Computers in engineering

Nonlinear modeling improves rotorcraft safety

As part of the mission of the Structural Technology and Prototyping group, **Boeing** Rotorcraft engineers are pursuing greater uniform margins of safety for aircraft load capacity. A benchmark was set in 2003 when they simulated fatigue-causing loads on a CH-46E helicopter and defined an improved, efficient methodology for nonlinear FEA.

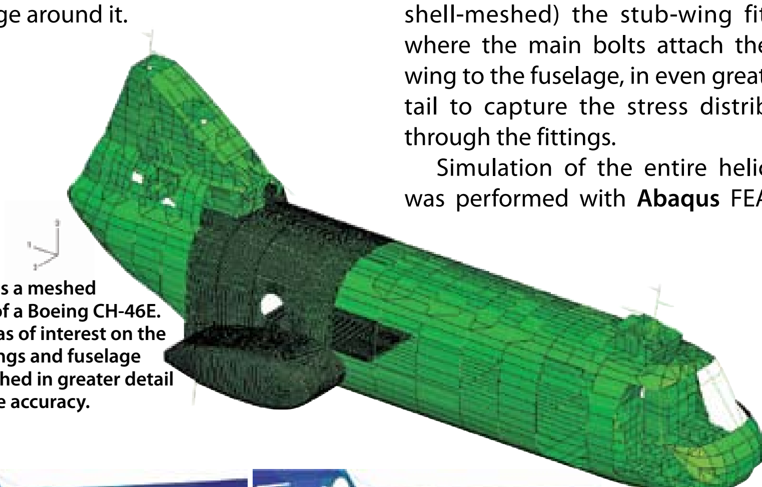
Boeing began work on the CH-46E in the 1980s, upgrading it to include a larger stub wing that accommodates a bigger fuel tank. The stub wing also houses the landing gear and other equipment. Over time, some of the upgraded helicopters developed fatigue cracking at the attachment locations for the stub wings, both in the wing fittings and on the airframe nearby. To determine the cause of the cracking, the **U.S. Navy** asked Boeing to analyze the CH-46E, focusing on the stub wing and the area of fuselage around it.

In 2001, stress analysts at Boeing had made a business case for purchasing new computing resources that could perform exactly this sort of analysis. With advanced hardware that could run the latest generation of nonlinear stress analyses, the engineers could perform a post-buckled simulation of a known condition that occurred in the CH-46E at field-determined load levels.

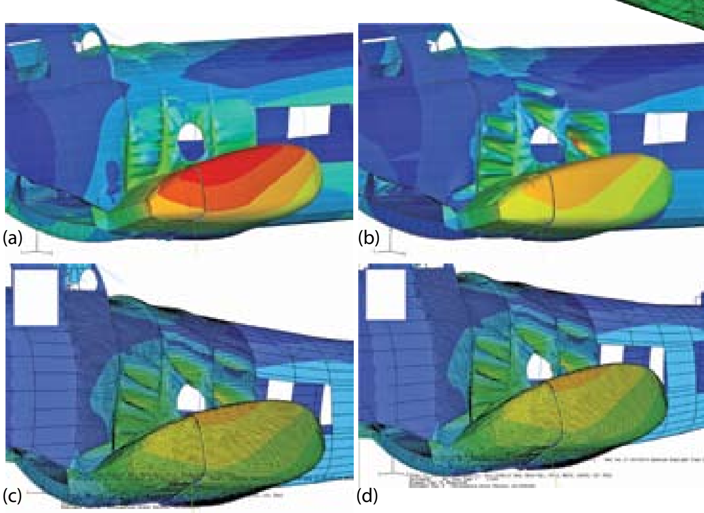
The Navy provided Boeing with a complete model of the CH-46E meshed with roughly one finite element per skin bay height. (A skin bay is a unit of airframe construction bounded on four sides by frames and stringers or longerons.) For a more accurate local analysis, Boeing engineers refined the mesh for the fuselage around the stub wing using a 1-in mesh. They used a finer, 0.25-in mesh in the stub-wing interface region, and they solid-meshed (as opposed to shell-meshed) the stub-wing fittings, where the main bolts attach the stub wing to the fuselage, in even greater detail to capture the stress distribution through the fittings.

Simulation of the entire helicopter was performed with **Abaqus** FEA software with various load configurations, such as landing and vibratory loads, bolt pre-load at the stub-wing fittings, and rotor hub loads during flight maneuvers. The engineers first performed a linear static analysis, then three separate static nonlinear analyses with:

- Damping from dashpot elements
- Dashpots and geometric imperfections derived from a buckling analysis
- Dashpots and geometric imperfections derived from a linear static analysis.



Shown is a meshed model of a Boeing CH-46E. The areas of interest on the stub wings and fuselage are meshed in greater detail for more accuracy.



Linear static analysis did not predict the same degree of deformation and buckling that all three nonlinear analyses did (a). A static nonlinear analysis with damping by dashpot elements proved to be the most efficient of the nonlinear simulations (b). Adding geometric imperfections to static nonlinear analyses did not significantly improve simulation accuracy, and it increased run times by roughly 60% (c, d).

The engineers compared all four analyses based on strain energy, deformations, buckling shapes, and run times.

To obtain physical data for comparison with the analyses, the Navy and Boeing jointly performed a CH-46E test flight with strain gauges. The engineers were initially concerned that differences between the test flight and the modeling assumptions might prevent a meaningful correlation. For instance, the physical data came from a level flight, but the aircraft was analyzed in hover condition because level flight was not considered to be a critical condition to run. Other differences between the test flight and the simulation included the change in mass as fuel was spent during flight and the decision not to model the stub-wing fairings. Finally, stresses were fairly low during level flight, making the test results more susceptible to fluctuations in gauge data.

In the end, the differences were not significant, and the level-flight loads were close enough to hover loads. There was good correlation between all four analyses and the test gauge stress data. As expected, the linear static analysis did not show the degree of deformation and buckling modes that the nonlinear methods predicted. All three nonlinear static analyses produced strongly similar deformed shapes and magnitudes that closely approximated the test flight data.

Review of the analyses indicated that running a nonlinear static analysis without geometric imperfections was most efficient. The engineers learned that including geometric imperfections in the model did not significantly improve accuracy and increased analysis run time by approximately 60%.

By using the data obtained from these analyses, Boeing engineers were able to identify the cause of fatigue cracking on the CH-46E helicopter stub wing. They also determined an accurate method for nonlinear analysis with an acceptable run time.

Frank A. Smith Jr., Lead Stress Engineer, Boeing Rotorcraft, and Paul M. Hopkins, Stress Analyst, Boeing Rotorcraft, wrote this article for Aerospace Engineering.

Briefs

NASA is using **IBM** software to develop the software and systems that will operate the James Webb Space Telescope, the successor to the Hubble Space Telescope expected to launch by 2013. Because space agencies from several different countries are developing the software that will operate the telescope's guidance, navigation, and control systems; command and data handling; and the integrated space instrument module, NASA mandated that each agency develop their systems using IBM's Rational Rose Real-time software.

Siemens signed an agreement to acquire product lifecycle management software and services provider **UGS** for $3.5 billion. UGS' activities will be integrated into the Siemens Automation and Drives Group, making it the first supplier for the manufacturing industries to provide an end-to-end software and hardware portfolio encompassing the complete lifecycle of products and production facilities.

Hamilton Sundstrand selected **austriamicrosystems** to supply time-triggered protocol (TTP) controllers for use in the **Boeing** 787 Dreamliner. The AS8202NF controller integrated circuit, with a communication speed of up to 25 Mbit/s, forms the core of the TTP-based data communication platform in Hamilton Sundstrand's electric and environmental control systems for the Dreamliner series.

Thales Technical Unit Control and Display Systems has begun using **Flomerics** electromagnetic compatibility (EMC) simulation in the design of cockpit instruments. Flomerics' FLO/EMC software enables Thales engineers to evaluate radiated emissions and susceptibility during the early design stages.