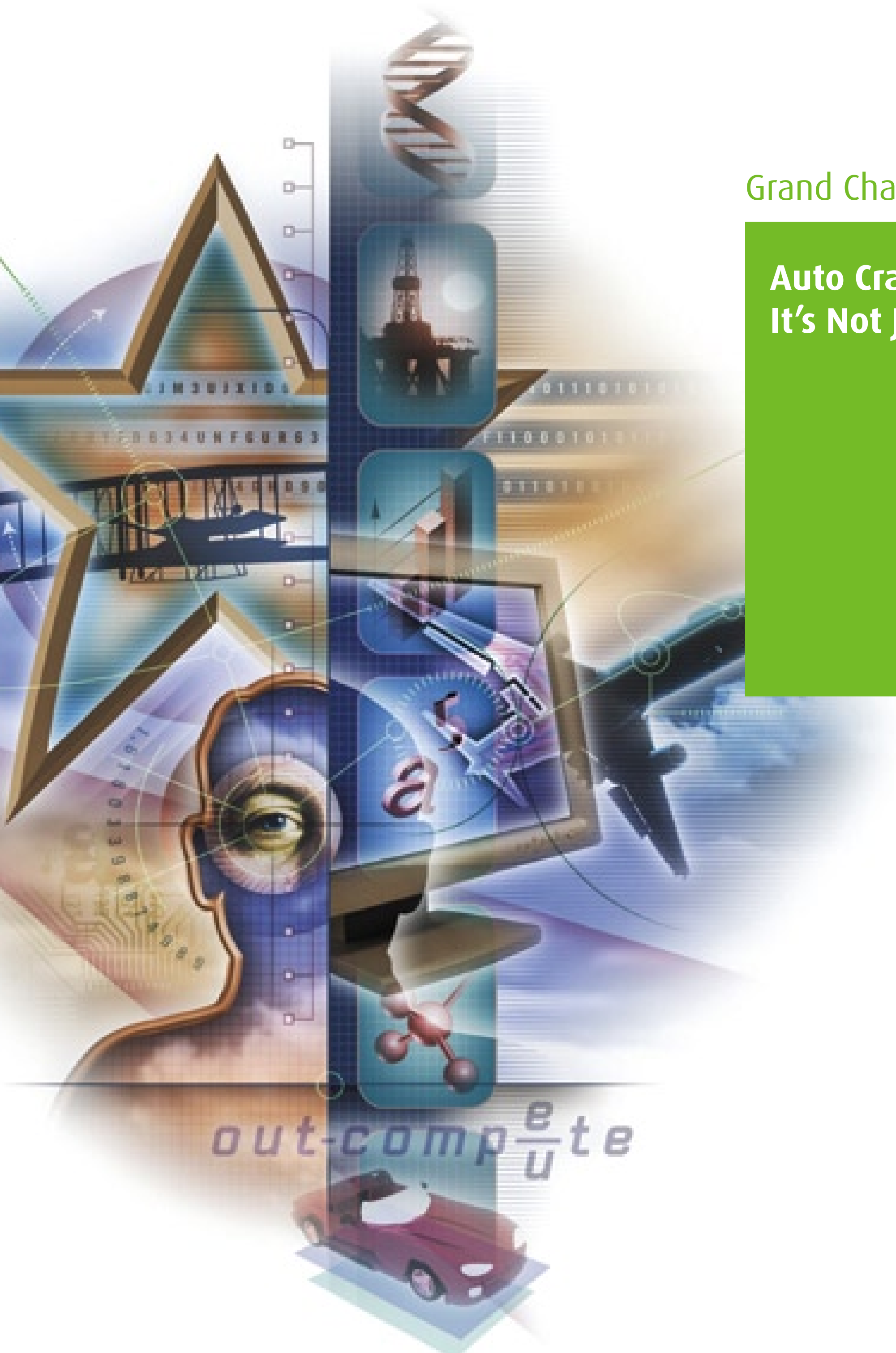
High Performance Computing and Competitiveness



Grand Challenge Case Study

Auto Crash Safety: It's Not Just For Dummies

Council on Competitiveness

High Performance Computing and Competitiveness

Grand Challenge Case Study

Auto Crash Safety: It's Not Just For Dummies

Until recently, auto companies tested alternative safety designs by crashing real vehicles with dummies inserted to represent human occupants. Now most crash tests are computer simulated, and the occupants are "virtual" dummies. Like their physical counterparts, virtual dummies lack much of the complexity of real people. The auto industry faces a daunting, grand challenge: Optimize the safety of a vehicle by measuring the effects of a crash on all of the physical attributes of the human body, not just on the structural characteristics of the vehicle and a mechanical dummy. In other words, we need to move from testing the car to testing the human. Such testing requires a mathematical model of the full human body, a "grand challenge" in itself to develop. The industry also will require orders of magnitude more powerful computing to integrate this highly complex model into its already complex crashworthiness simulations. If this can be done, breakthrough designs in automotive safety can be achieved, delivering enormous societal and economic gains through dramatically reduced injuries and fatalities from automotive crashes.

Auto Accidents: Unacceptable Human and Economic Loss

Automotive manufacturers are continuously working to enhance the safety of cars and trucks, and it is easy to understand why. The human tragedy from auto accidents is wrenching. In the United States, nearly 3 million motor-vehicle crashes killed more than 40,000 people in 2000 and caused more than 5 million non-fatal injuries.[1] With the number of vehicles on the road growing, and the number of miles driven steadily rising, the annual crash death toll is expected to reach 51,000 by 2005.[2]

While the human toll is sobering, the economic impact is staggering. The lifetime economic cost to society for each fatality is estimated at about $1 million, largely due to lost productivity in the workplace and in the household. The economic cost of each critically injured survivor averages slightly more than $1 million, mainly in medical costs and lost productivity.[3] In 2000, vehicle crashes in the United States are estimated to have accumulated total medical costs of $32.6 billion, lost productivity (both market and household) of $81 billion, and an array of related costs including emergency services, insurance administration, workplace costs, and legal costs, totaling another $32.3 billion.[2]

Thus, the direct economic costs of deaths and injuries sustained in motor vehicle crashes are estimated to total $146 billion annually. In addition, there are intangible consequences of death and injury, such as pain and suffering, which are estimated to be an order of magnitude higher than the economic costs of the injuries.[2] Making cars and trucks safer has the obvious potential to save thousands of lives, eliminate thousands of injuries, and deliver enormous economic gains.

Making Vehicles Safer with High Performance Computing

Simulating the crashworthiness of vehicle structural designs is one of the most complex high performance computing application areas to become fully embedded in the automotive design cycle process. What began as an experiment more than 10 years ago to computationally reproduce the results of physical crash tests has progressed into a mature capability.[4] Crash simulations now deliver such accurate structural evaluations of potential vehicle designs that companies have reduced the number of physical crash tests by about 85 percent, while still meeting requirements for safety-compliant designs.[5] Current safety requirements, however, are derived more from an understanding of the effects of a crash on the structural integrity of a vehicle rather than the effects on the physical integrity of the occupants. Although we currently have a sophisticated grasp of the effects a crash has on a vehicle, we only have rudimentary insights into the effects of a crash on the human body.

Vehicle Safety Design Still Needs the "Human Touch"

In the quest to meet safety requirements and offer safer vehicles, auto manufacturers are continually refining their vehicle designs by incorporating new materials and restraint systems. Physical dummies are used in the physical crash tests to approximate the impact these design changes will have on the reduction of injuries. (See Figure 1.) As safety features have expanded from simple lap belts to include shoulder and head restraints, front and side air bags, and other material modifications, manufacturers have required more sophisticated dummies to better measure the effectiveness of these changes. (See Figure 1.) Using a combination of medical data and biomechanics experiments, the dummies have been enhanced.[6, 7, 8]

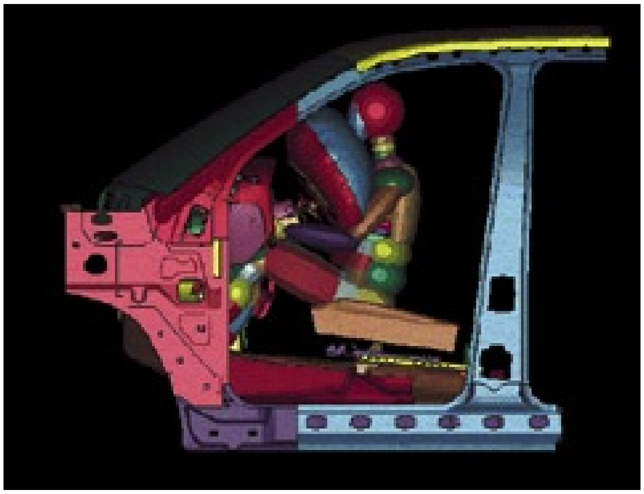


Figure 1 Occupant simulation with a 50th percentile unbelted male at 25 mph.

While improvements were being made to the physical dummies, crash simulations on high performance computers evolved as an accurate alternative to many physical crash tests. In the process, design engineers have had to work out ways to represent the vehicle occupants in the crash models. Early crash simulations only modeled the vehicle and the crash "wall." As simulations were refined, engineers needed to include "virtual humans." Engineers used the dummies employed in the physical crash tests as the basis for creating these mathematical humans. (See Figure 2.)

As the physical dummies have become more intricate, the "virtual humans" in crash simulations have been enhanced to reflect these advances. However, this process yields a computational model of a human that is only as complex as the latest mechanical dummy. Because the dummies do not realistically reflect many body features (such as organs, muscles, connective tissue, bones, vessels, and the nervous system), the computational models do not reflect these characteristics, making it difficult to measure the ability of vehicle safety features to protect against injuries in these areas.[9]

One expert describing a collision noted, "Even if the skull doesn't hit anything, brain tissue is still moving. In a head impact crash, it would take a few seconds until the brain actually makes contact with the skull. Just to do a model of the skull and the brain would require several orders of magnitude increase in computing resources to move from dummies to humans."[9] Another expert observed, "We need to learn more about real injuries to real people."[10] Clearly, computational models are needed that reflect the actual features of a complete human instead of the features of the latest dummy.

A Grand Challenge: Making Cars Safe for Humans, Not Dummies

The auto industry faces an enormous grand challenge: *Optimize the safety of a vehicle by measuring the effects of a crash on all of the physical attributes of the human body, not just on the structural characteristics of the vehicle and a mechanical dummy.* In other words, we need to move from testing the car to testing the human. This can only be accomplished if a computational model of a complete human can be developed. This in itself is a "grand challenge", as it can only be achieved through the modeling of the many body systems. (See Figure 3.) And one human body model is not sufficient. Multiple models are required to reflect gender, age, size, etc.[9]

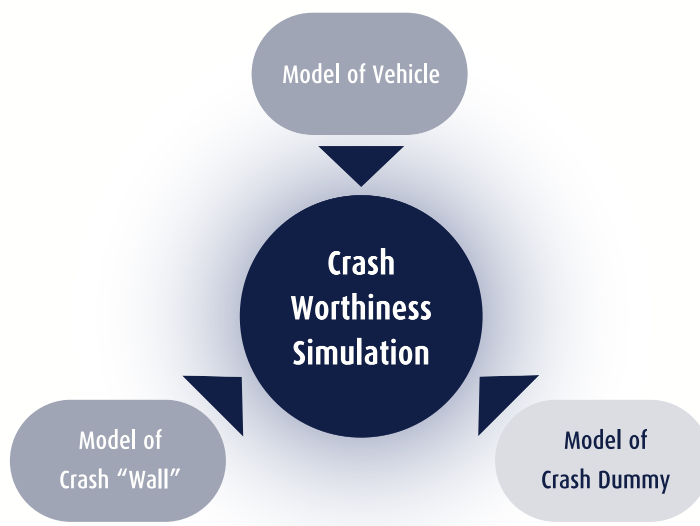


Figure 2 Components of a cashworthiness simulation.

Researchers have made some progress in developing partial computational models of human anatomy, but even this task is immensely complex. For example, researchers at Wayne State University have created a mathematical representation of a "50th percentile male" in a sitting position.

This required detailed modeling of bones (ribs, vertebrae), costal cartilage, sternum, organs (heart, lungs), vessels (aorta, pulmonary vein, etc.), diaphragm, and various muscles.[11]

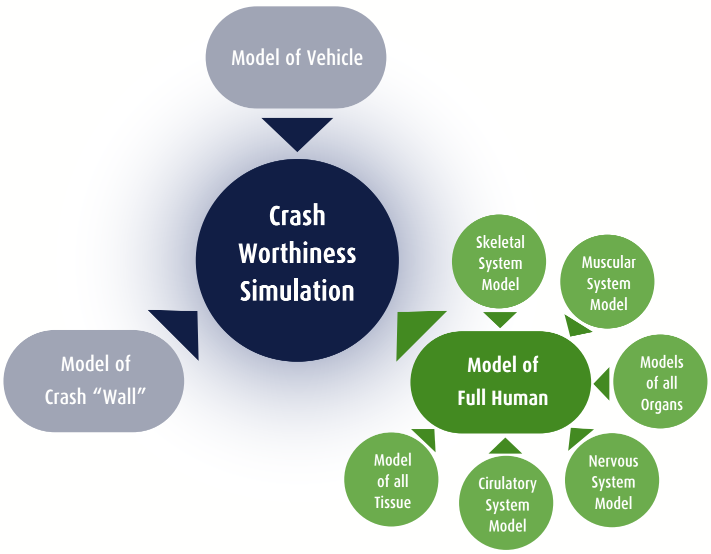


Figure 3 Crashworthiness simulation optimized with model of a full human.

But this is only a start. In order to be able to design truly safe vehicles that protect against a myriad of injuries, crash simulations must reflect what a doctor sees when examining the crash victim, as well as what the policeman and insurance adjustor see when they arrive at the accident scene. The doctor sees the external and internal damage to the victim, while the police and insurance adjustor see primarily the external and internal damage to the vehicle. If the auto manufacturers are going to be able to optimize car designs to protect against serious injury, the doctor's perspective is required in the simulation process. That can be achieved only with mathematical models of complete human bodies, including skeletal and muscular systems, soft tissue, and organs. Once these models have been developed and validated, they must be integrated into the crashworthiness simulations so that the entire auto design can be optimized. Such integration is only on the horizon and would require several orders of magnitude more computational capability than is currently available.

Societal, Economic and Competitiveness Benefits

While it is impossible to know exactly how much the human toll and economic cost could be reduced by solving this grand challenge, it would certainly be profound. When manufacturers can optimize vehicle safety using full human models in the simulation process, they will be able to customize the vehicle's interior safety features, such as air bags and seat belts, to address unique needs of different ages, genders, and body characteristics. They will be able to refine the design and operation of restraint devices to better protect against internal and external injuries that can result from the devices themselves. They also will be able to design all restraints as an integrated safety system.

The saved lives and reduction of injuries, particularly for children and the elderly, could be dramatic. For example, just adding a small adult female dummy in side-impact performance testing reportedly resulted in a proposed design change that will save 700 to 1000 lives per year.12 This means a reduction in annual crash deaths of approximately 2 percent. If using a full human body model in crash simulations could result in greater safety enhancements and

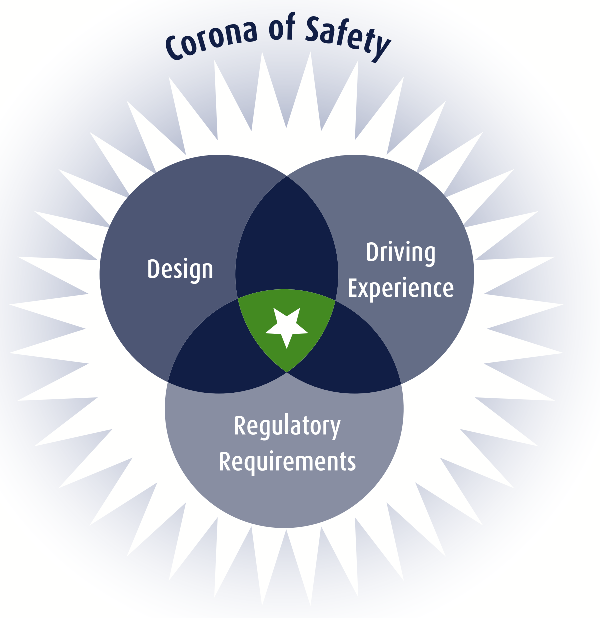


Figure 4 Auto design optimized within a corona of safety.

achieve a 10 percent reduction in deaths and injuries, more than 4,000 deaths and 500,000 injuries could be averted. This would result in an annual savings in direct economic costs alone of more than $14 billion.2 The insights gained from these advanced simulations also could induce revolutionary changes in engineering safety design across all of the transportation modes, driving policy choices that determine the architecture and standards across the entire transportation complex.

Developing the capability to include full human models in crash simulations also will allow manufacturers to better analyze the effects of accidents involving pedestrians. The ability to perform detailed studies of vehicle-pedestrian interactions could provide significant new insight, leading to feasible design changes to reduce pedestrian injuries.

Closely linked is the potential to advance injury treatment from an auto or any type of transportation accident. Auto safety design simulations could provide the cipher to decode specific cause-effect relationships between vehicle design and human trauma resulting from vehicular accidents. Understanding these relationships could enhance the study of trauma diagnosis, as well as treatments administered at the scene of an accident and throughout the recovery process.

The implications of this kind of simulation and analysis reach beyond the automotive sector. For example, increasing threats of chemical/biological agents introduced into the environment by accidents or terrorism require not only antidotes, but also a more detailed understanding of the human injuries themselves. The ability to model and simulate anatomically complete human systems could impact the availability and economics of effective treatment, protection, and early detection to save lives of victims and early rescue teams alike.

In fact, any industry that needs to understand better the health, safety, comfort, and productivity implications of human interaction with a product could benefit from the pursuit of this grand challenge by the automotive industry. Once auto manufacturers have been able to integrate full human models into crash simulations, they can begin to consider the human element across the entire design process, weighing the safety implications of any design modification. This will allow the auto industry to achieve the competitiveness challenge of truly merging the beauties of design, an exciting driving experience, and the realities of regulatory requirements, all within a corona of safety. (See Figure 4.) The auto companies that achieve this capability will create a new competitive framework and establish themselves as the global market leaders.

References

1 Blincoe, Lawrence J., et al. “The Economic Impact of Motor Vehicle Crashes, 2000.” National Highway Traffic Safety Administration, U.S. Department of Transportation, Table 3. (May 2002.)

2 Cole, Suzanne, and Brooke, Lindsay. “Engineers in the ER.” Automotive Industries. (June 2000.)

3 Blincoe, Lawrence J., et al. “The Economic Impact of Motor Vehicle Crashes, 2000.” National Highway Traffic Safety Administration, U.S. Department of Transportation, Table 1. (May 2002.)

4 North Carolina Supercomputing Center. “High Performance Computing Improves Automotive Products, Builds Competitive Edge for U.S. Auto Industry.” Available at www.ncsc.org/casc/papers/.

5 Boulton, Clint. “IBM Inks Major Supercomputing Deal with GM.” Available at www.internetnews.com/bus-news/article.php/3343401. (April 21, 2004.)

6 Information about the use of dummies in crash tests. Available at inventors.about.com/library/inventors/blcrashtestdummies.htm.

7 “History of Crash Test Dummies.” Available at www.ftss.com/about.cfm.

8 “New Dummy simulates a 10-year-old.” Detroit Free Press. (March 5, 2003.)

9 Interviews with U.S. auto manufacturers.

10 Quote by Dr. Martinez, medical doctor and former administrator of the National Highway Traffic Safety Administration. Cole, Suzanne, and Brooke, Lindsay. “Engineers in the ER.” Automotive Industries. (June 2000.)

11 Researchers in the Wayne State University Bioengineering Department have made progress toward developing a human model for the auto industry. The model represents a 50th percentile male in a sitting position, and details ribs and vertebrae, costal cartilage, sternum, heart and lungs, aorta and pulmonary vein, diaphragm, and various muscles. Recent research also includes finite element modeling of the human abdomen. An account of this work is available at the Web page of King H. Yang, ttb.eng.wayne.edu/~yang/RESEARCH/human/

12 National Highway Traffic Safety Administration, U.S. Department of Transportation. Information on vehicle and equipment safety tests and results, and ne ws items on safety, are available at www.nhtsa.dot.gov.

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.

To learn more about the Council on Competitiveness, visit our home page at www.compete.org.

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

1500 K Street, NW Suite 850 Washington DC 20005 www.compete.org