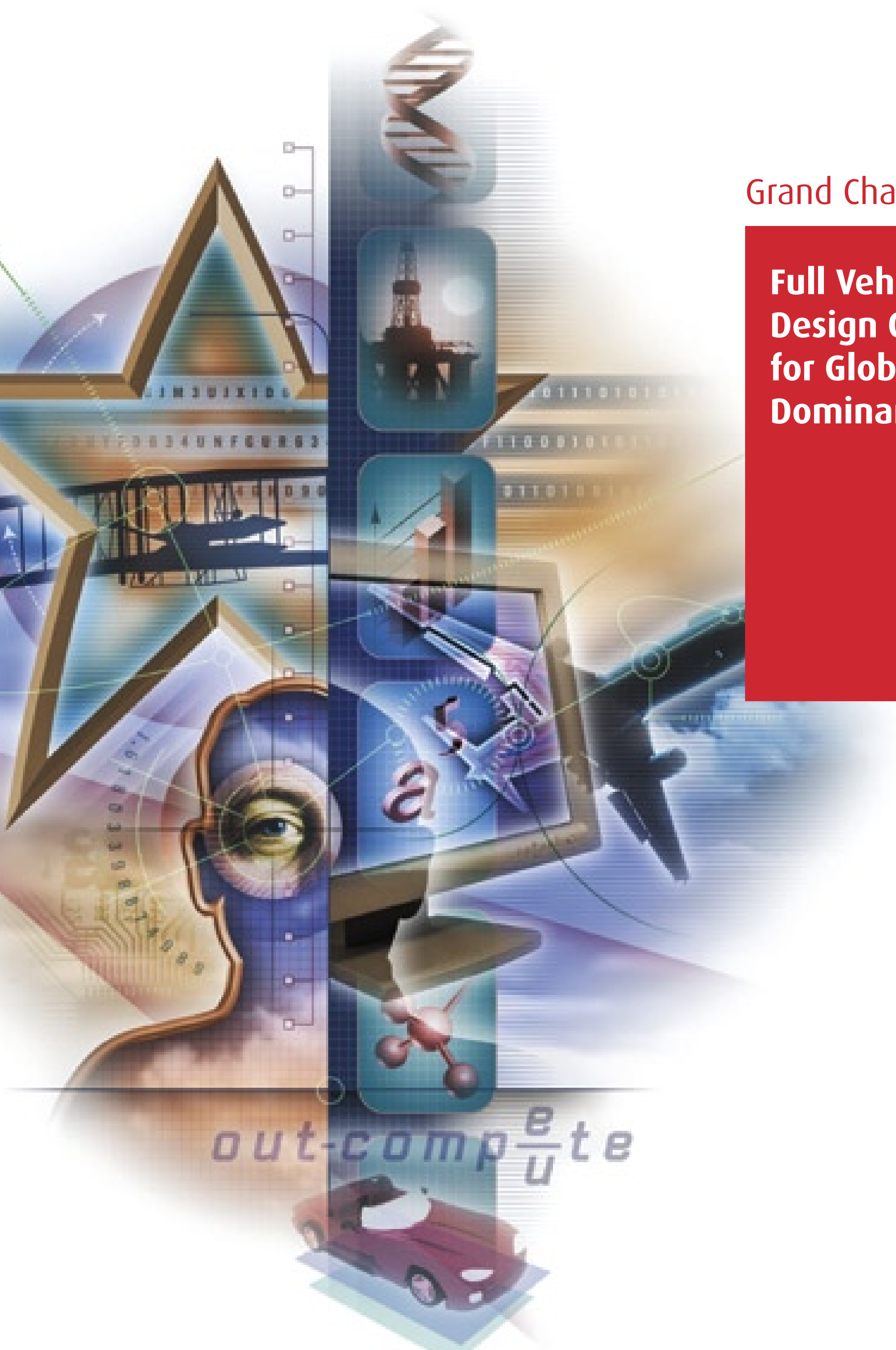
High Performance Computing and Competitiveness



Grand Challenge Case Study

Full Vehicle Design Optimization for Global Market Dominance

Council on Competitiveness

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The introduction and broad application of modern high performance computing during the past two decades has dramatically transformed the automotive design and engineering process. For example, auto manufacturers now simulate collisions on high performance computers, saving millions of dollars in development costs and substantially shortening design cycle times. Despite the impressive gains in using high performance computers to advance vehicle design, market and regulatory requirements often compete with each other making it difficult to achieve an optimal design. Even though the requirements are interdependent, current computational tools can only address these competing requirements through multiple, independent simulations. The next high-payoff high performance computing grand challenge is to optimize the design of a complete vehicle by simultaneously simulating all market and regulatory requirements in a single, integrated computational model. Meeting this challenge could generate billions of dollars in benefits but requires dramatically more compute capability than is available today.

Two Decades of Advances Enabled by High Performance Computing

Twenty-five years ago, automotive companies built and tested physical prototypes to assess new designs and concepts for cars and trucks. This approach was both time consuming and extremely expensive. Launching a new car model, for example, took about 5 years in 1980, from conception to production of a complete car, and typically entailed the building and crashing of many prototypes.[1]

The introduction and broad application of modern high performance computing during the past two decades has dramatically transformed the automotive design and engineering process. Design cycle times have been reduced by as much as 60 percent, and the productivity of the cycle has increased through the delivery of dramatically improved vehicle performance, safety, and durability at a reduced cost.

Instead of building and crashing multiple physical prototypes, auto manufacturers now simulate collisions on high performance computers by creating mathematical cars and "crashing" them into mathematical objects. This application of high performance computing has reduced the number of physical prototypes that must be assembled and tested, while dramatically increasing the number of major design alternatives that can be assessed feasibly. The result has been millions of dollars in development cost savings and substantially shortened design cycle times. A General Motors representative stated that using supercomputers in place of physical prototypes had reduced engineering costs by 40 percent.[2] By the late 1990s, the time to launch a new automotive model had fallen to 2–2.5 years at most companies, and at least one of the big three auto manufacturers believes it can cut the time to 15 months.[1]

Computational Modeling and Simulation Now Drive the Development and Evaluation Cycle of Virtually Every Design Requirement

Auto manufacturers must address consumer demands as well as government regulatory requirements if a vehicle is going to have a successful entry and sustained run in the market. For example, research may suggest that there is a market opportunity for a family-oriented SUV. The market demands that the design "turn heads" for kids, moms, and the traditional male customer; that the vehicle be safe; that it drive smoothly in rough terrain as well as on neighborhood streets; and that the interior be quiet enough so that the occupants do not hear their car operating or any outside noise. In addition, the manufacturer must meet EPA fuel efficiency requirements and government safety regulations.

In order to move a new vehicle from concept to showroom delivery, auto manufacturers use high performance computing to model and simulate component and subsystem designs, applying different computational disciplines to address each requirement. (See Figure 1.)

For example, a family of structural analysis application software enables evaluation of the crashworthiness (and therefore safety) of the design, as well as its structural capacity to withstand rough terrains. Computational fluid dynamics applications enable aerodynamic simulation and

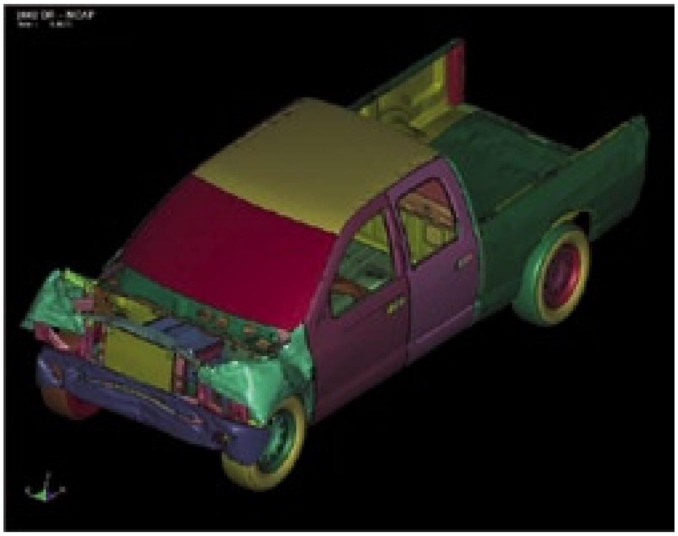

Figure 1 Frame from vehicle simulation.

internal combustion simulation to evaluate fuel efficiency. Table 1 shows some of these market and regulatory requirements that auto manufacturers must regularly consider, and examples of computational disciplines employed in the modeling and simulation process.

Despite the impressive gains in using high performance computing to advance component and subsystem designs, market desires and regulatory requirements often compete with each other making it difficult to achieve an optimal design of an entire vehicle. For example, if the results of a side-impact crash simulation suggest that the vehicle's doors need to be strengthened, the manufacturer could decide to use a stronger material for those parts. While the vehicle would now be more crashworthy, the additional weight could degrade fuel efficiency, increase costs, complicate manufacturing, or impact regulatory compliance.

Even though the requirements are interdependent, limitations of current computational tools force design engineers to address these competing requirements using multiple simulations of independent models. Each simulation generates data that must be integrated iteratively into the simulations of every other requirement. (See Figure 2.)

This is a difficult, time consuming process, and often cost and/or schedule constraints force acceptance of a "best we can achieve" solution that is short of the optimal design. As a result of this inability to simulate interdependent requirements concurrently in a single model, auto manufacturers confront competitive challenges of higher modeling and simulation costs, less-than-optimal designs, and delayed time to market.

A Grand Challenge: Full Vehicle Design Optimization

The auto industry faces a demanding grand challenge that offers a potential high payoff: *Optimize the design of a full vehicle by simultaneously simulating all market and regulatory requirements in a single, integrated computational model, often referred to as a "multiphysics model" because it represents concurrently a vehicle's multiple physical attributes.* (See Figure 3.)

As one auto company computer expert put it:

> "We've solved some problems very well, but they were within a subject field. The approaches we have are lacking cross-compatibility. Each area by itself is very demanding, and if we could put them together, our requirements for supercomputing would be huge. We need investment to make the various kinds of software talk to each other. We haven't got that—nobody has got that. It's very daunting. But by having these different disciplines integrated, you'd have something unique that would convey a real competitive advantage. Furthermore, the ability to integrate here (in the auto industry) would have tremendous carryover to other applications. With this capability, we'd be able to get a product faster, and it would have cost us less. We would have the right product, we would have it sooner, and we would have it at a cheaper cost than if you did it any other way."[1]

Example Requirement Categories	Computational Discipline
Body Styling	3D Full Body Computer Aided Design
Crash Worthiness	3D Dynamic Structural Deformation Analysis
Vehicle Structural Integrity	Finite Element Structural Analysis
Fuel Efficiency	Computational Fluid Dynamics
Passenger Comfort (Noise & Vibration)	Acoustic & Finite Element Analysis

Table 1 Examples of the computational disciplines employed to meet market demands and regulatory requirements.

Such an integrated approach would enable the design team to observe even very subtle, and not well understood, implications of changes to seemingly unrelated requirements. Armed with new insight, more precise trade-offs could be

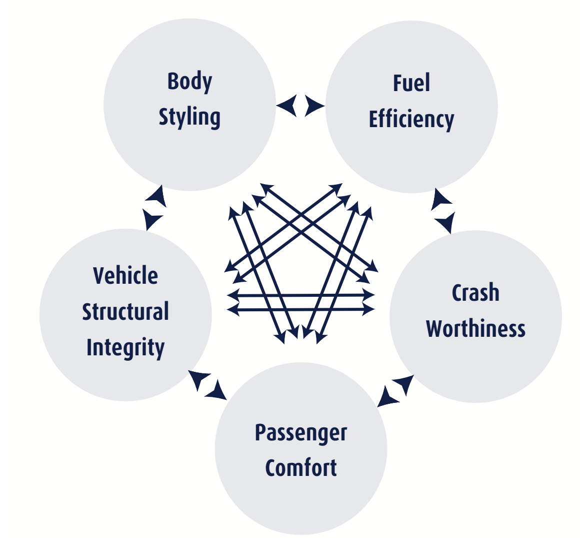

Figure 2 Data exchange between multiple simulations of independent models.

made earlier in the vehicle design process.

In order to develop such an integrated model, fundamental changes may be required in the underlying science embodied in the various application software suites used to simulate each design requirement. Because the resulting integrated model would be far more complex than any of the individual models used today, dramatically more compute capability would be required to execute each simulation within a reasonable time frame.

But how much more compute capability is needed to achieve this integrated approach? Executives from one company estimate that 100 times more compute capability would be required in order to achieve real advances in multiphysics modeling and problem solving. While they do not believe that these problems could be solved immediately, such compute capability would enable the development of needed methodologies.[1]

Executives from another company emphasized that computational problems should be turned around in one day, or ideally overnight, in order to impact design decisions. Today, this firm requires 30 days and 362 CPUs to run a medium-sized multidisciplinary design optimization problem, similar in concept to the iterative approach pictured in Figure 2 above. With today's technology, they would need 11,000 CPUs to run the same problem to meet one-day turnaround and 22,000 CPUs to achieve overnight results.[1] Clearly, dramatically more compute capability is required to run an integrated design optimization problem and achieve needed results within the time frames required to affect the design process.

Economic and Competitiveness Benefits

The auto industry's diverse and successful experience with high performance computing, and computational modeling and simulation, has created an environment poised to utilize the next generation of computational tools to a competitive advantage. Accelerating the development of integrated multiphysics models, therefore, can be expected to yield immediate, and in some cases dramatic, competitive benefits. For example, engineers will be able to evaluate more scenarios and more complex design options within the same or shorter time frame. The time to launch a new vehicle has already been reduced from an average of 5 years to 2–2.5. As manufacturers strive to reduce that time even further, there will be little or no opportunity to recover from design errors, or to make significant changes late in the design cycle, without the availability of integrated multiphysics models and the high performance computing tools to run them.

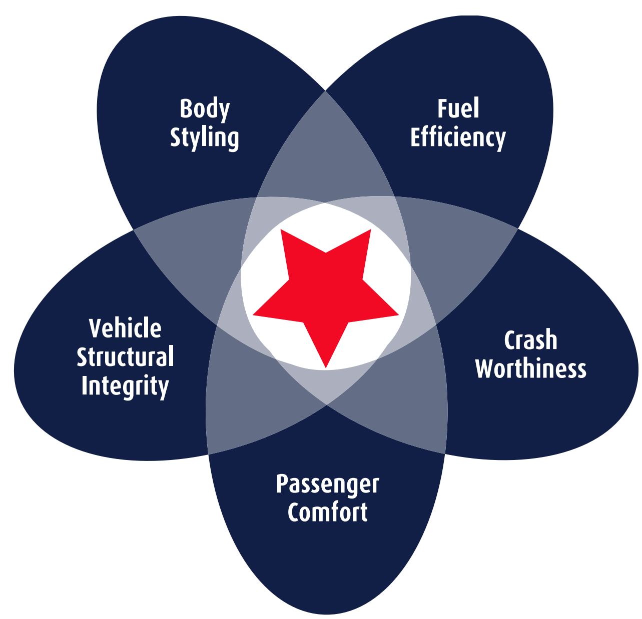

Figure 3 Integrated computational model generates optimal design.

Furthermore, design optimization across the entire vehicle will reduce risks introduced by unanticipated interactions

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of changing requirements. Producers will be able to deliver more rapidly customized vehicles that meet constantly changing consumer desires and emerging market niches, while still adhering to shifting regulatory requirements. This would result in potentially hundreds of millions of dollars in benefits through significant cost reductions, faster time to market, and maximum market penetration. Consumers stand to benefit by being able to buy—at an affordable price—cars and trucks from U.S. producers that appeal to more personalized tastes and are safer, more comfortable, more fuel efficient, more durable, and available on demand.

Executives from one company estimate that the "digital development" process would result in one-tenth the cost and one-third the time of traditional methods. According to another company's "rule of thumb," if the time to design a car can be cut in half, the costs can be cut roughly in half also because time and money are roughly proportional. Another company indicates that reducing time to market by one month offers potential cost savings of $10 million for that vehicle program. If this could be achieved for each vehicle program, the savings would add up quickly.[1]

The ability to respond to change with such precision and timing has the potential to transform the U.S. auto industry and to increase its share of the global automotive market. A U.S. government economic study estimated that just a 1 percent capture of additional market share by U.S. auto producers would yield an economy-wide gain in a single year of more than $4.4 billion, measured in terms of national industrial output and restated in 2003 dollars. The same study estimated that a 1 percent gain in global market share would increase national employment by tens of thousands of new jobs.[3]

Developing and implementing multiphysics models is more than a computational "grand challenge" for the U.S. auto industry. It is a competitive opportunity to develop an optimized vehicle that not only meets regulatory requirements, but addresses the market dream of the moment at an attractive price point, does not disrupt the company's development cycle, and reaches the marketplace ahead of the competition. With these models, U.S. manufacturers will be able to push beyond the competition. Without them, it will be difficult to even maintain current market share.[4]

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The Council on Competitiveness is a nonpartisan, nonprofit organization whose members are corporate chief executives, university presidents and labor leaders dedicated to setting an action agenda to drive U.S. economic competitiveness and leadership in global markets. The Council helps shape the national debate on competitiveness by concentrating on a few critical issues including national and regional innovation, competitiveness and security globalization, workforce development and the benchmarking of U.S. economic performance against other countries.

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The Council on Competitiveness is a nonprofit, 501(c)(3) organization as recognized by the U.S. Internal Revenue Service. The Council's activities are funded by contributitions from its members, foundations, and project contributions.

Design: Soulellis Studio

Cover Illustration: Tom White, tomwhite.images-illustration & design

Printed in the United States of America

Council on Competitiveness

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