-39

187838

p-13

N94-19472

Directions for Computational Mechanics in Automotive Crashworthiness

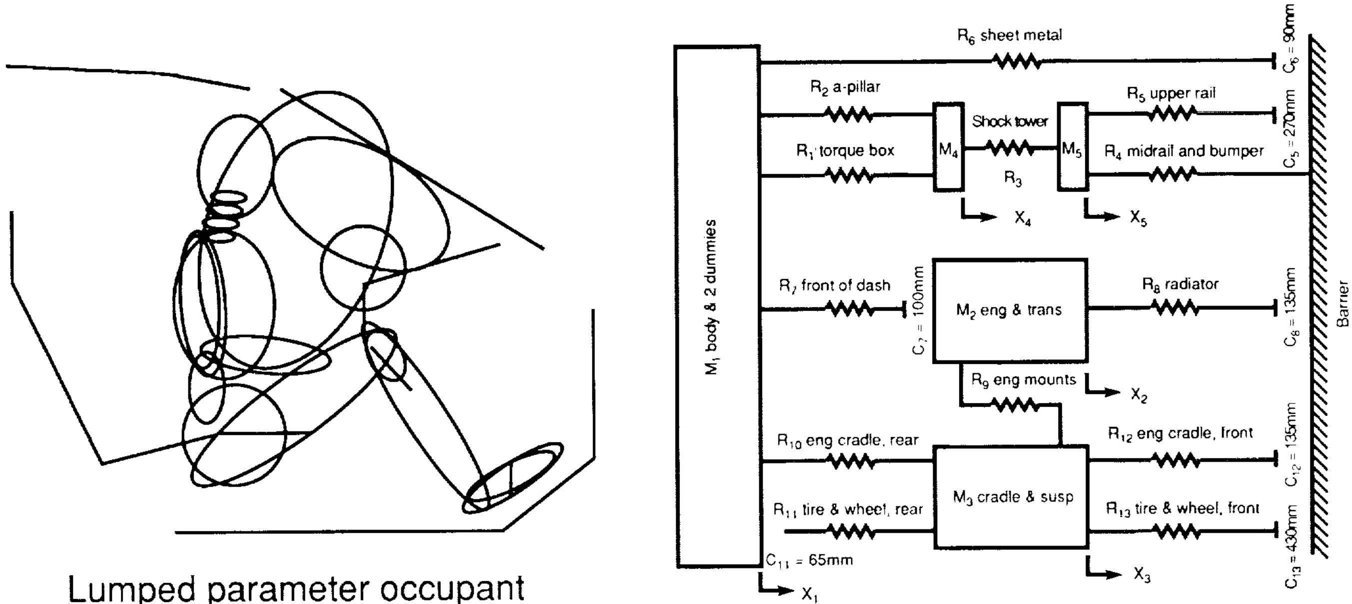
James A. Bennett and T. B. Khalil
General Motors
Warren, MI

INTRODUCTION

The automotive industry has used computational methods for crashworthiness since the early 1970's. These methods have ranged from simple lumped parameter models to full finite element models. The emergence of the full finite element models in the mid 1980's has significantly altered the research direction. However, there remains a need for both simple, rapid modeling methods and complex detailed methods. This paper will discuss some directions for continuing research.

142 [illegible]

Although the design problem in automotive safety is coupled, traditionally automotive crashworthiness analysis has been separated into methods that address the structural performance and methods that address the occupant performance. The coupling is usually handled by using the results of the structural analysis, typically passenger compartment accelerations and some panel motions, as input into the occupant analysis. In addition, a wide range of modeling methods are used ranging from simple lumped parameter models to full nonlinear finite element models and including virtually all possible intermediate hybridizations. The simple models have the advantages of ease of generation and interpretation with some sacrifice of accuracy, whereas the finite element methods have the potential to express our best knowledge of mechanics but at the expense of model creation and computational time.



Lumped parameter occupant model with air cushion

Lumped mass structural model

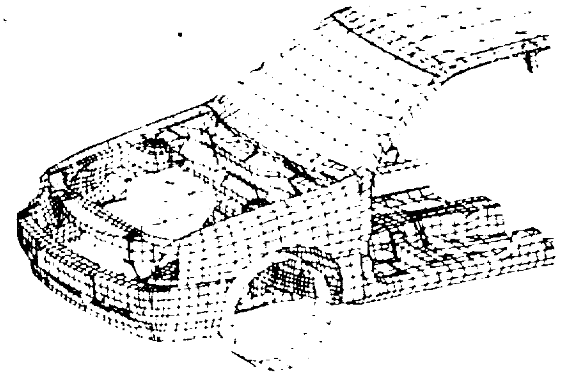


Figure 1. Typical computational models.

USE OF NONLINEAR FINITE ELEMENT METHODS

Since the thrust of this workshop is to focus on new directions in computational methods, this presentation will concentrate on the finite element methods. By now virtually every automotive company has published simulations using one of the many commercially available nonlinear finite element programs. These simulations are reaching significant complexity, showing front, side, rear, car-to-car and angled impacts. The typical results that are shown are a deformed mesh plot and some overall measure of accuracy, typically a passenger compartment deceleration.

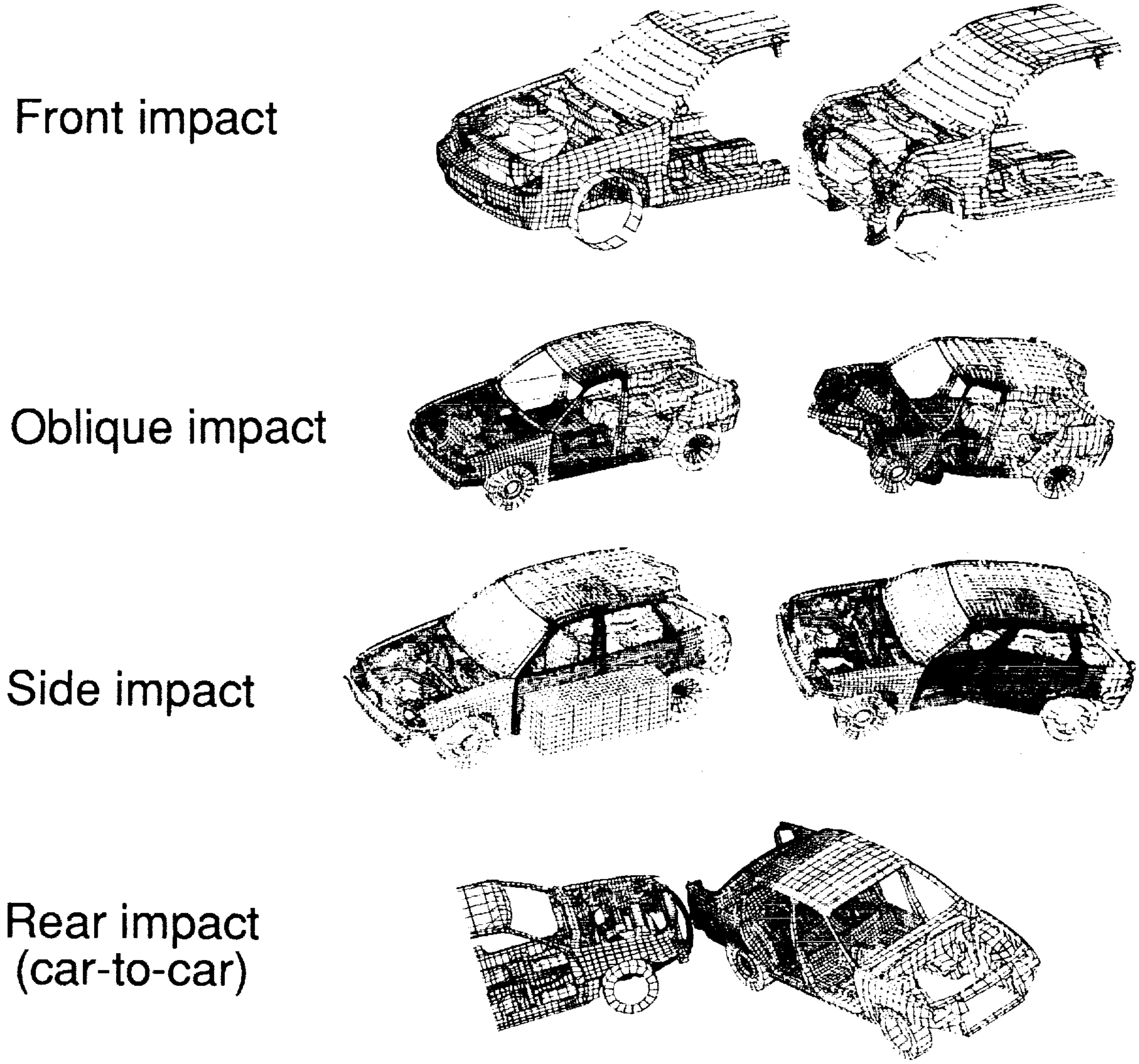


Figure 2. Typical nonlinear finite element results (Ref. 1).

OCCUPANT MODELS

Although most of the published work has focused on the structural models, some work is starting to appear on interior components and the occupant. Typically, the occupant modeled is the mechanical surrogate used in tests rather than the actual human. In these cases the accuracy of the finite element model is compared to the performance of the mechanical surrogate, called the anthropomorphic test dummy (ATD) rather than to the human response. The performance requirements for the ATD are specified based on bio-mechanical modeling of the human. Federal mandated standards are based on mechanical quantities (acceleration, force) that are measured on the ATD. Thus, in the figure below the human cadaver results were used to establish a corridor of behavior in which the Hybrid III ATD chest should perform.

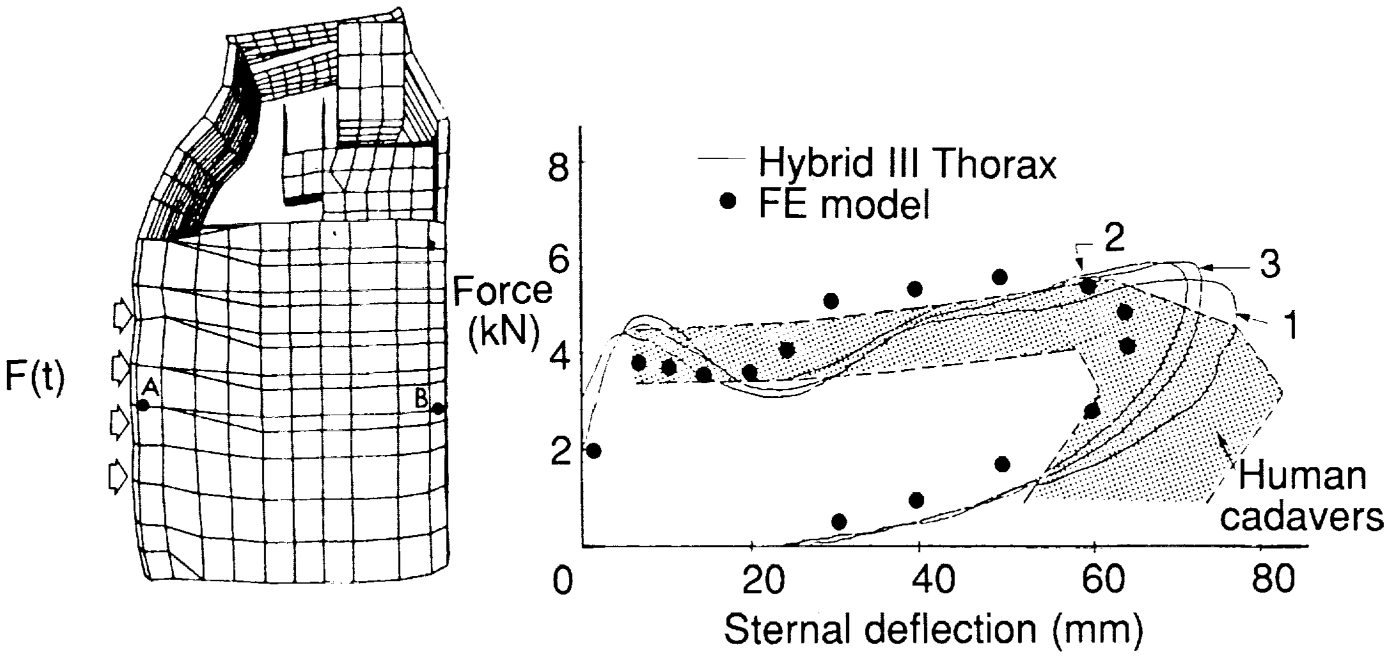


Figure 3. ATD thoracic response for pendulum impact (Ref. 2).

SO WHAT ARE THE PROBLEMS?

Reading the literature, one would conclude that nonlinear finite element methods are a well used and understood technology and that there is relatively little research work that needs to be pursued. We believe that there are four areas that need to be examined. First, the published work tends to mask a real difficulty in capturing local details of response that can be significant in crash performance. There is a dearth of appropriate failure models of any except the traditional isotropic materials. The issue of implementation for these techniques on the next generation of parallel computers is important. Finally, how these models are integrated in a rapidly shrinking design cycle must be addressed.

1. **ACCURACY OF LOCAL DETAILS**
2. **MODELS FOR NON-TRADITIONAL MATERIALS**
3. **MASSIVELY PARALLEL IMPLEMENTATIONS**
4. **DESIGN**

Figure 4. Issues to be addressed.

FIDELITY OF LOCAL MODELS

The literature rarely contains the efforts that are expended to produce high quality local results that ultimately lead to high quality global results. In this figure two models of an engine cradle are shown. The engine cradle is used to attach the engine to the front rails in a front wheel drive vehicle. The difference in these two models is the inclusion of the small lightening holes which are approximately 1 cm. diameter. The subsequent difference in geometric failure modes defines how the engine will move in the crash and may lead to a significant difference in occupant behavior.

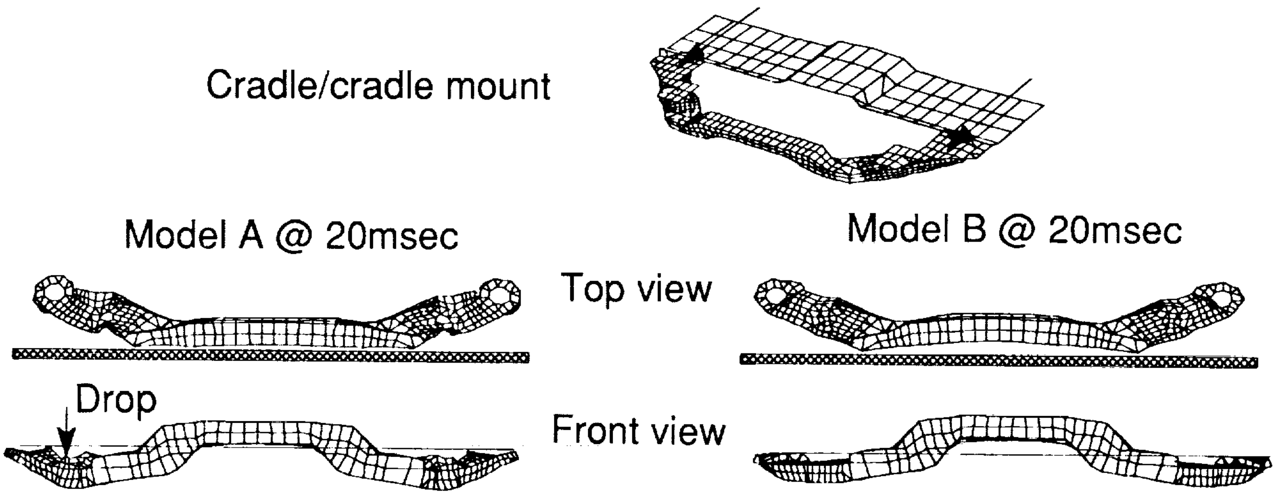


Figure 5. Two detailed models of an engine cradle (Ref. 3).

FIDELITY OF LOCAL MODELS

A second example is the rail shown below. The difference in the two models is the level of mesh density. Clearly the failure modes are different. While it is easy to dismiss these two examples as trivial examples of modeling techniques, virtually every project that we are aware of has encountered similar difficulties that could not be resolved without careful examination of test results and repeated remodeling. To become an effective design tool we need to be able to better understand the complexity of modeling required to make design decisions.

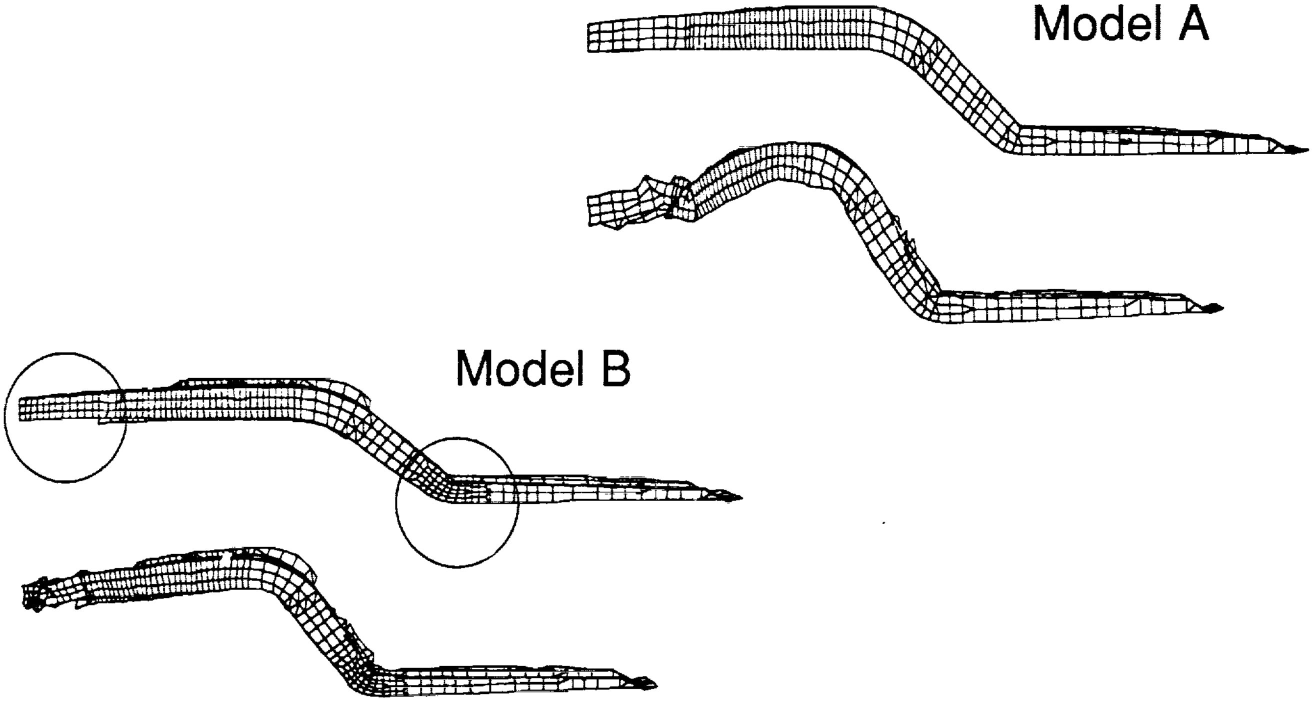


Figure 6. Influence of mesh density on front rail response (Ref. 3).

MATERIAL MODELS

As indicated earlier the current suite of effective material models available in the nonlinear finite element programs is somewhat limited to isotropic materials. Although there are current efforts to model non-traditional materials, our success rate for modeling nonlinear and failure behavior of non-traditional materials for design is not strong. In particular, we see a need to model fabric (airbag), composites (chopped and continuous), honeycombs, and foams.

NONTRADITIONAL MATERIALS

AIRBAGS

CHOPPED AND CONTINUOUS FIBER COMPOSITES

HONEYCOMB

FOAMS

Figure 7. Non-traditional materials.

COMPUTATIONAL EFFICIENCY

There is a widespread belief that the next big leap in computational efficiency will come from the massively parallel computer architecture. There is also a belief that this will require fundamental changes to the current group of codes that are being developed. As the figure shows, for example, significant speedups can be obtained if contact algorithms are properly implemented. If the changes needed to implement these massively parallel versions of existing codes are as great as presently thought, it is possibly a project for which a cooperative approach would be appropriate.

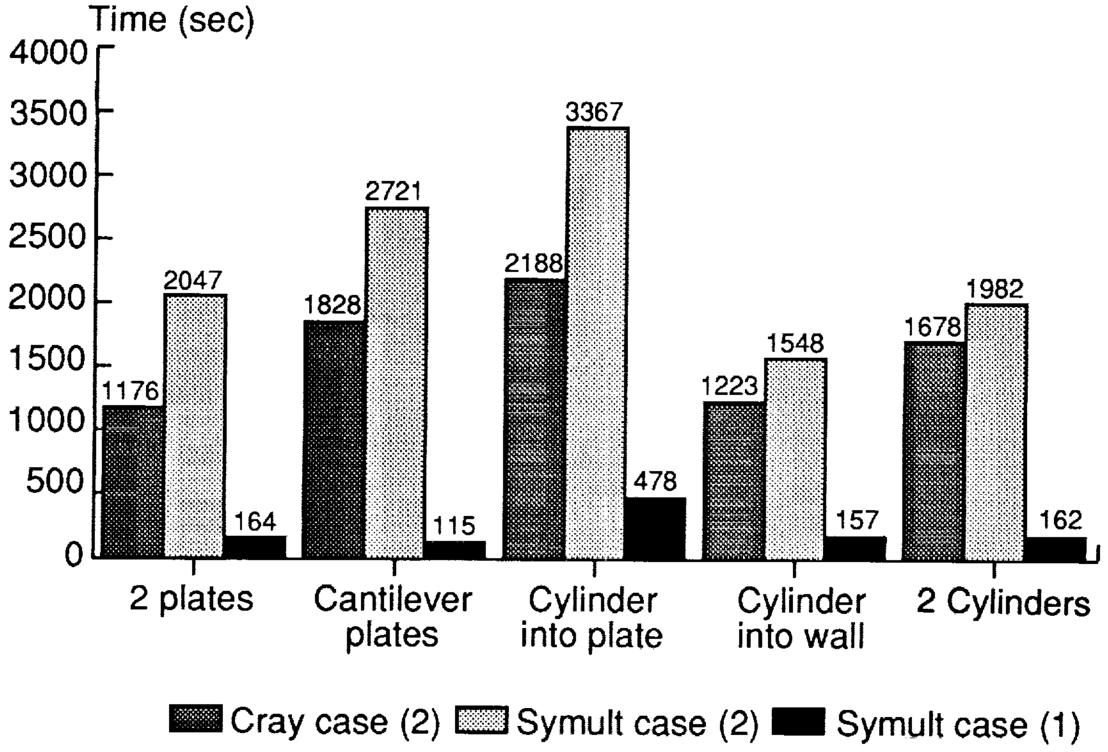


Figure 8. Comparison of execution times for case(1) (improved parallel contact) and case (2) (no parallel contact) (Ref. 4).

DESIGN ISSUES

Currently it takes from three to six months to develop a validated full vehicle finite element model that can be effectively used for design direction. With the current push to reduce the automotive vehicle design cycle into the 24-month time range, this model building cycle is clearly unacceptable. Thus, even if we cut the execution time for the codes to minutes rather than hours, we still may not have significantly affected the design process. Although fully automatic mesh generators for two-dimensional fields have been around for almost ten years (for both triangles and quads), they have not been effectively used for assembled structures. This suggests that more work needs to be focused on this critical problem.

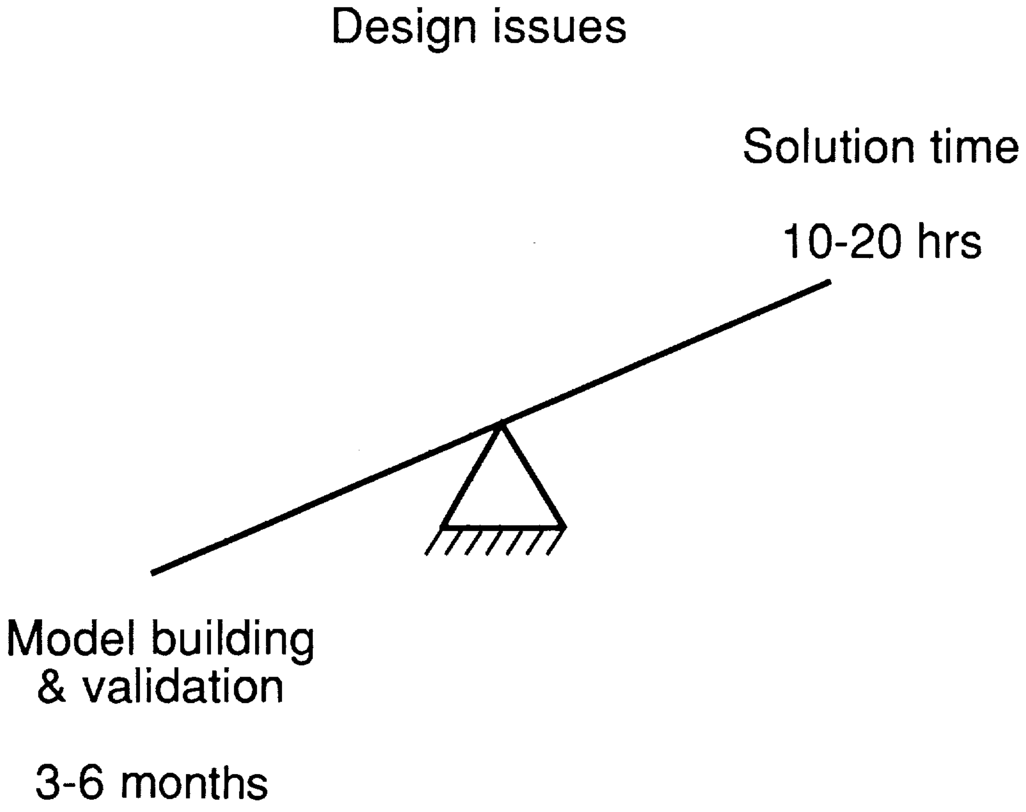


Figure 9. Significance of improved modeling methods.

DESIGN ISSUES

Finally, although linear elastic structural optimization is one of the most developed fields of engineering design research, there have been a mere handful of papers in the area of crashworthiness optimization. Based on work in linear elastic structural optimization, there are two potentially fruitful areas of research. First, there is the question of efficient calculation of sensitivity information. This is made doubly difficult because of the presence of nonlinearities introduced by contact. Second is the idea of constructing inexpensive, robust local design space approximations. In the example shown below, a lumped mass model was used as the local approximation and the finite element model was used only at a few number of points in the design space.

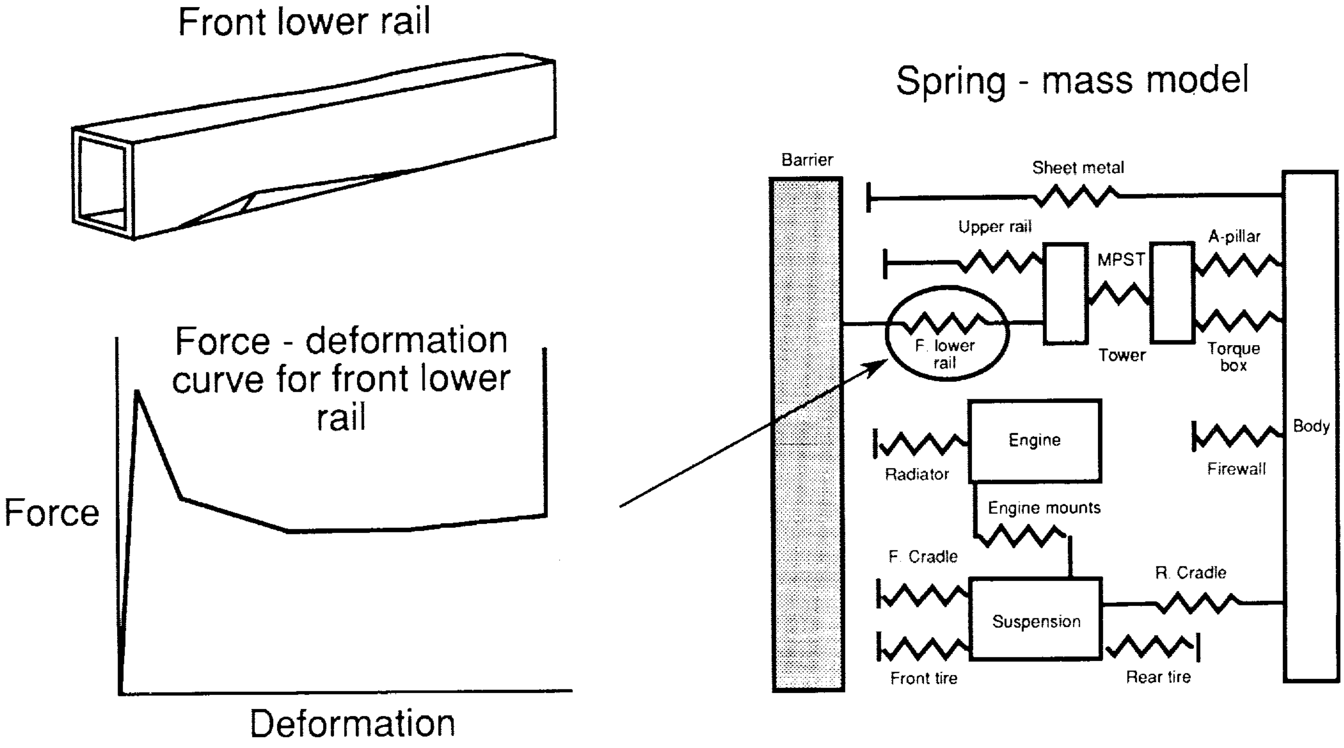


Figure 10. Optimum design with crashworthiness constraints (Ref. 5).

REFERENCES

1. Kaiser, A., "Some Examples of Numerical Simulation in Vehicle Safety Development," Proceedings of the Eighth International Conference on Vehicle Structural Mechanics, Society of Automotive Engineers, 1992, pp. 107-117.

2. Khalil, T. B. and Lin, K. H., "Hybrid III Thoracic Impact on Self-Aligning Steering Wheel by Finite Element Analysis and Mini-Sled Experiments," Proceedings of the 35th Stapp Car Crash Conference, Society of Automotive Engineers, 1991, pp. 73-84.

3. Sheh, M. Y. and Reid, J. D., "Vehicle Crashworthiness Analysis Using Numerical Methods and Experiments," Proceedings of the Eighth International Conference on Vehicle Structural Mechanics, Society of Automotive Engineers, 1992, pp. 119-128.

4. Malone, J. G. and Johnson, N. L., "A Parallel Contact Algorithm for Finite Element Analysis of Shell Structures," Proceedings of the Eighth International Conference on Vehicle Structural Mechanics, Society of Automotive Engineers, 1992, pp. 165-170.

5. Lust, R., "Structural Optimization with Crashworthiness Constraints," General Motors Research Laboratories Publication, GMR-7154, Sept. 1990.