The Airplane Doctors

Sophisticated systems constantly monitor the health of airplanes – military and commercial – to deliver preventive care and quick cures

By Daryl Stephenson

Gone are the days when aircraft maintainers relied on guesswork, intuition or tribal knowledge to diagnose and fix health problems in airplanes. Thanks to more advanced analytical capabilities, they can now get a clear picture of the health status of an aircraft or an entire fleet.

Armed with precise information, they can perform the right maintenance on the right component at the right time. They also can perform timely preventive maintenance to prevent components from failing in flight.

It's not enough to fix what's broken (or thought to be broken) for the next mission or flight. The maintainer's job is to ensure the overall health of the aircraft system – not just for today, but for several decades to come.

Ensuring the overall health of an aircraft fleet requires a comprehensive approach – known in the aerospace industry as Integrated Vehicle Health Management (IVHM).

The Boeing approach to IVHM includes four analytical areas of concentration:

- diagnostics (identifying the root cause of a problem)
- prognostics (predicting system health with current and historical data)
- condition-based maintenance (basing maintenance on the material condition of the aircraft components rather than on flight time or worst-case scenarios)
- adaptive control (providing the means to complete a mission despite battle damage or system failures)

Good health, lowering cost

The benefits of IVHM include improved vehicle availability, mission reliability and safety, longer system life, and reduced ownership costs. As IVHM improves and as new maintenance technologies develop, the U.S. military services and commercial airlines increasingly turn to Boeing, a large-scale systems integrator, to identify and implement innovative support solutions for platforms and fleets.

Left: A close-up of the Maintenance Access Terminal. This is where maintenance personnel at an airline can conduct tests of airplane systems. Often these tests are performed as part of the installation test, after a line-replaceable-unit has been changed.

Far left: Two experts check the systems of a 777 in the Fixed Base Maintenance Training Simulator in Everett, Wash. William Ahl, Boeing Technical Fellow (right), checks out the Maintenance Access Terminal, with the help of Don Bittenbender, maintenance training instructor.

Phantom Works initiates many of the company's IVHM solutions. Phantom Works collaborates with industry, government, and academic institutions to develop new IVHM technologies and architectures that can be incorporated into new and existing products and services.

Phantom Works laboratories create new capabilities by integrating advanced sensors, signal processing, and diagnostic/prognostic modeling with vehicle controls and operations planning. An Open Virtual Integration Laboratory leverages Boeing's expertise by extending these new capabilities to all locations.

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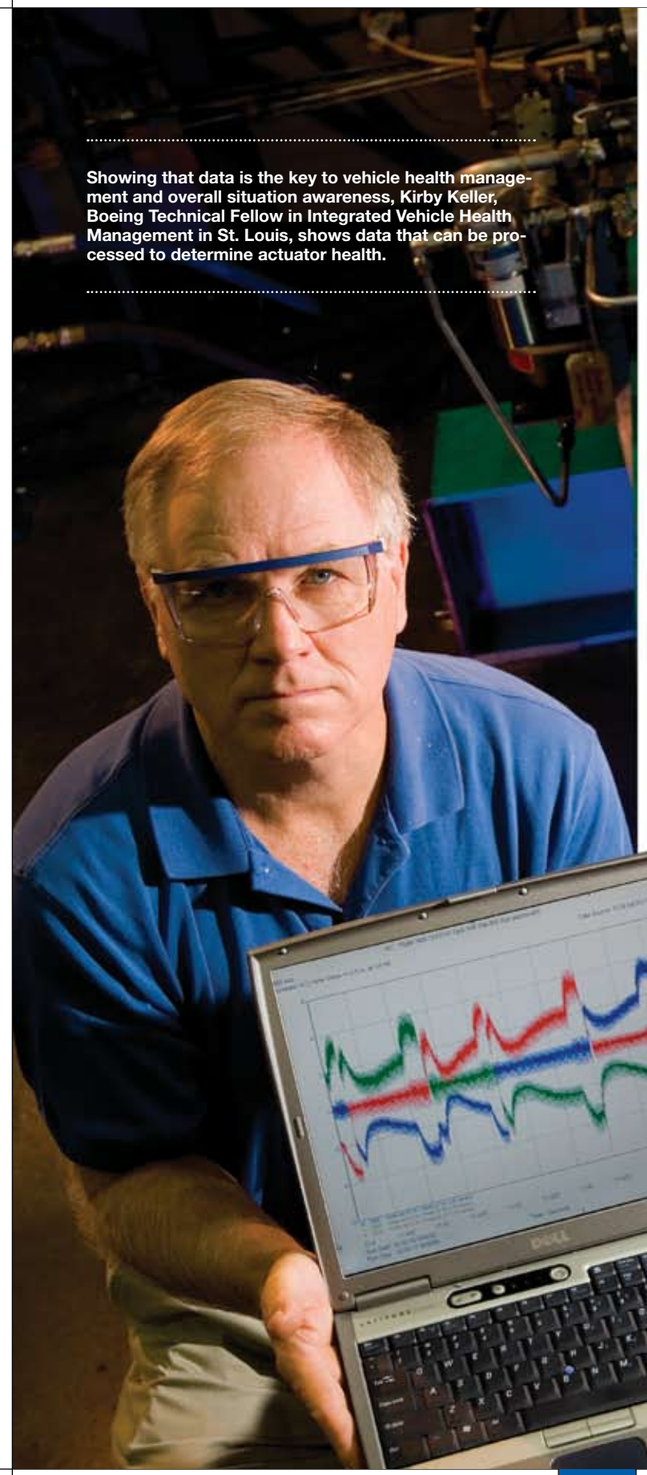

Showing that data is the key to vehicle health management and overall situation awareness, Kirby Keller, Boeing Technical Fellow in Integrated Vehicle Health Management in St. Louis, shows data that can be processed to determine actuator health.

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As part of its work with developing advanced unmanned air vehicles and space vehicles, Phantom Works is developing IVHM adaptive control capabilities. Reconfigurable controls ensure that missions can be completed, despite battle damage or system failures, by allowing operators to make full use of remaining system capabilities. This IVHM solution determines the capability of a system, modifies system control for optimum performance, and offers mission replanning recommendations according to current system health.

Phantom Works' IVHM Solution Center, created in 2003, draws on the best of Boeing, industry, government and academia to design technical, financial and operational aspects of IVHM solutions. The Solution Center gives customers access to technologies, processes and tools for comprehensive IVHM solutions that improve operational availability and reduce cost. These tools range from upfront analysis and simulation of IVHM benefits to the development and demonstration of solutions. The Solution Center also works with program teams to implement preferred solutions.

> Increased system-level complexity creates challenges for mechanics trying to figure out the root cause of a failure.

Andrew Baldwin, Phantom Works manager of the IVHM Solution Center, says that the Boeing approach to IVHM "is to work with our customers to define and implement tailored health management solutions that leverage our experience from across the enterprise. At the same time, we're using this expertise to provide an improved tool chain to design health management into future products better, faster, and more affordably."

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The growing list of IVHM customers

Boeing has a really good health plan – not only for its employees but for its airplanes, too. Integrated Vehicle Health Management capabilities are already part of many Boeing systems, as well as other aircraft.

Boeing Commercial Airplanes offers the Airplane Health Management (AHM) service to commercial customers. Integrated Defense Systems provides the Integrated Maintenance Information System (IMIS) for the F-15, T-38 and C-130 and the Automated Maintenance Environment for the F/A-18 to military customers. There are also IVHM solutions for the C-17, the 737 Airborne Early Warning and Control aircraft, the P-8A Multi-mission Maritime Aircraft, and various rotorcraft programs.

Boeing Commercial Airplanes' AHM is an in-flight health monitoring and prognostic maintenance system that uses real-time data from an airplane's Central Maintenance Computer and electronic logbook to provide enhanced fault forwarding, troubleshooting, and historical fix information to reduce schedule interruptions and improve maintenance efficiency.

The U.S. Air Force employs a system developed by Boeing Integrated Defense Systems – the Integrated Maintenance Information System (IMIS) – on the F-15, C-130 and T-38 programs. IMIS, an automated fault diagnosis and maintenance reporting and tracking system, reduces the time it takes to isolate faults.

For the U.S. Navy, Boeing IDS is the lead system integrator for the Automated Maintenance Environment (AME), which supports F/A-18s. The AME downloads aircraft built-in test data, which pilots and maintainers use to diagnose faults.

Boeing programs with IVHM health benefits

The IDS C-17 Globemaster-III Sustainment Partnership program provides the U.S. Air Force with innovative propulsion system health monitoring. Boeing-developed software reads and analyzes C-17 Quick Access Recorder propulsion data. Reports are then sent by the Internet to a Web portal where the engine manufacturer and its suppliers can view them.

The IDS 737 Airborne Early Warning and Control (AEW&C) program has deployed an integrated Health and Usage Monitoring System (HUMS) and an Operational Loads Monitoring System (OLMS) to meet Australia's aircraft structural integrity needs. The heart of the system is a data recorder that holds than 20 hours of continuous flight data.

The AEW&C program is also nearing completion of an automated Aircraft Structural Integrity Ground Station (ASIGS) that will process and analyze HUMS/OLMS data. The system will calculate accumulated fatigue damage. The ASIGS will track the lifetime history of individual airplanes as well as the entire Australian AEW&C fleet. An AEW&C fleet management system that will include the ASIGS is expected to be deployed in mid-2007.

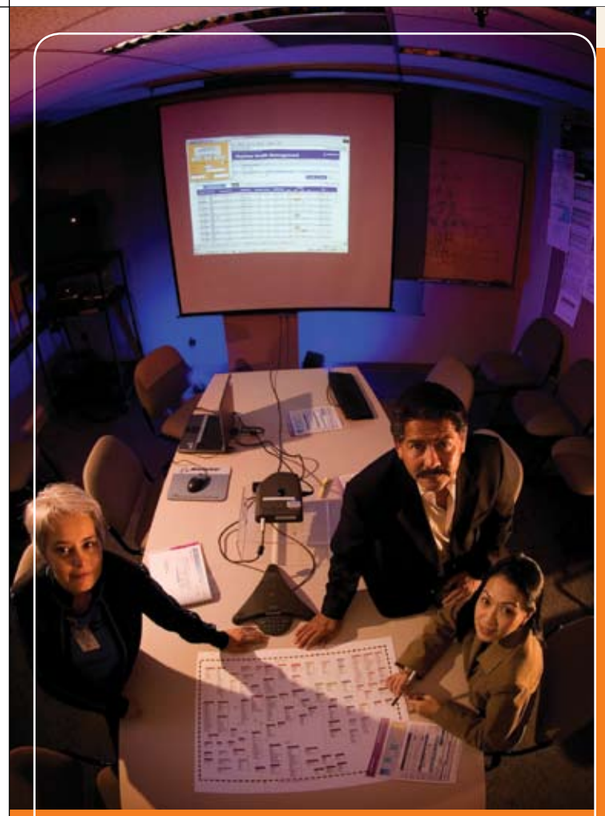
For the P-8A MMA program for the U.S. Navy, IDS uses a mix of vehicle health management philosophies to provide an Integrated Health Management System. The P-8A's mission equipment will collect information about vehicle health that will be passed to a recorder within the aircraft's avionics for better diagnostics.

The P-8A also will use prognostics to increase operational availability and reduce cost by collecting parametric data on components. If the prognostics algorithms indicate that a component is near the end of its life, it may be scheduled for replacement at a convenient time.

IDS is working with the U.S. Army and suppliers to develop a condition-based maintenance approach for the AH-64D Apache Longbow and C/MH-47F/G helicopters. Condition-based maintenance is a system that monitors the health of rotating mechanical and fatigue critical components, then transmits aircraft maintenance data for selected components during flight. Data from vehicle health monitoring systems is sent to a ground station that performs diagnostic and prognostic analysis to assess the structural integrity and remaining useful life of components.

And IDS is working with the NASA Ames Research Center to install an airborne Health Usage Monitoring System (HUMS) on an experimental JUH-60A helicopter called the NASA/Army Rotorcraft Aircrew Systems Concepts Airborne Laboratory (RASCAL). The system monitors rotor and drive train loads, vehicle flight parameter data, and component loads.

Right: Laboratory characterization of failures prevents failures in flight. Engineer scientists Jeremy Gaither (left) and Jim Sheahan examine the instrumentation of an electric actuator under test in the Facility for Integration and Research of Subsystems Technology (FIRST) lab in St. Louis.



From left, Airplane Health Management (AHM) system analysts Carmel Cameron, Rich Turrubiate and Myly Vu discuss how the AHM program can be used on commercial airplanes. The in-flight health-monitoring and prognostic maintenance system from Boeing Commercial Airplanes uses real-time data to prevent schedule interruptions, improve fault isolation, and increase maintenance efficiencies.

Boeing's airplane health capabilities

There are four major parts the Boeing approach to Integrated Vehicle Health Management – diagnostics, prognostics, condition-based maintenance, and adaptive control.

"These capabilities allow IVHM to provide aircraft operators with improved performance, cost and longevity," says Andrew Baldwin, manager of the Phantom Works IVHM Solution Center.

Diagnostics refers to the use of technology and processes to collect, fuse and analyze data on system faults. The proper use of diagnostics speeds up maintenance and improves the availability of aircraft systems. Boeing Commercial Airplanes, for example, offers a service called Airplane Health Management (AHM) that monitors the health of an aircraft in flight. AHM uses real-time data from the airplane's central maintenance computer and electronic logbook to provide enhanced fault forwarding, troubleshooting, and historical fix data to reduce schedule interruptions and increase maintenance efficiency.

AHM integrates the remote collection, monitoring and analysis of airplane data to determine the status of the airplane's current and future serviceability. It converts the data into information that maintainers can use to make the fix-or-fly decisions that can make the difference between profit and loss.

Prognostics involves the prediction of future system health by assessing current system status and historical trends. The goal is to improve maintenance time and system availability by getting the right information to correct problems before they occur or become serious.

The Boeing Integrated Defense Systems P-8A Multi-mission Maritime Aircraft program will use prognostics algorithms to increase operational availability and reduce cost. A recording device called a PCMCIA card will collect data on life-limited components, mission equipment, and structural fatigue. The card will be removed after each flight.

Data from the cards will be used to generate work orders for maintainers of the P-8A. If the prognostics algorithms indicate that a component is nearing the end of its service life, the component will be scheduled for replacement.

Condition-based maintenance takes advantage of technology that tells what's actually going on with a particular system, so that maintainers can perform work based on the known material condition of a specific component, rather than relying on statistical history or worst-case estimates. Knowledge of the material condition of components can be used to eliminate scheduled maintenance that is insensitive to the actual component's condition.

Embedded sensors in aircraft can monitor vibration, temperature, pressure and other variables that describe the actual state of an aircraft. Engineers and maintainers can analyze the data these sensors collect to determine the health of components. This reduces unnecessary maintenance and inspections.

Through **adaptive control**, IVHM can help an aircrew complete its mission despite damage or control system failures. As air and space platforms become more sophisticated, it becomes harder for even veteran pilots to use system data, their senses, intuition and experience to compensate for such problems. IVHM integrated with adaptive control can determine the capability of a system and modify the system controls to achieve optimal performance. It takes account of failures and degradations, allowing replanning to meet new mission goals based on the current vehicle capabilities.

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Legacy airplanes

Customer interest in IVHM is driven by the need for improved operational availability, lower costs, longer service lives, and the increasing complexity of aircraft.

"Today you have B-52s that are about 50 years old and still flying, and it's conceivable that some may still be flying when they're 100 years old," Baldwin says. "If you're going to be using an aircraft that long, you need a comprehensive approach to maintaining that aircraft.

"Airplanes themselves are becoming more complicated. While we've been integrating digital avionics for some time now, the increased system-level complexity creates additional challenges for mechanics trying to figure out the root cause of a failure. Training and troubleshooting manuals exist, but the system is sometimes so complex that mechanics have a hard time trying to identify the cause of problems and appropriate corrective action. In addition to data coming from the vehicle itself, mechanics get reports from pilots, crew chiefs, and loadmasters who describe various flight anomalies. This can result in a lot of conflicting information, much of which may not pertain to the actual problem the mechanics need to correct. IVHM can consolidate this disparate information into a cohesive health assessment."

> "A key feature of IVHM is its ability to understand the system's current behavior (diagnostics) and to anticipate failures (prognostics)."
>
> *Andrew Baldwin – manager, IVHM Solution Center*

At the core of IVHM is the realization that sensors and data buses onboard an aircraft can be storytellers of the aircraft's experience, condition and readiness for future missions. The challenge is to convert this data into information that's understandable, specific, pertinent and accurate, and get it to mechanics quickly enough to maintain the system effectively.

For aircraft already in service, one common IVHM solution involves attaching digital data collection devices to aircraft "to collect all the pertinent data coming off the various data busses and sensors," says Baldwin. After a flight, mechanics can download data from these devices into a ground station with a larger data base that contains comprehensive maintenance information about the aircraft and fleet. Mechanics have a tool that can analyze the data to help isolate faults in the aircraft system much more quickly, get reliable information to predict parts failures, and make the appropriate repairs.

The essential diagnostic tool

The IVHM Solution Center works with integrated product teams to embed IVHM into aircraft design and support concepts to provide health status information at near real-time levels. As a result, mechanics don't have to wait for a data download after landing to determine an aircraft's condition. The onboard IVHM system continuously feeds data into a maintenance database, which enables pilots to perform corrective operations in flight and mechanics to schedule maintenance tasks before the plane lands.

"A key feature of IVHM is its ability to understand the system's current behavior (diagnostics) and its ability to anticipate future failures (prognostics)," Baldwin says. "Taking full advantage of accurate onboard and offboard data will give our customers higher aircraft availability without having to add the costs of spares, scheduled maintenance, and maintainers. It doesn't mean we have to add a lot of new sensors to airplanes. What we're really talking about is taking full advantage of the sensors and data that are already there, so that a mechanic knows when and when not to turn a wrench." ■

William Ahl uses a laptop to access the Boeing electronic performance support system (EPSS) called Maintenance Performance Toolbox. The Maintenance Performance Toolbox is a new performance support tool designed to improve the efficiency of airline personnel. It is a standard offering on the 787.