Nondestructive Evaluation Correlated With Finite Element Analysis

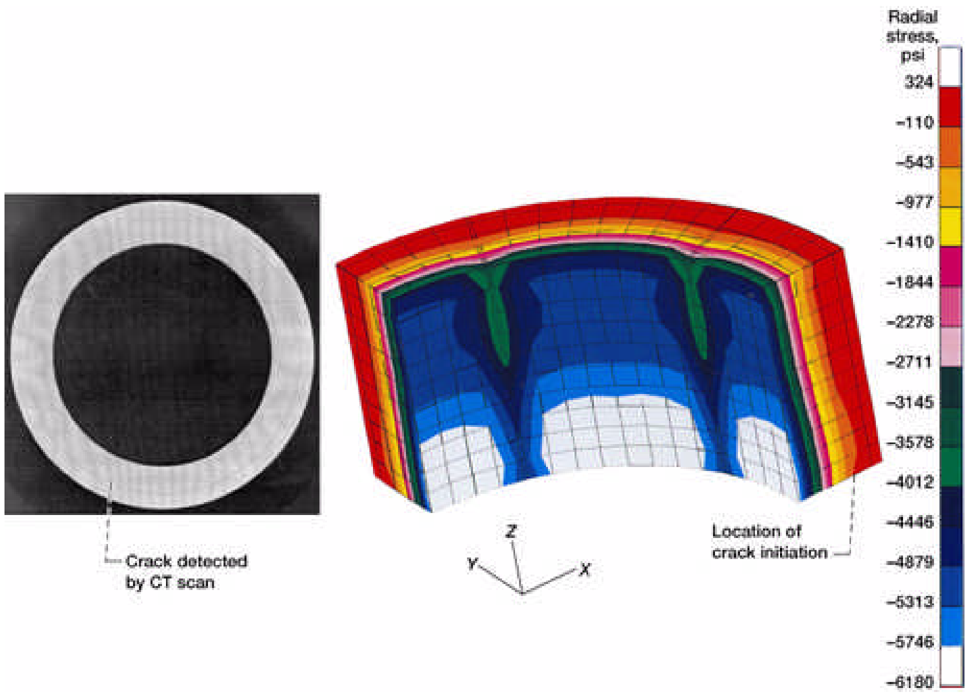
Advanced materials are being developed for use in high-temperature gas turbine applications. For these new materials to be fully utilized, their deformation properties, their nondestructive evaluation (NDE) quality and material durability, and their creep and fatigue fracture characteristics need to be determined by suitable experiments. The experimental findings must be analyzed, characterized, modeled and translated into constitutive equations for stress analysis and life prediction. Only when these ingredients--together with the appropriate computational tools--are available, can durability analysis be performed in the design stage, long before the component is built.

For example, for NDE information to be useful in structural characterization and modeling, the NDE data format must be compatible with microstructural and structural models currently being developed (refs. 1 and 2). In addition, qualitative and quantitative computer analysis tools based on NDE imaging modalities must be developed to enhance the usefulness of NDE applications. Qualitative tools include two- and three-dimensional visualization methods. Quantitative tools include segmentation methods that can send output to commercial finite element, micromechanical, and/or continuum damage model software (refs. 3 and 4) for evaluation of composite materials and components. Linking NDE data with engineering analysis methods will provide the engineering community the great ability to do a complete structural analysis on as-manufactured or as-inspected components rather than solely on as-designed components. With this capability, extensive effect-of-defect studies can be performed to determine the effect of manufacturing anomalies or in-service component degradation on part performance. This will provide an NDE capability for engineering structures and condition-based maintenance.

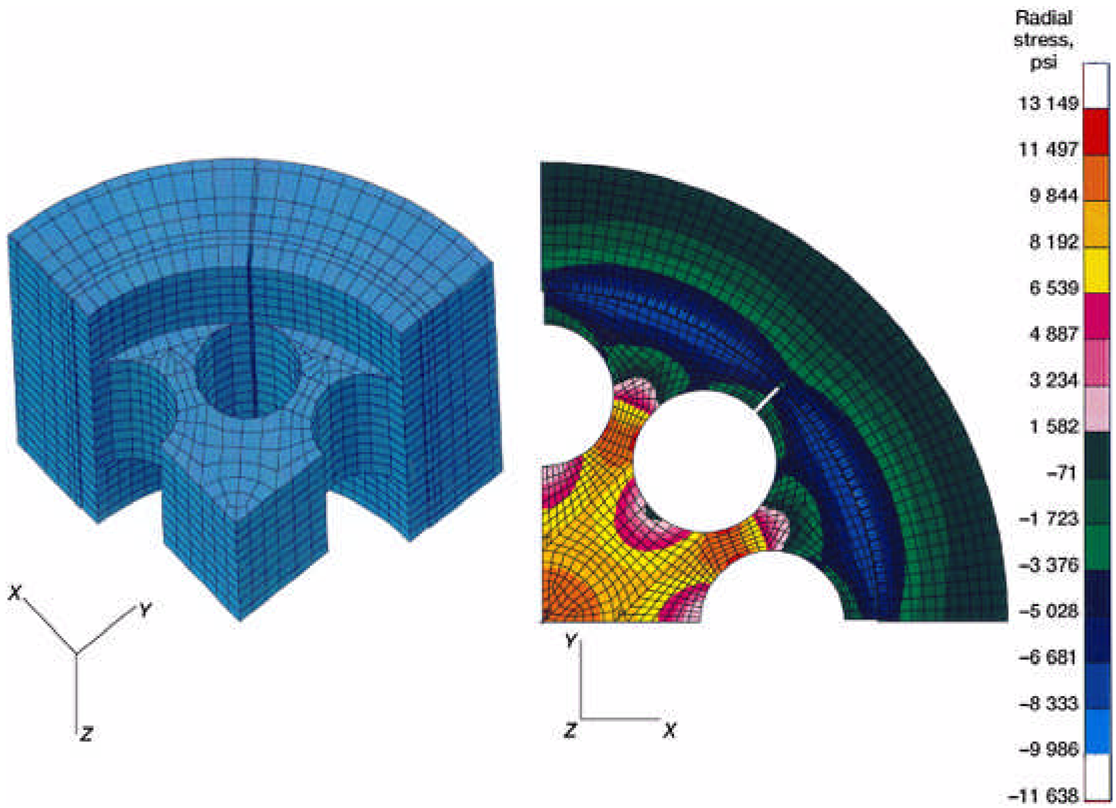
One of the many structural components being evaluated by the NDE group at the NASA Lewis Research Center is the flywheel system. It is being considered as an energy storage device for advanced space vehicles. Such devices offer advantages over electrochemical batteries in situations demanding high power delivery and high energy storage per unit weight. In addition, flywheels have potentially higher efficiency and longer lifetimes with proper motor-generator and rotor design (ref. 5). Flywheels made of fiber-reinforced polymer composite material show great promise for energy applications because of the high energy and power densities that they can achieve (ref. 6) along with a burst failure mode that is relatively benign in comparison to those of flywheels made of metallic materials (ref. 7).

However, the big challenge of developing materials for high-energy flywheel systems that can withstand the stresses caused by high rotational speeds remains eminent. For example, a typical 16-in. steel or titanium flywheel can shatter at 20 000 rpm. However, flywheels made out of composites show good promise since they can store 20 to 30 times more power per unit/weight than lead-acid batteries, can be recharged repeatedly, and can handle a wide range of temperature variations. They can also be respun thousands of times to regain their stored energy.

Therefore, to help improve durability and reduce structural uncertainties, we are developing a comprehensive analytical approach to predict the reliability and life of these components under these harsh loading conditions. The combination of NDE and two- and three-dimensional finite element analyses (e.g., stress analyses and fracture mechanics) is expected to set a standardized procedure to accurately assess the applicability of using various composite materials to design a suitable rotor/flywheel assembly. Following the figures is a brief description of some preliminary analytical results.



Left: Computer tomograph (CT) of a flywheel. Right: Radial stresses in a rotor.



Left: Three-dimensional finite element model; 6747 nodes, 5424 hexagonal elements. Right: Radial stresses in a rotor-hub assembly.

These figures represent typical NDE-finite element results. The top left figure shows a computed tomography (CT) scan for a rotor made of polymer matrix composite. This scan illustrates the defects in the rotor due to centrifugal loading (spun at 34 000 rpm); a crack along the circumferential direction is very obvious. The bottom left figure shows the finite element models for the rotor assembly. This assembly consists of the composite rotor (Hexel's IM-7 and AS4D) and an aluminum hub (7075-T6). Two and three-dimensional models were generated (ref. 8) because of analysis requirements. Results obtained via finite element analyses (ref. 9) are shown in the figures on the right, where the stress levels depend on the applied loading. Furthermore, the bottom right figure illustrates the radial stress distribution in the rotor whereby the tensile stresses near the middle indicate the presence of the crack as detected by the computed tomography scanning shown in the top figure. Although these results are considered to be preliminarily, they reflect a step forward in correlating NDE findings with finite element analysis.

For more information, visit A HREF="http://www.grc.nasa.gov/WWW/RT/namechng.html">Lewis' Life Prediction <BRANCH< A>.

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