COMPUTER FINITE ELEMENT MODELING

2005 COMPUTERWORLD HONORS CASE STUDY

TRANSPORTATION
THE SAFETY OF THE TRAVELING PUBLIC IS ENHANCD BY THE DEVELOPMENT OF FINITE ELEMENT MODELS OF VEHICLES AND ROADSIDE SAFETY DEVICES FOR TRANSPORTATION SAFETY APPLICATIONS **[2002348]**

SUMMARY

Development of finite element models of vehicles and roadside safety devices for transportation safety applications

APPLICATION

The FHWA/NHTSA National Crash Analysis Center (NCAC) at the George Washington University is a unique research center conducting research that significant strides in defining the present state-of-the-art and the future research activities in automotive crashworthiness, roadside safety, and homeland security. The center is the first of its kind to combine the resources of government agencies, automotive industries, roadside hardware manufacturers, computer hardware venders, computer software developers, and other university research centers to address research problems related to transportation safety. At NCAC, research is conducted on statistical analysis of accident data, crash related injury investigation, biomechanics, vehicle dynamics modeling, crashworthiness and nonlinear deformation, simulation analysis, modeling of vehicle-to-vehicle, vehicle-to-barriers, and vehicle-to-roadside object impacts using non-linear dynamic finite element methods. Most recently, infrastructure and building protection of federal building and facilities is being address for homeland security applications. The computational aspects of vehicle crashworthiness research, particularly, computer simulation and parallel computing software and hardware are among other advanced leading research conducted at the NCAC.

As an important part of these ongoing researches in road-side hardware, vehicle, and occupant safety analysis, the NCAC has engaged important analysis tool development activity - developing finite element (FE) models of vehicles, roadside hardware devices, occupants with various levels of detail and complexity and execute simulations of different impact scenarios. Although finite element models of vehicle are developed by automotive manufacturers for their product development, these models are all proprietary and not available in general public. Therefore, it is very important to develop public domain finite element models of vehicle, roadside hardware and occupant for researchers and engineers to carry out research activities in transportation safety and security field world-wide.

NCAC uses “reverse engineer” method to develop vehicle finite element models that virtually recreate automobiles and trucks. With these accurate models, the researchers can simulate several different crash scenarios and predict vehicle and occupant response to incidents. Such foresight leads to more efficient research time and more effective and useful data for making safety decisions.

Developing accurate and comprehensive FE models is a complex task that requires precise detail work and a tremendous amount of mathematical computation. Researchers must:

• Apply tape over an entire vehicle to get an accurate representation of the geometries
• Digitize every component using a seven-degree-of-freedom coordinate measuring machine
• Disassemble all vehicle components
• Collect mass and material thickness data for vehicle and individual parts
• Identify all parts and connections
• Conduct center-of-gravity calculations
• Execute material property tests for component strength
• Create a computerized “mesh” grid of the vehicle using advanced computer codes
• Reconnect all parts accurately, including spot welds, rigid body constraints, joints, springs and dampers.

The methodologies developed at NCAC have also been used to determine physical data of other devices such as anthropomorphic test dummies, child car seats, highway barriers and crashed components. In addition

NCAC performs material characterization coupon testing and destructive cross section measurement as needed. Among other reverse engineering functions are the material thickness measurements and specimen and component testing.

NCAC has developed more than ten vehicle models varying in complexity and size depending on their applications. These models have been in use successfully by the researchers and engineers world-wide for different application in safety and infra-structural protection applications.

NCAC also develops human biomechanical models, anthropomorphic test devices, air bags, seat belts, and other occupant/safety restraint components. The NCAC's integrated approach in attempting to solve the total crash safety problem requires accurate modeling and validation of all components of the safety systems including belts, steering wheel, airbags, vehicle interior, in addition to the occupant and full vehicle models. Material testing is conducted to characterize mechanical properties of parts. Component testing is required to isolate the effects of individual parts in crashes and their respective crush characteristics. Biomechanical testing is required to arrive at certain properties of bones, tissues, etc. which is incorporated in the FE models.

In addition to the vehicle and dummy modeling, NCAC has been developing finite element models for sophisticated hardware models to answers various safety questions and to optimize design of roadside hardware. Among the list of successful models are slip-base sign support systems, U-post signpost (used in evaluation of sign mounting height and FHWA policy decisions on the topic), end terminals, portable concrete barriers and their design evaluations and optimizations, modified G4 guard rail terminals, plate transitions, safety wall designs, steel cable guard rails, etc. Most recently, building security devises are being modeled, such as anti-RAM bollard, concrete wall, planter, steel fence, etc. for building protection purposes.

BENEFITS

While NCAC's primary research mission focuses on ground transportation safety issues, research efforts often extend beyond the road. Working in partnership with researchers and experts in other industries, NCAC has transferred the tools and knowledge used to address vehicle, passenger and highway structure safety issues to other transportation areas successfully.

For example, NCAC researchers are now simulating a variety of crash scenarios for wide-body commercial jetliners in their effort to model the September 11 World Trade Center attacks. Ultimately, the models will give investigators and federal agencies a better understanding of the mechanics a better understanding of the mechanics of the impacts, as well as the knowledge they need to establish new building structural design and egress codes.

In addition, the NCAC's work has helped the U.S. Department of State, the Secret Service and the National Capital Planning Commission step up protection of U.S. physical assets both here and abroad. This research has focused primarily on creating or improving anti-ram devices that protect buildings from vehicle bombings.

IMPORTANCE

Full-scale crash testing of several potential crash scenarios is cost-prohibitive and does not achieve comprehensive solutions. Instead, NCAC relies on simulating these scenarios on high-performance computers, which saves time and maximizes research dollars.

NCAC's approach to vehicle crashworthiness simulation involves developing computer models of every element involved in a crash - the vehicle structures themselves; dummies with human biomechanical components; airbags; moving deformable barriers; and roadside hardware. These highly precise, mechanics-based models serve the safety community worldwide. They enable researchers to perform accurate and detailed simulations and analyze various crash scenarios to improve regulations, vehicle designs, restraint systems and roadway structures. NCAC's capabilities can be applied to such other research areas as aircraft and aviation safety and anti-ram security device design for infrastructure protection.

Not long ago, even simple simulations — such as those of small models representing just a 100-millisecond event — required a day or more on a vector supercomputer to complete. Today, using low-cost parallel computing, NCAC researchers can perform large-scale car-to-car simulations — complete with occupants and airbags — in just a few hours.

The shift from using vector-based computers to more efficient high-performance parallel computer technology resulted from a landmark research program initiated by NCAC. Working in cooperation with government agencies, U.S. automotive manufacturers, the computer industry and commercial crash-software developers, NCAC accelerated the application of high-performance parallel computing in the field of crash simulation. Now, virtually all U.S. car companies have incorporated parallel computing into their normal, day-to-day design and analysis processes; few still use expensive, centralized vector machines.

The high-performance parallel computer capability complements and enhances NCAC's modeling work and enables researchers to execute and verify complex calculations and conduct large-scale crash simulations more quickly and at a fraction of the cost of live testing. Using this more efficient approach to transportation safety, researchers can assess the applicability or success of regulations and of vehicles, safety systems and highway infrastructure components to reduce damaged and injury to save lives.

ORIGINALITY

NCAC is the only research center that develops and maintains full ranges of public domain finite element vehicle models in the world.

SUCCESS

NCAC is a successful collaborative effort among government agencies, industry and academia that brings together faculty, engineers, policy makers research staff and graduate students with extensive experience in automotive and highway safety engineering who conduct research that serves the entire community.

A major part of the center is directing research programs in occupant safety and overall vehicle crashworthiness which includes child safety and restraint design; safety data analysis; programs for increasing safety belt usage; analysis of various crash modes; safety issues pertaining to occupant age, size and gender; vehicle compatibility; pedestrian protection; fire and fuel system crashworthiness; and post-crash signaling. This research is vital to ensure maximum occupant protection during vehicle crashes.

The finite element models that NCAC developed serves a great purpose for safety community and enables engineers and researchers world-wide to use these simulation analysis tools to conduct research to improve transportation safety.

DIFFICULTY

One of the major challenges is that in order to capture realistic physical response of these impact events these models must include all geometry information, which can result over 1,000,000 elements size models. In addition, these models include sophisticated nonlinear material properties, such as soil, concrete, wood, polyurethane, and other materials. Furthermore, the simulation run times of these impacts are on the order of 500 millisecond to 1 second. Coupled with these requirements, these simulations require enormous computing power. It is evident that high performance computers are playing an integral role in crashworthiness modeling and simulation, and future advances in these two fields will be largely coupled.