept stage, before a detailed design or physical prototype is created. This process has to allow ***earlier key decisions*** regarding functionality, geometry and materials (Ref. [11]). This new development ***paradigm shift*** must be supported strongly by upper management with ***training, support of implementation, selection of pilot projects***, etc.

4.5.1 Efficient Deployment of Digital Prototypes

Invariably, several digital models must be created and maintained to implement functional layout and verification and validation of results. Some of these digital models are designated for physical layout. In this respect, input values are limited to ***key-vehicle layout*** parameters like "main dimensions", "hard points", etc., as well as for characteristic parameters like mass, engine frequencies, etc. Other remaining digital models are needed for final geometrical layouts requiring additional parameters, such as surface geometries etc. (Fig 4.5.1.1).





Physical Layout
A MBS—Car Model

Geometrical Layout
A CFD—Car Model

Fig.4.5.1.1: Digital Models

Some of the digital models have completely different aims and require completely different input data. Others might be more similar and there might be a chance to combine or to merge them even. This of course would save maintenance costs and could help to streamline processes in a ***concurrent engineering environment.*** A careful selection of appropriate software tools would be required in that respect as well as a close working relationship with ISVs (Independent Software Vendors).

4.5.2 Becoming Faster in the Conceptual Design Phase

In the different design phases, digital models must conform and correspond with each other so that results support significantly reliable decision-making and progression through all stages. This means that at one design stage it would be appropriate to rely on qualitative decisions (e.g. version A is better than version B), whereas at another design stage quantitative simulation results are crucial for final verification and validation.

To ensure this conformity, it is becoming clear that CAE needs to take advantage of the existing PLM / PDM systems that can provide the tracking, access control and alignment of the various models and phases of the design, and link them to the main product structure (BOM = Bill Of Materials).

The SDM systems need to provide repeatable automation solutions (templates) that are open to any CAE application to open up the world of Multi - Disciplinary automation and Optimization (= MDO).

Therefore, we propose that CAE methods be applied Up-Front, either to do earlier and faster analysis runs or to leverage knowledge from previous designs, such as by means of Simulation Data and Process Management (e.g. Ref. [12]). Disciplines currently handled by SDM include: Front, Rear, and Side Crash; Pedestrian Protection; Occupant Safety; Head Impact; Global and Local Stiffness, and NVH Analysis. In addition, these different simulation disciplines have to be linked for collaborative working in order to fully support the conceptual design phase with an appropriate visualisation environment such as a VR system which already has shown its benefits in fields like packaging or ergonomics (e.g. Ref. [12]).

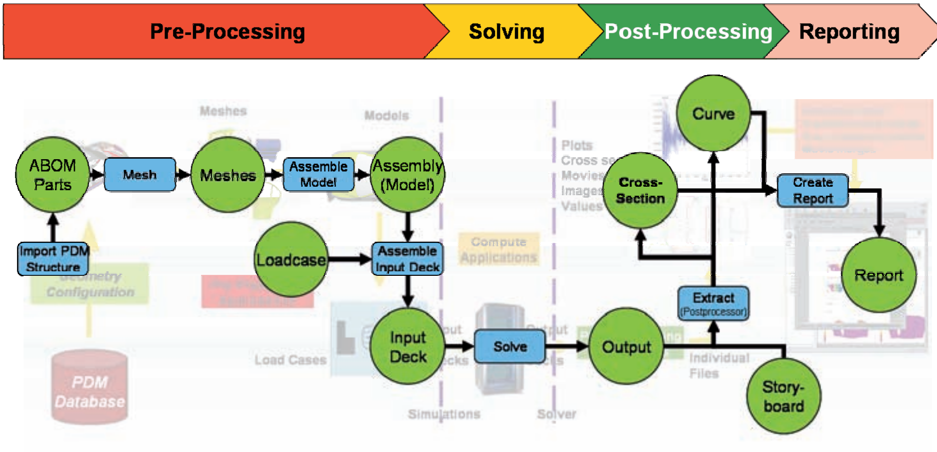


Fig. 4.5.2.1: Simulation Data and Process Management (courtesy of MSC Software)

Fig.4.5.2.1 shows a sample process map of a generic crash simulation process with both simulation data objects (green circles) and simulation process actions (blue boxes). SDM should manage the simulation data, and also offer the possibility of managing the simulation processes. This is particularly important for increasing confidence in simulation data, as it makes simulation processes repeatable and, thus, results easier to compare. It should be noted that, especially in early design phases, appropriate CAD data may not be available yet. For this reason any SDM system must be flexible enough that input data for building simulation models can come from different sources, not necessarily from PDM systems only, but of course desired in the future.

To enable a total procedure to become faster, an integrated software environment is needed. For example, the physical layout needs to be done rapidly either using CAE or (semi-)analytically or with symbolic CAE when only some basic data is available (Fig.4.5.2.2).

Very often in a typical new vehicle, in order to encourage design work using CAE during early development phases, parametric vehicle-concept models are desirable because they allow conceptual, geometric modifications to be evaluated rapidly at a time when no CAD data is yet available. Such tools should allow concept modification cycles (i.e. variation of parametric vehicle concepts) on data available either from predecessor models or from scratch (Fig 4.5.2.2).

In a typical vehicle development process, design constraints are at a minimum in the very early or conceptual phase. The lack of design constraints during the early vehicle development stage can be used to advantage, allowing for more exploration and optimization on a large scale. A good innovative process that takes the proper software tools and integrates them around a new vehicle development process has the potential to yield better body structure design with lower mass, higher performance, and wider bandwidth (Ref. [14]).

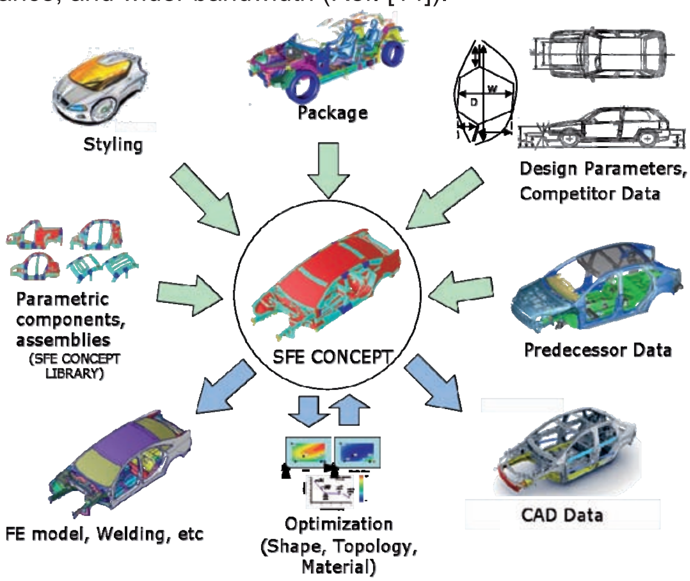


Fig.4.5.2.2: Parameterized Car Body Models (courtesy of SFE GmbH))

Later in production development, "conventional" CAD and CAE methods need to be used to confirm functional reliability, further and final optimization, and production capability of the concept design.

4.5.3 Clearly Defined Materials Characterisation Methodology

Along with the geometric representation of the vehicle structure, the approach taken to characterise the materials chosen for the vehicle is critical to achieving a reliable, accurate and robust digital model. The demand for models with greater predictive capabilities to be used ever earlier in the design phase therefore brings the topic of material characterisation to the fore.

Not only are there other objectives detailed in this chapter inherently dependent on the reliability, accuracy and cost of material characterisation, but the long-term competitiveness of the automotive industry depends on the effective use of conventional materials as well as the development of novel materials to meet new challenges in vehicle performance and price. This will be realised chiefly through digital modelling methods.

Where developments in material technology are led solely by the material suppliers there is often a delay in their introduction for use in vehicle manufacture. This can arise from uncertainty in many areas such as cost, manufacturing methods and issues such as recycling - but also, significantly, from uncertainty in how to correctly characterise these new materials for the digital model. Here, by correct characterisation, we mean the ability to describe the key characteristics of the material under the load cases of concern to generate accurate, reliable results – particularly under non-linear loading where bifurcation in results makes it essential to choose the best model from the very start of development. In many cases material properties are dependent on the manufacturing process, further complicating the ability to predict their response in the vehicle.

Many parties are involved in defining materials characterisation for simulation – including the material supplier, component manufacturer, testing house, the software developer and the CAE engineer in the end user organisation. Closer collaboration will allow the benefits from new material technology to be accrued sooner. There may be a new requirement for a “CAE Material Specialist” within the automotive OEM or Tier 1 supplier; the role would include coordination of activities between the key parties, establishment and maintenance of a materials database, guidance on the effects of forming and choices of assembly methods, and how to choose the best practice material model for a particular load case. Of course, any proposal for use of a new material must also consider cost – any change in practice has to be justified in terms of cost saving and/or revenue increase. This must reflect not just the raw material cost (and availability issues) but the total cost to the enterprise – including aspects such as recycling, environmental impact, legislative restrictions and applicable manufacturing methods.

A key requirement (and an area also highlighted in the confidence topic) is the need for a more powerful material database. This must provide the essential traceability but also would offer several other benefits such as controlled access to key data, support for choosing the best material, guidance on which parameters are needed for specific load cases, automatic updates via PDM/SDM systems, and simply avoiding wasted time searching for or re-generating missing data. Such a system will eventually need to include probability-based definitions of material properties.

A clearly defined materials characterisation methodology would permit new materials to be adopted with increased confidence. The methodology should commence with how a material is selected, and then fully detail the required data including the test method used, choice of material model and data fitting techniques. It must also include validation, verification and state the accuracy achieved, and even describe the known limitations with the current approach.

To date, innovation in vehicle performance has more often than not been dependent on innovation in materials. In the future, it may be that the material requirements will be driven directly by the demands of the automotive engineer, from a consideration of the required vehicle performance – indeed, novel materials may eventually be developed by modelling methods in a reversal of the current approach.

4.5.4 Accelerating the Model Preparation Phase

Of the total time needed by engineers to create a simulation for a system or subsystem, 80 percent is devoted to generating a model. An automatically generated model would significantly increase simulation productivity and allow sparse engineering resources to be concentrated on more vital tasks (Fig.4.5.4.1) e.g. Ref. [13]). A convincing example of an accelerated modelling strategy incorporating semi automatic and fully automatic meshing and quality control processes is sketched in the modelling process for thermal protection of passengers cars, e.g. Ref. [23].

For traditional finite element-based or volume-based CAE tools, it should be possible to re-use simulation models from predecessor products to evaluate design alternatives in the early (Pre-CAD) stage. These validated models can be used readily to evaluate the influence of new material, operation (loading) conditions, and the like. Shape changes (e.g. morphing technologies) on the mesh level can be made quickly, although the process is usually limited to small changes on parts. This approach may be further improved by associating geometry to a mesh model in which modification on geometry and/or topology (creating or deleting components) automatically accounts for modifications in mesh (Ref. [13]). New technologies, based on Boolean operations, allow for rapid investigation of topological changes on functional performance of parts. By generating models automatically in series development, it will be possible to shorten model creation processes significantly while simultaneously increasing mesh quality.

The integration between CAD and the model generator is of utmost importance. It is expected that fully CAD-integrated and closely CAD-linked (native geometry) simulation technologies will coexist.

Besides producing meshes according to pre-defined quality standards, automatic model generation systems should provide capabilities for cleaning and de-featuring of CAD geometry, recognition and intelligent meshing of important features, and application disciplines specific to modelling requirements (e.g. boundary layer modelling for CFD). It should also be possible to assemble and connect component models from different sources. This includes the automatic joining of dissimilar meshes, bolt generation, the application of complicated distributed loads, mapping of CFD results, and interpolation of data from other sources such as test data.

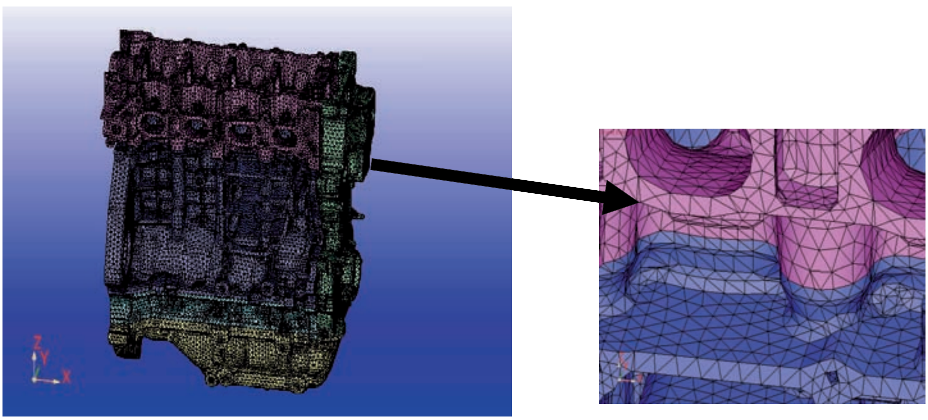


Fig. 4.5.4.1: Example of automatic assembly meshing (courtesy of Techno-Star Europe GmbH)

As design optimisation methods are increasingly adopted for the product development process, automatic model generation (re-meshing of design domain) should eventually become a necessity.

In Fig.4.5.4.2 there is shown the starting point for an SDM process as input from a PDM system, thus any SDM system needs the correct data for the correct analysis as its starting point.

There are essentially three starting points to any analysis:

(a) all the CAD data exists,
(b) no CAD data exists only CAE,
(c) a mix of the CAD and CAE data exists.

In all three cases the need to find existing data is the starting point. Using a Product Structure stored in a PDM system seems to be the best method to find the correct data for the correct analysis, as it provides the correct version / revision of all the products data (Ref. [25]). The product structure is then used as a template to generate a new CAE product structure.

This CAE structure includes existing CAE data, additional CAE data not in the Product Structure but needed for the analysis (e.g. a crash barrier), data only needed for this analysis (e.g. only symmetrical components); all of this is driven by rules configured for that analysis type (e.g. crash, NVH etc). Thus multiple types of analysis can then be generated from the same starting point, all of them are consistent and with the correct data for correct analysis. The generation of the CAE structure is repeatable and provides a fast reliable method of providing the correct data for the correct analysis.

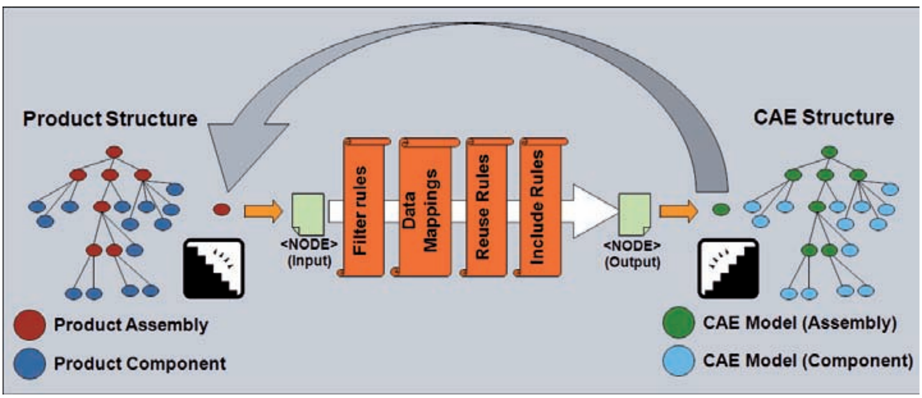


Fig.4.5.4.2 Product structure and CAE (courtesy of Siemens PLM Software)

This new CAE product structure provides the link to ensure changes can be tracked, and changes propagated under user control and “where-used” searches can be generated. The new CAE structure can be submitted to workflows that are specific to CAE and run in “parallel” with the CAD design work. This CAE structure is then used to “feed” process automation solutions for the actual analysis runs. The results of the analysis need to be captured and the simulation PDM system needs to be flexible enough to manage different types of result data, and these can vary from very large result files to a few parameter values. Also reports and visualization data needs to be captured.

All of this data is then available for the next design iteration or new designs re-using existing data. Linking the reports of an analysis to the original requirements stored in the PLM system provides the loop-back to ensure the design meets the performance requirements.

4.5.5 Robust Design and Complexity Management

With the advance of automated optimization methods it became clear that optimization “alone” applied to real world engineering tasks will not solve “the whole problem”. Optimization algorithms will drive the design to the constraint limits where scatter in the input parameters may cause a violation of these constraints and consequently a product to fail.

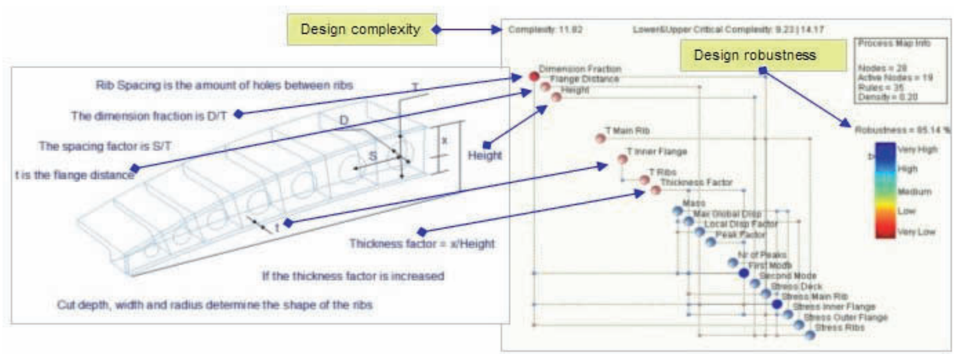


Fig. 4.5.5.1: Complexity Management

One means to avoid this and to get more insight into the design behaviour is to utilise the tools which have been developed which are mostly based on stochastic techniques. They have emerged in the past couple of years and have been improved continuously by academia and software vendors. These methods were conceived to be uncertainty management tools and their goal was to evaluate the effects of tolerances on scatter, quality of performance, most likely behaviour and the identification of dominant design variables (Ref. [12], [17], [24]).

The underlying algorithms of these tools became mature. At the same time also the expressiveness of these methods was improved in terms of graphical results interpretation.

Post-processing evaluation can now be used to detect and visualize the most dominant design variables using a correlation map showing the correlation between input and output parameters (Fig. 4.5.5.1). The intensity of correlation can be highlighted by various means e.g. by different colours, different line characteristics and the distinction between direct and indirect correlation etc.

But this is still not enough. There are no set standard methods or rules which can be applied to most of the problems. This means each problem needs to be investigated “by hand” to achieve an improvement in the design behaviour. A prerequisite to make the required next step is a further improvement of the underlying algorithms done by research and the presentation of the results to the analyst to demonstrate that these methods can be exploited for design “decision making” processes.

4.5.6 Current Status and Future Trends in CFD (Ref. [26])

CFD is considered to be a mature technology in many areas of automotive engineering, particularly in aerodynamics, vehicle thermal management, internal combustion analysis and cabin comfort, but its use is also growing quickly in areas of coupled physics such as fluid-structure interaction (FSI) and aero-acoustics. Even so, the process of analysis, starting from geometry handling through to solution and optimisation, is not painless. Sections 4.2 and 4.3 have identified those Breakthrough Technologies (BTs) and Best Practices (BPs) that would benefit the CFD process, and in Fig.4.5.6.1 we see how BTs and BPs can significantly improve the process pipeline;

Fig.4.5.6.1: From CAD to Analysis

- CAD Import:
    - **CAD Integration** (BT) provides a unified interface between the CAD and analysis tool. It implicitly educates the analyst how best to create a geometry so that it is suitable for analysis (BP).
    - **CAD/CFD associativity** (BT) allows changes to CAD to feed through seamlessly to the CFD solution, and makes it possible for easy parametric design changes to be assessed quickly (BP).

- Surface Preparation:
    - **Surface Wrapping** (BT) (Fig. 4.5.6.2): even for very dirty CAD importations, this allows for fast generation of closed surfaces suitable for CFD/CAE. User tolerances allow for the retention of detailed features, or to de-feature the model as necessary.

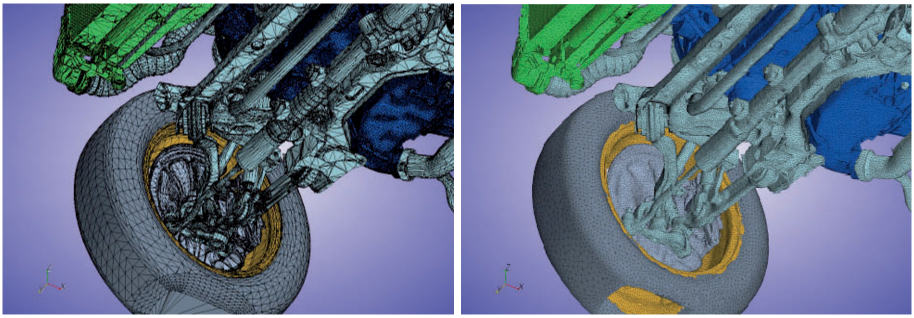


Fig.4.5.6.2 Imported CAD (left) and wrapped surface (right) with detailed feature retention and implicit small-scale de-featuring

- Surface Meshing:
    - BPs determine where and to what level to refine surface meshes.

- Volume Meshing:
    - **Polyhedral meshing** (BT) contributes enormously to ease of volume-mesh generation, accuracy and robustness of the CFD solution. BPs determine where and to what level to refine volume meshes. **Surface extrusions** (BP) are a necessity for boundary-layer resolution.

    - **Multi-Domain meshing** (BT) is essential for certain types of Multi-physics analysis such as conjugate-heat-transfer (CHT) and fluid-structure interaction (FSI). BPs determine which domain requires what level of volume meshing. Continuous and fully connected meshes (BP) ease solver issues between the multiple domains/physics. See examples in Fig. 4.5.6.3.

- Analysis:
    - Best Practices determine best use of mesh types, discretisation practices, physical model practices, and boundary conditions. Dependency analyses are always encouraged to **evaluate**, **verify** and **validate** the modelling practices.

- **Multi-Physics** (BT), either through coupled or integrated solver analysis. Uses of other BTs are highly encouraged, such as polyhedral meshes and continuous multi-domain meshing.

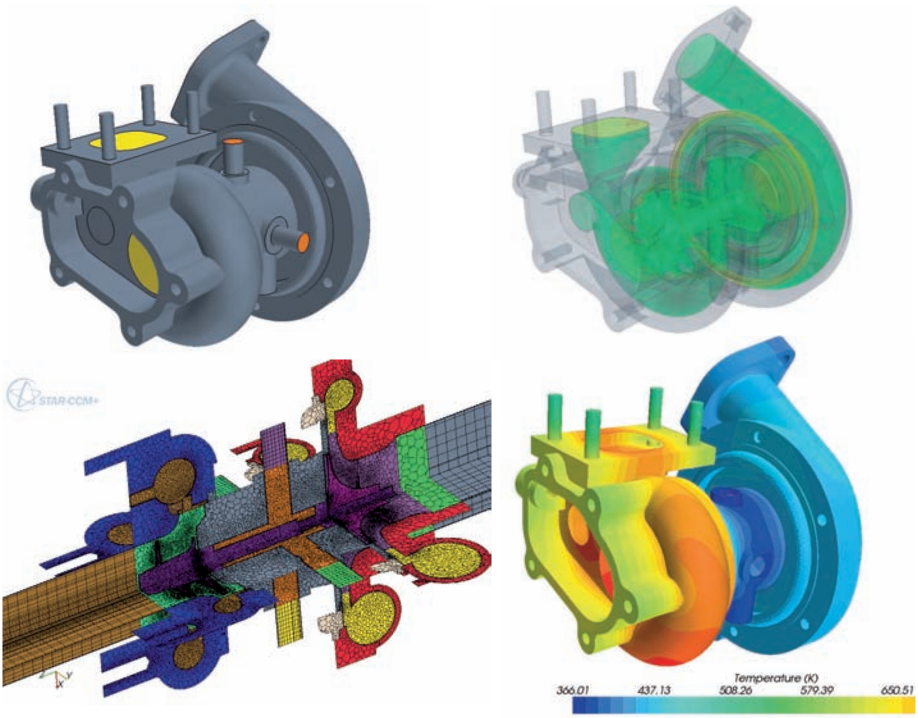


Fig.4.5.6.3: Turbocharger compressor and turbine complete assembly (top right), continuous multi-domain meshing incorporating fluid-side surface mesh extrusions (bottom left), flow and thermal solutions (right)

Pipelined processes, embedded in integrated software environments, are demonstrating the way forward to realise a new paradigm for simulation driven, up-front design and analysis.

4.5.7 Design-to-Cost

Functional Requirement and Cost Trade-off studies using Parameterized Vehicle Concepts in the Early Design Phase.

Affordability is one of the key issues for design engineers and manufacturers of new car body models. Sometimes vehicle development projects have failed to enter the production phase because cost was not factored in during the early development phase and it was realized later that the vehicle program could not meet the projected financial targets. Likewise, many vehicle projects that went into production with severe cost and manufacturing constraints failed in the marketplace because of limited improvement in vehicle functionality or performance. Either case is due primarily to the lack of understanding of the cost and performance relationship and engineering alternatives during the vehicle development cycle (Ref. [18], [19]).

To stay competitive, it is becoming vital to include cost engineering at every stage of a new program to ensure success in achieving performance targets while managing cost. Cost engineering has been applied in recent years starting in the aerospace and defence industries and researched continuously by academia.

Several enabling technologies have been developed over the years such that it is now possible to bring cost engineering into the modern simulation-based development process for vehicle body structure in the early concept stage. These include:

1) Reasonably accurate performance models based on finite element techniques
2) Capable cost estimating tools, with commercial or in-house developed tools.
3) Parametric concept development systems that allow for fast changes of concept geometry and the associated computational models.
4) A process integration and computational framework that can flexibly integrate simulation models and cost models into a simulation-based design iteration loop to study cost-performance trade-off.

Fig.4.5.7.1 shows a schematic workflow of such a system that can be applied to automotive body design. Changing the architecture features will trigger changes in cost estimates of materials and manufacturing.

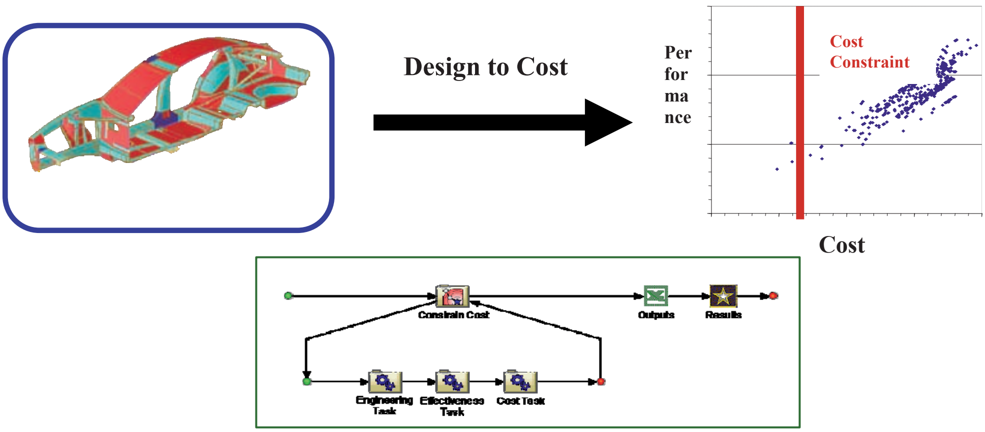


Fig.4.5.7.1: Schematic workflow of Design-to-Cost applied in automotive car body design (Courtesy of SFE GmbH and Engineous Inc.)

Within the environment of a competence center ASCS (Automotive Simulation Center Stuttgart) which was founded earlier this year in 2008 in the Federal State of Baden – Wüttemberg (Germany), Porsche (Ref. [21]) intends to investigate the Multi Disciplinary Optimisation (MDO) of vehicle structures with regard to functional requirements as well as to cost considerations (Fig. 4.5.7.1, Fig. 4,5,7,2).

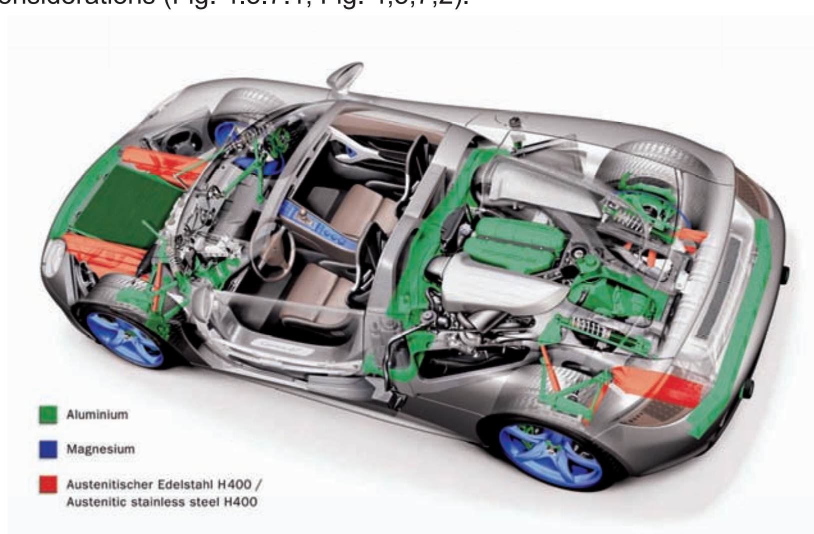


Fig. 4.5.7.2: MDO including cost as an additional design parameter (Courtesy of Prof. Erich Schelkle (Porsche AG), Ref. [21])

For a reasonable cost estimation and the achievement of target costs (= budget) a lot of parameters are vital. But as approximately 80 % of the life cycle cost of a new car body design is fixed by engineering and design, cost as a constraint offers the maximum influence on cost assessment with respect to the best engineering option or best performance effectiveness (Fig 4.5.7.2). An aim of the planned ASCS project therefore is to consider both concurrently.

5. Conclusions

- Today, simulation is typically used under predefined, predicted, and controlled conditions. The current state of the art seems to couple two disciplines, such as Structural Analysis and Computational Fluid Dynamics. But a car—tested as it would be driven—should have been tested by simulation for a combination of concurrent factors, such as Occupant Safety, CFD, Multi-Body-Systems, Structural Dynamics, Fatigue, and the like. Simulation and Analysis should become more comprehensive (Ref. [16]). We should proceed in the areas of **Multi-Physics** and **Multi-Disciplinary Optimization**.

- FE models are approximations of reality, but must be realistic and capture the physics of the situation. Inclusion of **Uncertainty** will boost the **Level of Confidence**. Uncertainty stems from the physics and must be considered. The availability of powerful and low-cost computers able to analyse parallel considerations will support this paradigm shift dramatically.

- It has been determined from the work carried out in AUTOSIM that the principal areas of interest and concern regarding CAE confidence relate to the validation of CAE models, CAE staff training, the quality of model material data and the discretisation of CAE models.

- With Materials Characterisation clearly of high importance, a methodology is needed to ensure that characterisation of materials is reliable, accurate and achieving best practice; this should also ensure that novel materials can be introduced as early as possible. Development of an extended database holding not only basic material properties but also essential information regarding, for example, the effect of forming processes on material behaviour is essential. Close collaboration between vehicle manufacturers, material suppliers, testing houses and software developers will be required to achieve this.

- In the future, CAE needs to take into account extended distributed development environments to address **Product Life Cycle Management**. Tools and Processes must be integrated, with consideration given to the OEMs and Suppliers, recognizing their knowledge and resources (Fig. 5.1 and Ref. [20]).

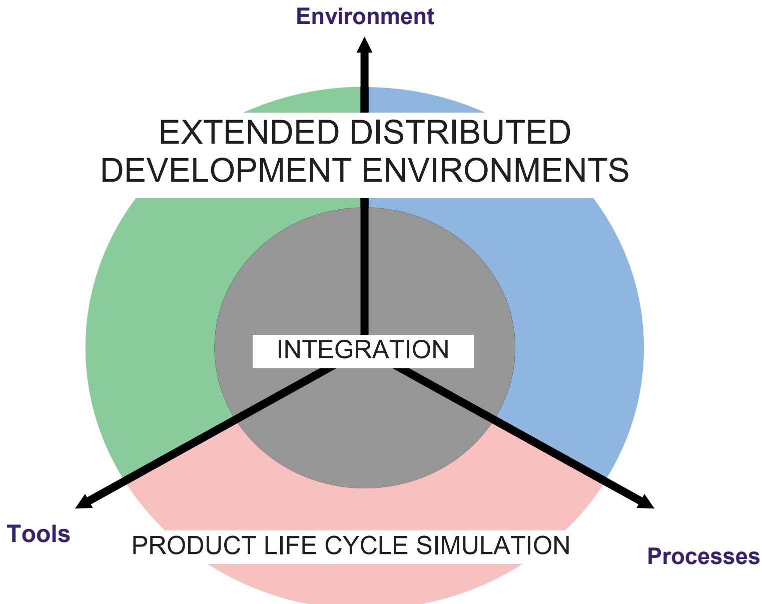


Fig. 5.1: Source: ***EUCAR EG—VE***
(Enabling Group—Virtual Engineering)
www.eucar.be/start.html

- In the future, automatically generated models should speed up the **Conceptual Design Stage**. The need is for tools that will allow a simulation analyst to do more analysis more quickly during the early stages of the design process, and to do them in a well organized way. For example, a designer could develop parameterized car body models to quickly study design variants when CAD data is not available. The use of these parameterized models, together with sophisticated optimization tools, will and must play a significant role in the future (Ref. [14], [15]).

- How to **Store Data** and how to **Retrieve Knowledge**. Tools should be set in place to take advantage of knowledge gained from analysis runs from designs of car predecessors, or simply from previous analysis runs of crash, NVH, durability, etc.

6. List of Technical Workshop Presentations

During the AUTOSIM project a series of workshops were held in which speakers were invited to present on BPs and BTs in the three AUTOSIM discussion areas of Integration, Materials and Confidence. The agenda for these workshops is presented in the following sections of this report. Further details on some of the presentations given at the workshops can be found at www.autosim.org/meetings.

6.1 1st Technology Workshop

Hotel HCC Montblanc, Barcelona
17th & 18th January 2006

Introduction to the AUTOSIM Project
T. Morris (NAFEMS, UK)

Introduction to the AUTOSIM project for Consortium members.
R. Oswald (NAFEMS, D)

Web site and administration
D. Quinn (NAFEMS, UK)

Technology Areas & CAE Success Stories
H. Sippel (CAEvolution GmbH, D)

Presentation of FENET Automotive Findings
F. Espiga (Labein, E)

Overview and Introduction of Best Practices
G. Duffett (Herbertus S.L., E)

Overview and Introduction of Breakthrough Technologies
A. Moser (Virtuelles Fahrzeug mbH, A)

Some Aspects on Upfront CAE and CAD/CAE Integration
R. Schweiger (CAEvolution GmbH, D)

CFD Optimisation Case Studies
F. Mendonca (CD-adapco, UK)

Overview and Introduction of Best Practices
Overview and Introduction of Breakthrough Technologies
F. Espiga (Labein, E)

Characterisation and Modelling of Dynamic Properties for Reliable Integrated System Simulation
S. Olutunde Oyadiji (Univ. of Manchester, UK)

Modelling Elastomeric Automotive Components using FEA and Multi Body Dynamic Analysis
H. Ahmadi (TARRC, UK)

Integration of Simulation into the Development Process
E. Schelkle (Porsche AG, D)

Impact of Manufacturing Processes on Crash Test Results
L. Kovar (MECAS ESI s.r.o., CZ)

Advanced Optimization Strategies in Automotive
L. Fuligno (EnginSoft SpA, I)

Virtual Product Development applied to Automotive Use Case
O. Tabaste (MSC.Software, F)

Material Characterisation for Accurate Simulation of new Metal Forming Processes
M. Gutierrez (Labein Tecnalia, E)

Forming Simulation and especially the Effects of Forming
T. Dutton (via NAFEMS Ltd. / Dutton Simulation Ltd., UK)

Overview and Introduction of Best Practices
J.-M. Crepel, E. Fournier (Renault, F)

Overview and Introduction of Breakthrough Technologies
F. Maggio (Enginsoft Spa, I)

Numerical Techniques for Robustness Stochastic Analyses and Model Fitting
L. Fuligno (EnginSoft SpA, I)

An Example of CAD Embedded CFD and CAE Process Integration (CFD and Electromagnetics)
F. Mendonca (CD-adapco, UK)

Conclusions and lessons learnt from the meeting Key technology 3: Confidence
M. Neale (TRL, UK)

6.2 2nd Technology Workshop

Manor of Sonnenhausen – near Munich, Germany
4th & 5th May 2006

The objectives of AUTOSIM – a reminder
Objectives of 2nd Autosim Workshop
H. Sippel (CAEvolution GmbH, D); T. Morris (NAFEMS, UK)

Barcelona – results & setting the scene

Integration
R. Schweiger (TechnoStar, D)

Materials
T. Dutton (Dutton Simulation Ltd., UK)

Confidence
M. Neale (TRL Ltd., UK)

Best Practices in Automotive Safety Simulations
R. Hoffmann (EASi Engineering GmbH, D)

Recommended Best Practices for Model Dependency Checks
F. Mendonca (CD-adapco, UK)

Integration of Simulation into the Development
M. Hoffmann (Altair Engineering GmbH, D)

Process Requirements and Realization Scenarios Tea Pipe, a Catia V5 totally integrated pipe simulation software
P. Morelle (Samtech Deutschland GmbH, D)

Reference Model for the Cooperative Exchange of Simulation Data (Integration)
M. Hofer (ViF, A)

Lessons learned from contributions & Summary

Integration
R. Schweiger (TechnoStar, D)

Materials
T. Dutton (Dutton Simulation Ltd., UK)

Confidence
M. Neale (TRL Ltd., UK)

6.3 3rd Technology Workshop

Sana Lisboa Park Hotel, Lisbon, Portugal
23rd & 24th November 2006

2nd Workshop in Sonnenhausen – Results & Setting the Scene

T. Dutton (Dutton Simulation Ltd., UK);

M. Neale (TRL Ltd., UK);

R. Schweiger (TechnoStar, D)

Application of Material Law in the Car Development Process
T. Schneider, S. Paulke (P+Z Engineering GmbH, D)

Materials Property Data for Simulation: Standardised Representation of Engineering Properties
N. Swindells (Ferroday Ltd., UK)

Up-front CAE Simulation - Just a Catchword or Already a Fact of Modern Automotive Engineering?
E. Schelkle (Porsche AG, D)

Increasing Confidence in the Use of Simulation: Views of the NAFEMS Analysis Management Working Group
C. Rogers (CREA Consultants Ltd., UK)

New Variants of Evolution Strategies for Global Optimization
M. Schütz (NuTech Solutions GmbH, D)

Enabling Technologies for Design-Simulation Integration
C. Armstrong (University of Belfast, UK)

Current and Continuing Issues in CFD
A. de Souza (Pall Aerospace, UK)

Design Languages – on some Technological Advantages and Commercial Benefits of a Potential Break-through Technology
S. Rudolph (IILS mbH, D)

Benefits of Multi-Objective Design Optimization and Process Integration Approach in the Early Stages of Design Process
L. Fuligno (EnginSoft Spa, I)

Computation of Stress Intensity Factors for Cracked and Notched Components by the Fractal-like Finite Element Method
S. Olutunde Oyadiji (University of Manchester, UK)

MSC SimManager - Enterprise Simulation Management
A. Soeiro (MSC.Software, F)

Aspects of Connection Modelling for Crash Applications
T. Münz (DYNAmore GmbH, D)

Integrated Flow, Thermal and Stress
F. Mendonca (cd-adapco, UK)

ANSYS Workbench - a New Environment for Complex Simulation Tasks
R. Rauch (Cadfem GmbH, D)

SFE Concept CAE Design: a Key Enabler in Virtual Product and Vehicle Development
H. Zimmer (SFE GmbH, D)

Summaries

T. Dutton (Dutton Simulation Ltd., UK);

M. Neale (TRL Ltd.);

R. Schweiger (TechnoStar, D)

6.4 4th Technology Workshop

Renault Technocentre at Guyancourt, near Versailles / Paris, France
5th & 6th July 2007

Welcome and Introduction
T. Morris (NAFEMS Ltd., UK); H. Sippel (CAEvolution GmbH, D)

Update on AUTOSIM, NAFEMS and World Congress
T. Morris (NAFEMS Ltd., UK); K. Zamazal (Das virtuelle Fahrzeug Forschungs gmbH, A)

AUTOSIM White Paper: Overview
H. Sippel (CAEvolution GmbH, D)

Integration: Overview - Progress to Date, White Paper Contents and Themes for Meeting
R. Schweiger (TechnoStar, D)

A Reduced Beam and Joint Concept Modeling Approach to Optimize Global Vehicle Body Dynamics
S. Donders , T. Van Langenhove, R. Hadjit (LMS International, B)

Multiphysics for Thermal Analysis: A Holistic Approach to Process Optimization
T. Kessling; S. Hildenbrand; V. Faessler (TWT GmbH Information & Engineering Technologies, D)

Controlling the Complexity in Coupled Simulation
K. Zamazal (Das virtuelle Fahrzeug Forschungs gmbH, A)

Integration of CFD-Computations into the CAE-process of a Racing Car Design based on a Formula Student Project Experience
S. Pfitzer, S. Rudolph (University of Stuttgart, D)

The Multi-Disciplinary Challenge: Heading Towards Global Optimization
A. Poisson (Esteco France, F) ; L. Fuligno (EnginSoft SpA, I)

Confidence: Overview - Progress to Date, White Paper Contents and Themes for Meeting
M. Neale (TRL Ltd., UK)

CAE Survey of User Priorities and Trends
F. Mendonca (cd-adapco, UK)

Data Confidence for CAX using SC4 Technologies
N. Swindells (Ferroday Limited, UK)

Materials: Overview - Progress to Date, White Paper Contents and Themes for Meeting
T. Dutton (Dutton Simulation Ltd, UK)

Composite Materials Characterisation
L. Ferrero (ISDG, I)

Effects of Mechanical Properties of Adhesives on Stress Distributions in Single Lap Joints
S. Olutunde Oyadiji (University of Manchester, UK)

Noise Factors in High Speed Tensile Testing - Specimen Setup, Instrumentation and Data Extraction
T. Dutton (Dutton Simulation Ltd, UK)

Summary Materials
T. Dutton (Dutton Simulation Ltd, UK)

Summary Confidence
M. Neale (TRL Ltd., UK)

Summary Integration
R. Schweiger (TechnoStar, D)

Consultation Process, Open Discussion and Wrap-up Workshop
H. Sippel (CAEvolution GmbH, D); T. Morris (NAFEMS Ltd., UK)

6.5 5th Technology Workshop

Parque Tecnológico de Bizkaia, Bilbao, Spain
15th & 16th November 2007

Welcome and Introduction
T. Morris (NAFEMS, UK); H. Sippel (CAEvolution GmbH, D)

AUTOSIM White Paper
H. Sippel (CAEvolution GmbH, D)

Design-to-Cost (D-2-C): Just a Catchword or a new Dimension in Modern Automotive Engineering?
E. Schelkle (Porsche AG, D)

Summary of Recent NAFEMS Work Session on the Management of Simulation Data
T. Morris (NAFEMS, UK)

Overview about Applications of "Symbolic CAE" for Upfront Simulation
S. Braun (SmartCAE GmbH, D)

Car Crash: Are There Physical Limits to Improvement?
J. Marczyk (Ontonix s.r.l., I)

Simulation Data Management with Interoperability Across Domains
M. Grau (Prostep ITS GmbH, D)

Material Subroutine for Gluing
T. Schneider (P + Z Engineering GmbH, D)

Steel Databases: False Friends of Fatigue Simulation
J. Albarran, R. Elvira (Sidenor I +D, E)

Methodology for the Thermal and Piezoresisitive Simulation of Materials Reinforced with Nanotubes
H. Vallejo (Inasmet Tecnalia, E)

What Should CAE Engineers Know and What They Do Not Need to Know?
M. Meywerk (University of the Federal Armed Forces Hamburg, D)

Aspects of Modelling: Examples from Consideration of Unusual Movements in Crash Simulation
M. Meywerk (University of the Federal Armed Forces Hamburg, D)

Break-though Technologies for Engine Cooling - Coupled Flow and Heat Transfer, Boiling, and Finite Volume Stress Analysis
F. Mendonça, R. Johns (CD-adapco, UK)

ProSTEP iViP e. V. / VDA – Integration of Simulation and Computation in a PDM-Environment (SimPDM)
G. Fabian (Kompetenzzentrum - Das virtuelle Fahrzeug Forschungsgesellschaft mbH, A)

Connecting 3D-CAD and Finite Element Simulations - Approaches, Problems and Solutions
A. Troll , F. Rieg, J. U. Goering (University of Bayreuth, D)

Materials Characterisation Using Image Based Modelling
F. Calvo (University of Manchester, UK)

Integration of Scalable Interactive Finite Element Analysis into the Design Process
L. Margetts (University of Manchester, UK)

Finite Element Modeling of Chip Formation Process: Possibilities and Drawbacks
P. J. Arrazola (Mondragon University, E)

Materials Characterisation
T. Dutton (Dutton Simulation Ltd., UK)

Confidence in the Use of Simulation
M. Neale (TRL Ltd., UK)

Integration of Simulation into the Design Process
R. Schweiger (TechnoStar, D)

6.6 *6*th Technology Workshop

Macdonald Burlington Hotel, Birmingham, UK
22nd & 23rd April 2008

The Consultation Process: The Structure of the Questionnaire – first Results
T. Morris (NAFEMS)

The Status of the AUTOSIM White Paper
H. Sippel (CAEvolution, D)

How to Move On?
H. Sippel (CAEvolution, D)

Automotive Simulation Centre Stuttgart - First Transfer Centre between Industry and the University of Stuttgart
E. Schelkle (Porsche AG, D)

Simulation Data and Process Management: Why PLM Integration is Critical to Success
G. Wills (Siemens PLM Software, UK)

Virtual Vehicle Development: Requirements for Safety CAE
M. Buckley (Jaguar Land Rover, UK)

Current Status and Future Trends in CFD
F. Mendonca (CD-adapco, UK)

Optimisation and Robust Design for Car Body Development
F. Duddeck (Queen Mary University London, UK)

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8. Appendix 1: Glossary of Terms

- **Best Practices:** How we currently make the best use of available technologies and procedures to tackle engineering problems with near-optimum results.

  In this regard, AUTOSIM aimed to identify opportunities to better exploit functionality of available methods and tools. A further aim was to propose actions on the side of dissemination, training, standards and technological development to overcome barriers in topics where the state of practice is low.

- **Breakthrough Technologies:** Novel or revolutionary technologies and procedures required to successfully solve the engineering problems within the next 10 years.
  In this regard, AUTOSIM aimed to identify needs for which basic or radical technological development is required to overcome a lack of available technology. A further aim was to specify emerging technologies requiring further R&D to progress over the concept proof through the feasibility stage.

- **CAD:** Computer Aided Design

- **CAE:** Computer Aided Engineering

- **CAM:** Computer Aided Machining/Manufacturing

- **CAT:** Computer Aided Testing

- **CFD:** Computational Fluid Dynamics

- **Conceptual Simulation Models:** Often, very simple models, bearing less resemblance to the final CAD model, which can provide more insight in a shorter period of time than can a more complex and highly detailed solution.

- **CSM:** Computational Structural Mechanics

- **Design Grammar Rules:** or (engineering) design languages offer a graph based design representation. They are aimed at the automation of model generation and model update and are inspired by the concept of natural language using “language grammar”.

- **Knowledge Data Mining and associated Data Referencing:** Highly visual and interactive tools for post-processing of e.g. multi-objective optimization results.

- **Multi-Domain Simulation:** Physical modelling and simulation of complex systems with mechanical, electrical, thermal, fluid flow, and feedback control components.

- **MDO: Multi-Disciplinary Optimization:** Find the optimum solution for a complex multi-disciplinary design problem considering a given number of design variables.

- **Multi-Disciplinary Simulation:** Simulation results obtained for one discipline are transferred and used as loads or boundary conditions for the simulation of another discipline. The data transfer is unidirectional only.

- **Multi-Physics Simulation:** Simulation of bi-directionally coupled physical phenomena at the same time and location.

- **OEM:** Original Equipment Manufacturer

- **Parametric – Vehicle – Concept models:** Generation of parametric geometry models based on the available design space, topology, packaging information, styling etc. with or without CAD information.

- **PDM:** Product Data Management

- **PIDO:** Process Integration and Design Optimization

- **NVH:** Noise Vibration Harshness

- **SDM:** Simulation Data Management

- **Symbolic CAE models:** Symbolic parametric mathematical models for functional layout in the early product design stage.

- **Tier 1 Supplier:** Organisation supplying equipment or services directly to an OEM.

- **Tier 2 Supplier:** Organisation supplying equipment or services to a Tier 1 company.

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a NAFEMS Project

- **Up-front Simulation**: Methodology to do more simulation (activity front-loading) and to re-use predecessor simulation models (knowledge front-loading) as early as possible in the product development process.

  The main focus for up-font simulation within the AUTOSIM project is CAE driven concept design and decision making process to obtain result trends during the concept phase (fast evaluation of different vehicle concepts).

- **Validation:** describes the process of determining the accuracy that the simulation matches the behaviour of the structure or process under investigation. Typically the process of validation involves establishing the accuracy with which model predictions match comparable experimental results.

- **Verification:** is the process of determining that the fundamental behaviour of a simulation is consistent with the fundamental laws of motion, energy conservation and momentum. Verification of a model establishes that the physics of the simulation are correct.

- **Virtual Prototype**: Computer-based simulation of a system or parts thereof with a degree of realism comparable to a physical prototype.