ANSYS CASE STUDY

ANSYS and Battle Readiness: Prognostic Model Keeps Helicopters Flying

IMPACT TECHNOLOGIES AND NAVAL AIR SYSTEMS

EXECUTIVE SUMMARY

Challenge:

To calculate numerous physical values and create gear tooth models for UH-60 helicopters in U.S. Navy aircraft fleet.

Solution:

Implement ANSYS software to perform to convert gear tooth models into a finite element modeling and analysis (FEM/FEA) mesh that can be analyzed.

Benefits:

- Increased mission reliability, better scheduled maintenance to reduce aircraft downtime, and dramatically decreased life cycle costs.
- Identified sensitivities and uncertainties in the effects of material properties and manufacturing defects on component capacity.
- Provided invaluable calibration of a prognostic model at various times in the life of a component so that it can be evaluated both in terms of long-term capability prediction (asset management) and more near-term damage minimization (fault accommodation).

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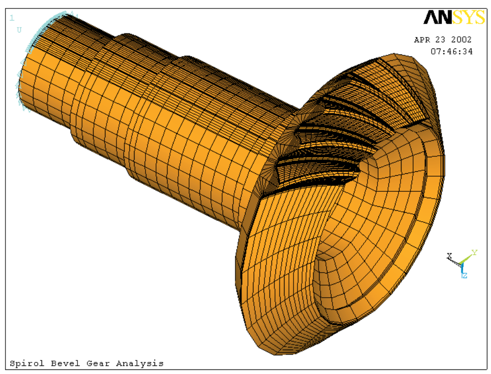
Introduction

For 20 years, the U.S. has asked its military to do more with less. Even as resources are trimmed, the armed forces are asked to take on new missions in faraway places. All too often, this is done with equipment that is far beyond the service life for which it was designed. Despite their increasing age, aircraft remain in service because replacements are not being acquired.

As necessity is the mother of invention, so budget constraints and readiness pressures have led to analyzing problems and finding new solutions. Among the most scientific and ingenious is a program focused on gears from UH-60 helicopter transmissions in U.S. Navy aircraft.



Initially meshed ANSYS model of the spiral bevel pinion gear from the intermediate gearbox of a UH-60 helicopter. The steel is AISI 9310.

The Naval Air Systems Command has done extensive predictive and diagnostic work at its Helicopter Transmission Test Facility (HTTF) at Patuxent River. Funding is from the Defense Advanced Research Projects Agency (DARPA). The program also reaches down to consultants and engineering analysts in Upstate New York. Analytical work has been undertaken by Impact Technologies LLC, in Rochester, and a subcontractor in nearby Ithaca, Fracture Analysis Consultants Inc. (FAC).

Holding all this together is ANSYS Mechanical design and optimization software, which was used to calculate numerous physical values, to create the gear tooth models from proprietary gear-design geometry, and to convert that model into a finite element modeling and analysis (FEM/FEA) mesh for analysis.

Challenge

Prognostics builds on 40-plus years of aircraft diagnostics and trouble-shooting. Diagnostic systems provide increased safety, but unfortunately, "they can require pulling components early while they still have a remaining useful life," said William E. Hardman of the Naval Air Warfare Center Aircraft Division's Propulsion & Power Department, Patuxent River.

The goal is to create on-board systems to help commanders, maintenance crew chiefs and pilots make "go/no go" decisions in situations from routine maintenance to battlefields and rescues. Bringing prognosis capability on-board, NavAir believes, eliminates the potential for lost data, data dropout, and incorrectly processed data at the ground station.

Hardman, DARPA, NavAir and Patuxent River experts are building on their understanding of the relationships between existing diagnostic capability, damage evolution models, and rules and tools for prognosis of power drive train systems in combat aircraft. These are being integrated with the sciences of fracture mechanics (and fault progression), vibration-based mechanical diagnostics, component failure prediction, statistics, and material science.

In the program's early stages, NavAir experts evaluated statistical risk-reduction methods in terms of available and advanced mechanical diagnostics technologies. This was done in a series of seeded and propagation-fault tests. (In a "seeded" test, a crack or fault is intentionally induced rather than waiting for it to occur on its own.).

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—Greg Kacprzynski, Project Manager for Prognostics Work, Impact

ANSYS
CASE STUDY

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—William E. Hardman, Naval Air Warfare Center Aircraft Division's Propulsion & Power Department

At the end of its work for NavAir, Impact concluded that useful and reliable prognostic models for helicopter gears can be built that will predict remaining life as a function of speed and load.

Solution

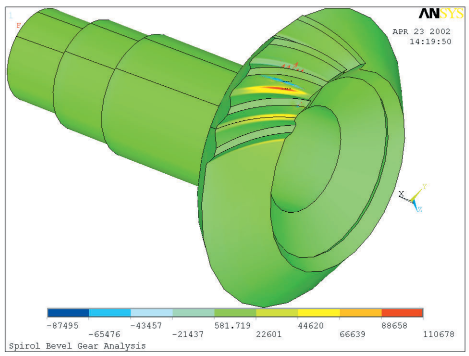
Geometry and loading for three gear teeth were obtained in the form of finite elements written in ANSYS format from a proprietary gear-generation program, explained Lamirand, an Impact analyst who worked closely with Greg Kacprzynski, project manager for prognostics work at Impact, and Avinash Sarlashkar of Impact, who with Brad Lamirand, did the ANSYS work.

Using ANSYS, the model was expanded into a full 3-D model. "We did multiple static analyses at each tooth load increment," said Lamirand. "These were post-processed in ANSYS to establish the static stresses over engagement of the three teeth. The crack propagation and trajectory model was developed working with the fully meshed ANSYS model.

The initial ANSYS model was meshed with about 31,000 ten-node Solid92 tetrahedral elements. The model was started with proprietary formatted gear data, plus associated load definitions for the pinion's load history when teeth are completely engaged with a mating gear. The fracture mechanics model had 920,000 degrees of freedom and used 13 crack fronts, also known as load steps.

"Each load step was subjected to 18 load cases simulating instantaneous pinion loads," Kacprzynski noted. "These corresponded to 18 discrete angular positions during the load-unload cycle for the pinion. As the crack grew, more elements were required to resolve the geometric details of the crack surface. By the 12th load step, the model reached nearly 1.4 million DOFs."

The modeling effort was not to figure out what happens with a cracked gear tooth, but to see how high a level of confidence could be built into the prognostic model. Kacprzynski's results showed that the mean predicted time to crack initiation was 11 hours while the actual time was 15 hours. In a second test, the mean prediction was 2.38 hours and the actual time was approximately 2.5 hours. This put the prognostics in the 98th and 63rd percentiles for accuracy and yielded (statistical) standard deviations of 1.64 and 0.36 hours, respectively.



ANSYS model of the spiral bevel pinion gear from the intermediate gearbox of a UH-60 helicopter, showing areas of gear teeth that see maximum stress when engaged.

"The ANSYS calculations required tracking a moving load on the gear tooth surface with a continuously changing point of contact," Sarlashkar explained. "There is a changing magnitude of load, which reaches its maximum as the tooth fully engages, then decreasing as the tooth disengages.

"This was handled with ANSYS multi-load analysis as a function of the tooth engagement," he added. "This was a linear-elastic problem in an isotropic and homogeneous material using the preconditioned conjugate gradient solver."

Benefits

The ANSYS work by Impact was aimed at "developing validated models for predicting asset readiness," Kacprzynski wrote. In his IEEE paper, he pointed out that NavAir results are used to:

- Provide realistic indications of state aware ness, that is, health indicators such vibration features, and non-destructive evaluations related to actual material damage levels.
- Identify sensitivities and uncertainties in the effects of material properties and manufactur ing defects on component capacity.
- Provide invaluable calibration of a prognostic model at various times in the life of a component so that it can be evaluated both in terms of long-term capability prediction (asset management) and more near-term damage minimization (fault accommodation).

The key to a successful prognostic model for pinions is to link state awareness to material properties. "The software module," he explained, "integrates advanced stochastic failure mode modeling, failure progression information from vibration features, and run-to-failure experience bases to enable IGB pinion gear failure predictions in the H-60 critical drive train.

"The failure rate prediction strategies are implemented within a probabilistic framework to directly identify confidence bounds associated with IGB pinion failure progression," he added. "The results of seeded fault, run-to-failure tests on the IGB pinion gear are being compared to prognostic module predictions."

Impact's results were verified in additional Patuxent tests. A pinion gear was driven to failure three times and Impact's prognoses closely matched what actually occurred in the test stand.

"Mission reliability could be greatly increased, maintenance could be better scheduled to reduce aircraft downtime, and a dramatic decrease in life cycle costs could be realized," Hardman said.

"What the ANSYS models provided us," concluded Kacprzynski, "is the foundation upon which high-fidelity prognostic models for helicopter gears can be built that will predict remaining life as a function of speed and load."

www.ansys.com

Southpointe
275 Technology Drive
Canonsburg, PA 15317
U.S.A.

ansysinfo@ansys.com

Toll-Free:
1.866.ANSYS.AI (1.866.267.9724)

Toll-Free Mexico:
001.866.ANSYS.AI

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