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The Role of Advanced Engineering Simulation in Model-Based Design

P.J. Hommert and J. H. Biffle
Engineering Sciences Center
Sandia National Laboratories

The agile manufacturing paradigm engenders many new concepts and work approaches for manufacturing operations. A technology often invoked in the concept of agility is modeling and simulation. Few would disagree that modeling and simulation holds the potential to substantially reduce the product development cycle and lead to improve product reliability and performance. Advanced engineering simulation can impact manufacturing in three areas: process design, product design, and process control. However, despite that promise, the routine utilization of modeling and simulation by industry within the design process is very limited. Advanced simulation is still used primarily in a troubleshooting mode examining design or process problems after the fact. Sandia National Laboratories has been engaged in the development of advanced engineering simulation tools for many years and more recently has begun to focus on the application of such models to manufacturing processes important for the defense industry. These efforts involve considerable interaction and cooperative research with U.S. industry. Based upon this experience, this presentation examines the elements that are necessary for advanced engineering simulation to become an integral part of the design process.

First, it is necessary to define what is meant by advanced engineering simulation. Obviously this is a broad term that cannot have a single definition. Therefore, it is best illustrated through examples of physical phenomena or geometric complexity that continue to recur as being important in the simulation of design or process control applications.

Characterisitics of Advanced Engineering Simulation

Three dimensional geometries (models) with complex part/part interfaces

Multiple materials with often substantially different response characteristics

Significant material non-linearities such as non-newtonian behavior, plastic deformation, visoelasticity, anisotropy, localization, and failure

Multi-phase phenomena

Multi-mode energy transport with chemical reactions

Moving or free boundaries

Non-linear structural dynamics

Phase change, including solid phase transitions

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MASTER

This list was developed through collaborative research with industry that involved the following manufacturing processes.

Example Manufacturing Processes that invoke Advanced Engineering Simulation

Casting

Coating (Continuous and Spray)

Polymer Processing

Induction Hardening

Plasma and Chemical Vapor Deposition Processes

Foam Processing

Metal Forming (Drawing, Punching, Machining)

Material Removal

Joining (Welding, Soldering, Brazing)

These two lists, which are not intended to be complete, indicate both the complexity that can accompany a manufacturing application and the diversity of applications for which engineering simulation can be important. There are a number of implications to these complexities. First, significant demands will be placed upon the computing environment for model-based design since the mere combination of any one of these complex phenomena and three dimensions implies a compute-intensive application. Second, many of these phenomena, even at a very macroscopic level, remain active areas of engineering research. Thus the risk is always present that if the underlying research is not conducted, the computing infrastructure may outpace the physics treatment included in the calculation. Finally, it is unrealistic to expect a designer or process engineer to be knowledgeable, other than in a global fashion, with the details of these phenomena. Thus it is imperative that advanced engineering simulation be packaged in an intelligent design environment that can be utilized by the appropriate target population within manufacturing.

It is not the purpose of this presentation to detail the research issues and status around the phenomena listed earlier. Suffice it to say that considerable progress continues to be made in all these areas through work conducted throughout the engineering research community. There are nearly continuous advances that are available to be incorporated into an engineering simulation environment that supports model-based design. With this background, what then must be the elements of an intelligent design environment if advanced engineering simulation is to be incorporated integrally with design?

We believe the following technologies are critical to creating the software system that will be necessary to achieve model-based design.

Technologies Critical to Realizing Advanced Engineering Simulation within Model-Based Design

User interface design

Analytical solid modeling

Advanced mesh generation algorithms for shells and solids

Efficient computational tools capable of solving large, multiphysics, and nonlinear problems

Solution error analysis and adaptivity

Objective function design for optimization

Object-oriented software engineering

Massively parallel computing

Visualization

When all these technologies are integrated it will be possible for a designer to create a model, apply service loads to the solid model description, and visualize the results. Designers who understand mechanics but not the analysis method can design a product and a manufacturing process for producing the product. This will require the use of adaptive analysis techniques which take advantage of advanced mesh generation techniques, error analysis, and computing. Adaptive capability is necessary to insure the accuracy of the analyses. Since the important geometric features can be parameterized, shape optimization will be available.

It is important to understand the technology elements listed above. Each one is briefly explained below.

User interface design

The interface is the critical pathway for the designer to access the underlying power of simulation. If the interface is inadequate in any of the following areas the overall ability to impact the design process will be compromised. The interface must be user friendly -- seamlessly linking together all the various subelements critical to an overall simulation (solid model, mesh generation, solver, visualization, and optimization). Furthermore, the interface must contain the intelligence to guide the designer through material property data bases and perhaps most important, contain the intelligence to define the parameter space within which the simulation is applicable. This is important to prevent erroneous application of a model especially for users that are not experts in engineering sciences.

Analytical solid modeling

The infusing of solid modeling tools for design has been a boon to the designer to describe the part and view the results. For the most part, however, these CAD modelers do not produce an analytical model which is suitable for analysis. Analytic description of the surfaces and volumes are needed so mesh generation algorithms can reliably place nodes on the surface of a model and create nodes internal to the volume. Tighter integration of advanced meshing algorithms with CAD systems is needed with the use of analytical solid modeling. In addition, solid modeling software must become more flexible allowing the solid model detail to be a function of the type of analysis.

Advanced mesh generation algorithm for shells and solids

To successfully provide an adaptive analysis capability to a designer, advanced mesh generation algorithms are needed. The ultimate objective of all the adaptive algorithms is the requirement that a suitable mesh be generated on an arbitrary geometry without the analyst having to decompose the geometry. This will require meshing algorithms which can place elements in a volume to the prescribed requirements of the analysis technique.

Efficient computational tools

Even with the continued advances in computing capabilities, advanced engineering simulation cannot be performed without highly efficient solution algorithms. Innovative solution techniques are needed for treating computationally intensive phenomena, examples of which include contact search algorithms, sparse matrix inversion, constitutive equation integration, and visualization.

Solution error analysis and adaptivity

Given that a meshing algorithm exists that can be controlled to produce the right size elements in the volume or on surface that is being analyzed, the computational technique must be able to specify to the meshing algorithm the size and distribution which is needed for an accurate analysis. The is done by accessing the accuracy of the solution and modifying the mesh locally based on an error calculation. The error analysis, while approximate, must produce a convergent iterative process to obtain an appropriate mesh given a predescribed error value.

Objective function design for optimization

Given that an analysis technique is available which can produce an analysis when the design is changed, the analysis technique can be incorporated into a design optimization program. However, there remains the task of designing the objective function for use in the optimization process. For example, if cost is the function of interest, all the cost factors of a manufacturing process must be characterized. This implies a greater utilization of statistical concepts, non-deterministic solution methods, and inverse solution methodologies.

Object-oriented software engineering

Because we anticipate a much more complicated software system, object-oriented software engineering, with its promise to allow more complex programs to be reliably written, is being tried. The experiences to date suggest that while, in concept, object-oriented techniques are very powerful, care must be taken in the design of the software system. However, we expect that object-oriented approaches will be the programming technique of the future.

Massively parallel computing

The modeling of manufacturing processes requires a highly complex and nonlinear analysis capability. Massively parallel computers have made available the ability to model more complicated processes. More accurate material models and more complicated geometries can be modeled. Designers will be able, with increased compute power, to make fewer assumptions and therefore produce more reliable design decisions. They can perform parameter sensitivity studies to insure that the manufacturing process is robust to changes in design.

Visualization

It is important to visually present to the designer information with which design decisions can be made. Since the models are complex in that more physics are included in the model, the designer must have tools to understand the data. The software and hardware capability for visualization must keep pace with the growth of analysis code capability and massively parallel computing capability. Very large data files must be processed. Virtual reality systems provide a new “visualization” perspective with the potential to invoke other human senses along with visual to understand the solutions.

The development of these technologies requires multi-disciplinary teams involving experts in computer science, engineering science, human factors engineering, mathematics, and computer-aided design. Developing and coordinating these teams will be one of the challenges facing managers charged with bringing advanced engineering simulation within model-based design to a reality.

In summary, the vision is that design software will progress to the development of simplified analysis capability for use by the designer of the manufacturing process or the product. For example, it will only be necessary for the design engineer to define geometry and the manufacturing steps to study the process. The designer will not be required to generate meshes or understand the analysis methods. Eventually an information system specific to a particular product can be developed which will completely characterize the manufacturing process and design of the product. When this is realized, the designer can explore different designs in a highly enriched self-learning environment. This information system will have embedded within it the advanced analysis elements that have been discussed in this overview.