Technology Focus: Data Acquisition

Inferring Gear Damage From Oil-Debris and Vibration Data

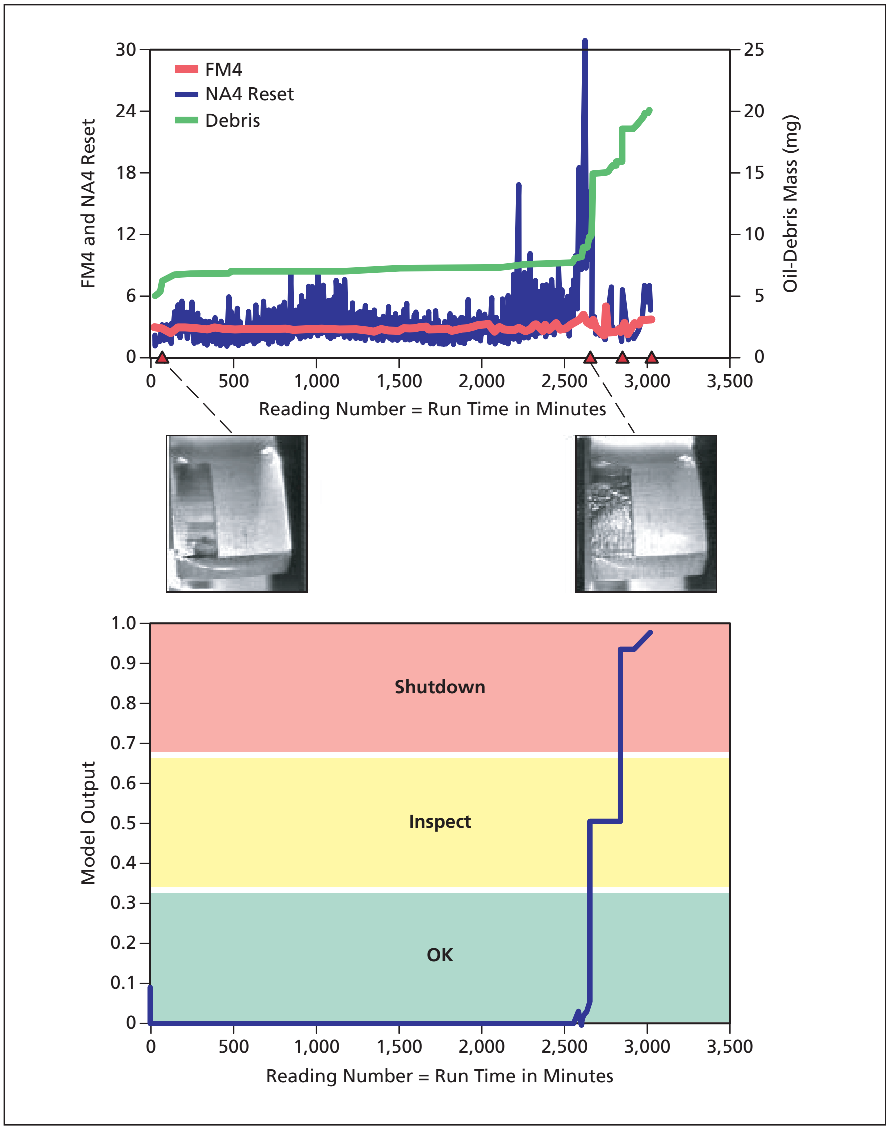
Data fusion increases the reliability and reduces the difficulty of gear-damage diagnosis.

John H. Glenn Research Center, Cleveland, Ohio

A system for real-time detection of surface-fatigue-pitting damage to gears for use in a helicopter transmission is based on fuzzy-logic used to fuse data from sensors that measure oil-borne debris, referred to as “oil debris” in the article, and vibration signatures. A system to detect helicopter-transmission gear damage is beneficial because the power train of a helicopter is essential for propulsion, lift, and maneuvering, hence, the integrity of the transmission is critical to helicopter safety. To enable detection of an impending transmission failure, an ideal diagnostic system should provide real-time monitoring of the “health” of the transmission, be capable of a high level of reliable detection (with minimization of false alarms), and provide human users with clear information on the health of the system without making it necessary for them to interpret large amounts of sensor data.

One of the main ideas underlying the present development is that by integrating oil-debris and vibration sensor subsystems into a single diagnostic system, wherein the data from the two types of sensors are appropriately fused, it is possible to make the damage-detection and decision-making capabilities of the resulting diagnostic system better than those of a diagnostic system that incorporates only one of the sensor subsystems. This idea was tested in 24 experiments in NASA Glenn Research Center’s Spur Gear Fatigue Rig, wherein vibrations were measured by two accelerometers and oil debris were measured by a commercially available inductance-type oil-debris sensor. Speed and load were also measured. The vibration and speed data were processed by two gear diagnostic algorithms that yielded temporally varying statistical parameters known in the art as “FM4” and “NA4 Reset,” respectively.

Multisensor-data-fusion analysis techniques were applied to the FM4, NA4 Reset, and oil-debris data. Data from the different sensors were combined to make inferences that could not be made on the basis of data from a single sensor. Such a process is similar to the process in which a human integrates data from multiple sources and senses to make decisions.



These **Vibration (FM4 and NA4 Reset) and Oil-Debris Data** and the corresponding output of the data-fusion model are the products of one of the experiments performed to test key parts of the developmental diagnostic system.

Sensor data can be fused at the raw data level, feature level, or decision level. In this development, the decision level was chosen because it does not limit the fusion process to a specific feature or sensor. The FM4 and NA4 Reset parameters and the accumulated mass of the debris were the features selected for use as input to the data-fusion part of the system. Fuzzy logic was used to identify the damage level indicated by each feature and to perform decision-level fusion on the features. The resulting data-fusion model was capable of discriminating between the stages of pitting wear. The output of the data-fusion model was in the form of parameters indicating which of three discrete conditions represents the current state of damage and the corresponding action recommended to end users. The three condition/action combinations were denoted "OK" (no damage and no action necessary), "inspect" (initial pitting), and "shutdown" (severe pitting).

The upper part of the figure depicts the FM4, NA4 Reset, and oil-debris data from one experiment during which pitting damage occurred. The lower part of the figure shows the corresponding output of the data-fusion model. Readings were taken once per minute. The triangles indicate when the gear was inspected for damage. As shown in the photograph connected to the second triangle, damage began to occur at approximately reading 2,669 during this experiment. Analysis of the data collected during this and the other experiments confirmed the expectation that it is advantageous to fuse features of data obtained through different sensors and that, as desired, the output of the data-fusion model amounts to clear, reliable information that can be used in making decisions about the health of the affected gears.

This work was done by Paula Dempsey of **Glenn Research Center**. *Further information is contained in a TSP (see page 1).*

Inquiries concerning rights for the commercial use of this invention should be addressed to:

NASA Glenn Research Center
Innovative Partnerships Office
Attn: Steve Fedor
Mail Stop 4–8
21000 Brookpark Road
Cleveland, Ohio 44135.

Refer to LEW-17889-1.

Forecasting of Storm-Surge Floods Using ADCIRC and Optimized DEMs

Maximum water levels are mapped for Hurricanes Camille and Katrina.

Stennis Space Center, Mississippi

Increasing the accuracy of storm-surge flood forecasts is essential for improving preparedness for hurricanes and other severe storms and, in particular, for optimizing evacuation scenarios. An interactive database, developed by WorldWinds, Inc., contains atlases of storm-surge flood levels for the Louisiana/Mississippi gulf coast region. These atlases were developed to improve forecasting of flooding along the coastline and estuaries and in adjacent inland areas. Storm-surge heights depend on a complex interaction of several factors, including: storm size, central minimum pressure, forward speed of motion, bottom topography near the point of landfall, astronomical tides, and, most importantly, maximum wind speed.

The information in the atlases was generated in over 100 computational simulations, partly by use of a parallel-processing version of the ADvanced CIRCulation (ADCIRC) model. ADCIRC is a nonlinear computational model of hydrodynamics, developed by the U.S. Army Corps of Engineers and the US Navy, as a family of two- and three-dimensional finite-element-based codes. It affords a capability for simulating tidal circulation and storm-surge propagation over very large computational domains, while simultaneously providing high-resolution output in areas of complex shoreline and bathymetry. The ADCIRC finite-element grid for this project covered the Gulf of Mexico and contiguous basins, extending into the deep Atlantic Ocean with progressively higher resolution approaching the study area. The advantage of using ADCIRC over other storm-surge models, such as SLOSH, is that input conditions can include all or part of wind stress, tides, wave stress, and river discharge, which serve to make the model output more accurate.

To keep the computational load manageable, this work was conducted using only the wind stress, calculated by using historical data from Hurricane Camille, as the input condition for the model. Hurricane storm-surge simulations were performed on an eight-node Linux computer cluster. Each node contained dual 2-GHz processors, 2GB of memory, and a 40GB hard drive. The digital elevation model (DEM) for this region was specified using a combination of Navy data (over water), NOAA data (for the coastline), and optimized Interferometric Synthetic Aperture Radar data (over land). This high-resolution topographical data of the Mississippi coastal region provided the ADCIRC model with improved input with which to calculate improved storm-surge forecasts.

Also used in the simulations was a commercially developed rainfall inundation model that originated in research performed for a NASA dual-use project. The rainfall model accepts as input an eleva-

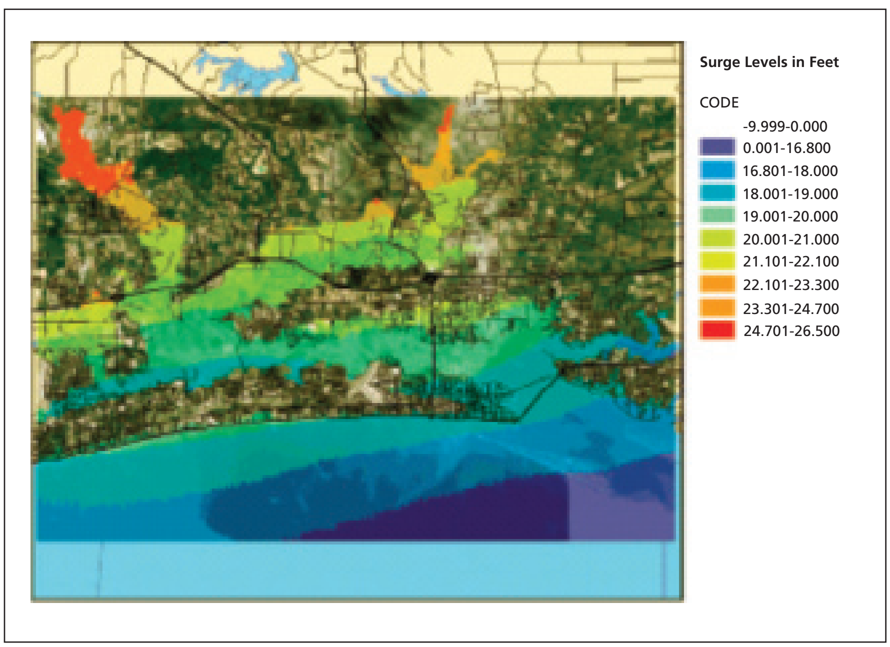


Figure 1. This **MEOW Map** shows the maximum storm surge at each finite-element node based on all simulations of category-3 hurricanes in the affected area.