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AEROSPACE ENGINEERING

Computers in engineering

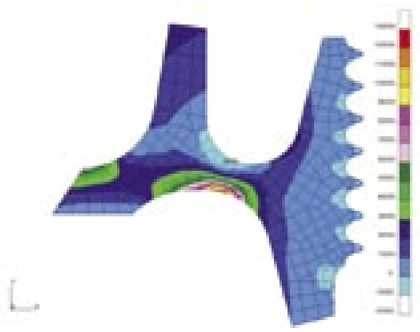
Crack prediction down under

Engine maintenance can account for up to 40% of the total through-life support costs for military aircraft. Much of this maintenance cost stems from engine overhaul to replace components that have reached a fatigue life limit, even after undergoing a relatively small number of stress cycles. Referred to as "low-cycle fatigue," this phenomenon is an area of increasing interest to aerospace engineering specialists. In aging aircraft, low-cycle fatigue often reduces the useful life of components. That reduction in life span increases maintenance expenses and potentially can affect aircraft availability and safety.

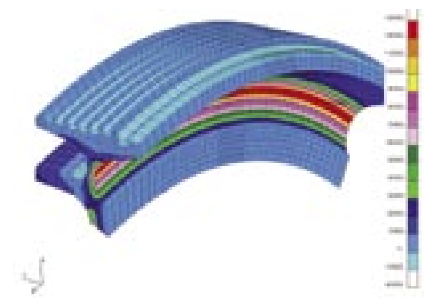
The **Royal Australian Air Force** (RAAF) has a fleet of large military transport aircraft that has been in service for more than three decades. The planes are powered by gas turbine engines that incorporate internal rotating components. Under engine operating conditions, certain parts are subjected to fluctuating high-thermal loads and centrifugal forces that could cause low-cycle fatigue. After a certain amount of repeated cycles, the turbine component has a probability of containing an initiated fatigue crack.

The manufacturer specified a maximum safe life for the rotating part under consideration based on the probable initial appearance of a crack. During the operation of the aircraft engines, the specified safe life of the part dropped by more than half. This problem has potential to create significant changes for maintenance expenses and logistical issues. But would the part actually be unsafe if a crack initiated?

To investigate, the RAAF turned to the **Defence Science and Technology Organisation** (DSTO), an independent branch of the **Australian Defence Organisation** that provides technological advice to the Australian Army, Navy, and Air Force. Within the DSTO, the Air Vehicles Division (AVD) advises the RAAF on issues that affect cost of ownership, airworthiness, and availability. Among the activities the AVD carries out are analyses of low-cycle fatigue in metal parts. "The Air Vehicles Division is charged with independently assessing the actual maintenance needs of aircraft and engine components," said Bryon Wicks, Head of Engine Reliability and Risk Assessment.



Analysis in ABAQUS of a 2-D axisymmetric finite element model of a rotating component in a turbine assembly by engineers at the Australian Defence Science and Technology Organisation showed the maximum principal stress distribution.



The 3-D analysis of the turbine component with ABAQUS used thermal and centrifugal loads. Iteration with Zencrack showed that after the crack initiated, the rotating component developed a significant compressive stress field that slowed and deflected crack propagation, sending the crack around the surface of the part, rather than into the structure.

"For components where low-cycle fatigue is an issue, finite-element analysis is vital to this process," said Manfred Heller, Head of Structure Mechanics.

AVD scientists and analysts reviewed aircraft and engineering data, such as drawings, recorded flight data, ground tests, nondestructive examinations, and fractographic tests. They also relied on a public-domain database of the commonly known properties for IN 901, the alloy used for the part. These data helped them to establish the geometry and loads for the components, gave them guidelines for locating and measuring defects, and provided initial estimates of crack growth rates.

The analysis itself followed a series of steps. First, using ABAQUS/Standard FEA software from **ABAQUS**, the analysts created a 2-D axisymmetric analysis model of the turbine section of the engine with contact, including the rotating component in question. The team then used this 2-D model to run a nonlinear global analysis of the system. The maximum thermal (800°F) and centrifugal (13,800 rpm) loads that the turbine could undergo during takeoff were used.

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"In the engine's case, a 2-D model is an economic way of analyzing the global behavior of a system," said Jian Hou, Senior Research Scientist in Engine Component Life Management at AVD.

For the 3-D analysis, the team created a geometric model of the assembly in CAD, transferred it into a preprocessor for meshing, and exported the meshed model to ABAQUS/ Standard. To analyze places where stresses and loads were particularly significant, the analysts also created a submodel of the rotating component. They determined the boundary conditions of the submodel automatically from the analysis of the component in the 2-D global model.

"Once we defined the submodel for this component, we applied the centrifugal load and temperature distribution to the model," said Hou. "The automatic transfer of data from the global analysis made this process easy and fast."

By subjecting the model to thermal and centrifugal loads, the analysts were able to identify the location at which a crack would initiate on the rotating component. They then exported the ABAQUS data to Zencrack, a stand-alone software tool for crack-growth analysis from British company **Zentech International**. Using Zencrack, the team modeled the propagation of the initial crack and gave feedback about crack size and direction back to ABAQUS, which was then used to re-analyze the component under study and return updated data to Zencrack. This process was repeated incrementally, providing a crack model that had a high degree of precision with minimal error in calculating stress intensity factors.

Automation of the data transfer was important, as was accuracy and speed of operation. "In some cases, analyzing a growing crack can involve a larger number of iterations, and we often analyze two or three submodels from an assembly," said Hou.

The analysis results showed that after the crack initiated, the rotating component developed a significant compressive stress field that slowed and deflected crack propagation, sending the crack around the surface of the part. Because the crack did not penetrate the part, the analysts concluded that low-cycle fatigue and the appearance of a crack would not significantly alter part strength or life.

"The AVD has equipment for high-speed spin testing of components for low-cycle fatigue, but in this case, physical testing was not warranted," said Wicks.

Agreement between the results of the crack propagation software and similar software used in **U.S. Air Force** laboratories was within 5%. The AVD forwarded its results to the RAAF for use in defining a logistically efficient, safe maintenance program for the part.

David Alexander

Managing informational assets

With global R&D spending in excess of $200 billion a year, research labs, development teams, and design departments are clearly in the forefront of the effort to drive innovation and growth. As companies and their customers become focused on faster, better, smarter, safer products and technologies, engineers are pressed to do more every day. And their work also affects an increasing volume of downstream applications.

From breakthrough product concepts to new manufacturing techniques to incorporating modern materials into existing designs, corporate technical advances are rivaling the work of the top research institutions of government and academia, but with the added pressures of time-to-market, profit margins, liability, and compliance with regulations and standards.

According to Jim Cooper, President and CEO of **Maplesoft**, in 2002, North American companies invested more money in informational assets than traditional hard assets. A 2004 survey found that more than 50% of U.S. managers considered informational assets to be the most important.

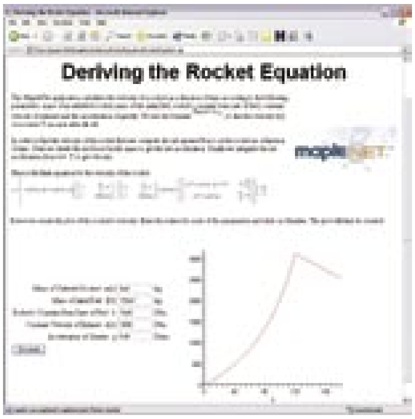
Technical informational assets typically exist in the brains of employees, buried in spreadsheets or computer programs, or kept in handwritten notebooks. Lack of technical information management wastes time, costs money, reduces effectiveness, and can expose companies to unnecessary liabilities.

Maplesoft has come up with a solution to this problem by combining its powerful computation engine with a worksheet environment that captures the knowledge behind the mathematical results, automatically documenting work as it is created.

Initially developed as a research project at the **University of Waterloo** in Toronto, Maple software is designed to be intuitive to use, with built-in presentation tools, tolerances, unit conversions, and self-checking features. Just released is MapleNet Commercial, a Web-based platform for deploying technical knowledge within and across departments or organizations. Scientists and engineers can embed dynamic formulae, models, and diagrams as live knowledge inside Web pages. Others can run the computations without needing any extra software on their local machines.

With Maplesoft's extensive deployment options, mathematical outcomes can be shared, in context, across departments or organizations, making information sharing, project auditing, design updates, technical documentation, and risk analysis fast and easy.

David Alexander



Maple software provides a worksheet environment that captures the knowledge behind mathematical results, automatically documenting work as it is created, and now able to be shared over the Web.

For more information on ABAQUS, visit www.abaqus.com