Structural Analysis Made 'NESSUSary'

Originating Technology/
NASA Contribution

Everywhere you look, chances are something that was designed and tested by a computer will be in plain view. Computers are now utilized to design and test just about everything imaginable, from automobiles and airplanes to bridges and boats, and elevators and escalators to streets and skyscrapers.

Computer-design engineering first emerged in the 1970s, in the automobile and aerospace industries. Since computers were in their infancy, however, architects and engineers during the time were limited to producing only designs similar to hand-drafted drawings. (At the end of 1970s, a typical computer-aided design system was a 16-bit minicomputer with a price tag of $125,000.)

Eventually, computers became more affordable and related software became more sophisticated, offering designers the "bells and whistles" to go beyond the limits of basic drafting and rendering, and venture into more skillful applications. One of the major advancements was the ability to test the objects being designed for the probability of failure.

This advancement was especially important for the aerospace industry, where complicated and expensive structures are designed. The ability to perform reliability and risk assessment without using extensive hardware testing is critical to design and certification.
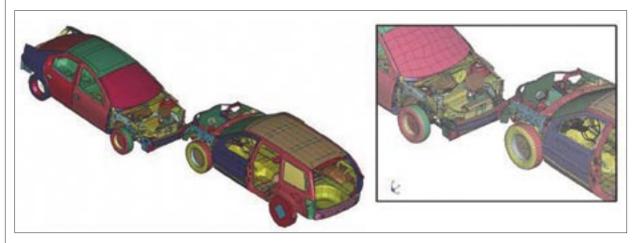
In 1984, NASA initiated the Probabilistic Structural Analysis Methods (PSAM) project at Glenn Research Center to develop analysis methods and computer programs for the probabilistic structural analysis of select engine components for current Space Shuttle and future space propulsion systems. NASA envisioned that these methods and computational tools would play a critical role in establishing increased system performance and durability, and assist in structural system qualification and certification. Not only was the PSAM project beneficial to aerospace, it paved the way for a commercial risk-probability tool that is evaluating risks in diverse, down-to-Earth applications.

Partnership

Southwest Research Institute (SwRI), headquartered in San Antonio, Texas, is a multidisciplinary, independent, nonprofit, applied engineering and physical sciences research and development organization. As the prime contractor on the PSAM project, the company developed a sophisticated computer program called NESSUS (numerical evaluation of stochastic structures under stress). Designed specifically for predicting structural response caused by uncertain basic variables such as loads, material properties, geometry, and boundary conditions, NESSUS is used by NASA to assist in the evaluation of existing critical Space Shuttle components, including the Space Shuttle Main Engines (SSMEs).

For example, the software examined a SSME fuel turbopump blade that was subjected to harsh conditions, which could ultimately affect its performance abilities. A finite element model of the turbopump blade was analyzed by NESSUS for the effects of high-temperature and high-cycle mechanical fatigue that could cause it to crack. The software computed a reliability value of 0.99978 for the SSME component. Furthermore, the probabilistic sensitivity factors revealed the variables for which tighter control would result in a more reliable blade design. (In this case, hot gas seal leakage clearly dominated other considerations.) Conversely, the sensitivity factors also exposed which variables are relatively unimportant in determining blade reliability—information important in establishing design and manufacturing controls for maximum cost-effectiveness as well as structural reliability.

The 10-year PSAM project officially ended in February 1995. Version 6.2 of NESSUS—regarded the final version for NASA's purposes at that time—was delivered to NASA in September 1995, along with a final report. Though in 2002, SwRI was again contracted by NASA, through Glenn, to further enhance NESSUS for application with large-scale aero-propulsion systems. Additionally, another government contract issued through the Los Alamos National Laboratory led to the utilization of NESSUS for extremely large and complex weapon-reliability problems, in support of its Stockpile Stewardship program.

Southwest Research Institute's NESSUS software is particularly useful for large, complex calculations, such as simulating a small car colliding with a large sport utility vehicle.

The conclusion of the NASA projects, along with the Los Alamos project, marked a new beginning for SwRI, as it went on to commercialize NESSUS program for non-aerospace applications.

Product Outcome

NESSUS is a modular computer software system that integrates advanced reliability methods with finite element and boundary element methods and probabilistic algorithms in order to model uncertainties in loads, material properties, and geometries with random variables. Probabilistic performance models implemented in NESSUS include stress, strain, displacement, vibration, fatigue, fracture, and creep. NESSUS can perform reliability analyses for multiple components and failure modes, and identify critical random variables and failure modes to support structural design, certification, and risk assessment.

Version 8.2, the latest, was released to U.S. government organizations in December 2004 and to the public in 2005. While the software continues to serve the aerospace industry, it is also solving a diverse range of problems in a variety of other industries, including health and medicine, automotives, biomechanics, nuclear waste packaging, munitions (weapon systems), and offshore pipeline construction. To accomplish this, NESSUS has been interfaced with many well-known third-party and commercial deterministic analysis programs.
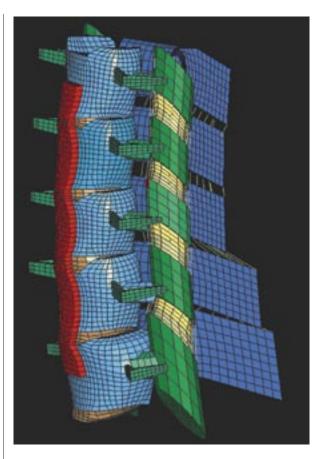
Recently, NESSUS provided the U.S. Naval Biodynamics Laboratory/U.S. Naval Air Warfare Center Aircraft Division with a probabilistic methodology and computational tool for evaluating the risk of cervical spine injury.

Cervical spine injuries occur as a result of impact or from large inertial forces such as those experienced by military pilots during ejections, carrier landings, and emergency crash-landings on water, also known as "ditchings." Other examples include motor vehicle, diving, and athletic-related accidents. Reducing the likelihood of occupant injury by identifying and understanding the primary injury mechanisms and the important factors leading to injury motivates most research in this area. Therefore, it is of broad interest to SwRI to design occupant safety systems that minimize the probability of injury.

To do this, the company says, the designer must have quantified knowledge of the probability of injury, due to different impact scenarios, and also know which model parameters contribute the most to the injury probability. Although complex numerical (e.g., finite element) models are becoming more widely used as a means of augmenting and extending laboratory testing, most are deterministic in that they do not quantify the effect of uncertainties on the computed model responses.

In developing a probabilistic methodology and computational tool for performing the spinal evaluation, calculations were generated using the NESSUS probabilistic analysis program in conjunction with the commercial finite element program, ABAQUS. The company intends to use the resulting models for additional applications, including the study of spinal behavior under normal and distressed conditions, the design of implants utilizing novel materials and/or configurations, analysis of novel instrumentation systems that may help avoid costly experimentation, and the design of anthropomorphic test devices or physical models that replicate human response such that injury under simulated dynamic conditions can be replicated.

In helping NASA return to flight, NESSUS 8.2 was recently used to solve a critical Space Shuttle problem for the Agency's Engineering Safety Center, which was created in the aftermath of the Columbia accident to serve as an independent technical resource for NASA managers and employees. This project involved developing probabilistic and deterministic fracture mechanics models to quantify the reliability of a flowliner in a SSME. In another "Return to Flight" project for Johnson Space Center, the software is being utilized on a regular basis to assess the probability of foam-impact damage to the Space

NESSUS 8.2 was used to quantify the risk of cervical spine injury to aviators during ejection.

Shuttle's reinforced carbon-carbon leading edge, if such were to happen upon ascent.

In July, SwRI won R&D Magazine's R&D 100 Award, with NESSUS Version 8.2 being crowned as one of the 100 most significant technological achievements of the past year. The company has won 29 R&D 100 Awards since 1971. ❖