

SPECIAL REPORT

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727 to 787: Evolution of Aircraft Maintenance Systems

Aircraft maintenance has come a long way, from push-button, light-up tests for determining the health of individual, federated avionics boxes to centralized airplane management systems that interactively collect data from all systems. It has evolved to become a valuable troubleshooting tool for maintenance technicians.



The central maintenance computer on Honeywell's Primus Epic® system

Testing mechanical and analog systems in vintage aircraft—such as the Boeing 727 and 737 Classic, and the McDonnell Douglas DC-9 and MD-80—consisted of little more than pushing a button to supply current to the internal circuitry. A green light would illuminate to say everything was OK. Such “push-to-test” and “go/no go” systems were the beginnings of built-in test equipment (BITE) for avionics technicians.

Starting in the early 1980s, digital systems that use electronic hardware and software to carry out functions previously performed by mechanical and analog systems were introduced on Boeing's 737 Next Generation, 757 and 767 aircraft, as well as the McDonnell Douglas MD-90 and Airbus A320. These new digital systems brought their own challenges to aircraft maintainers, as the ability to troubleshoot these black boxes by detecting and isolating faults was limited to the indications provided by the system.

From this challenge came the first standard for health management: ARINC 604, "Guidance for Design and Use of Built-In Test Equipment." Developed by ARINC and industry partners, this standard represents the birth of vehicle health management, where one or more line replaceable units (LRUs) equipped with dedicated front panels gave maintenance technicians the ability to test and query the system. Such panels included push-buttons and rudimentary display capabilities that showed alphanumeric readouts.

By the mid-1980s, with the introduction of the first glass cockpits on airplanes such as the McDonnell Douglas MD-11, mechanics were able to test and query several systems through centralized display panels shared by a number of LRUs. However, these common display panels report the results of each LRU independently and do not have the capability to consolidate related fault indications from multiple LRUs. While this is a significant improvement, maintenance technicians must still manually consolidate these results; otherwise they would remove and replace LRUs that merely report symptoms rather than replacing the actual faulty LRU.

In the late 1980s, the 747-400 was introduced. It contains two Central Maintenance Computers (CMCs) that receive fault status indications from most airplane systems, consolidate these results to determine the source fault, and correlate the source fault indication to the flight deck effects (e.g., flight crew alerts) caused by the fault. The CMC can display these results on the Multifunction Control Display Unit (MCDU) or downlink these results while in flight to ground sta-

tions to support maintenance planning. The CMC also provides an integrated user interface to perform ground tests on all connected member systems. However, the 747-400 CMC accomplishes the fault consolidation via a complex set of logic equation-based diagnostics. Development and maintenance of this "brute force" approach was a great technical challenge, due to the many interrelationships between the equations. This approach requires detailed understanding of all the equations in order to ensure that they are consistent and correctly represent system behavior.

These issues are compounded when the aircraft is upgraded with new systems. It took a long time to work out all the health management system's idiosyncrasies, causing an early lack of confidence in the system by airline mechanics—"Give me wrong answers once, and my confidence goes down 50 percent! Give it to me twice, and I stop using it!" In time, the 747-400 logic has matured and become a valuable tool for maintenance technicians.

Following the development of, and using lessons learned from the 747-400, Boeing, Honeywell and others in the airline, aircraft and avionics industries developed updated standards for maintenance systems, including ARINC 624, "Design Guidance for Onboard Maintenance System."

Central Maintenance & Airplane Condition Monitoring

Health management processes include the following:

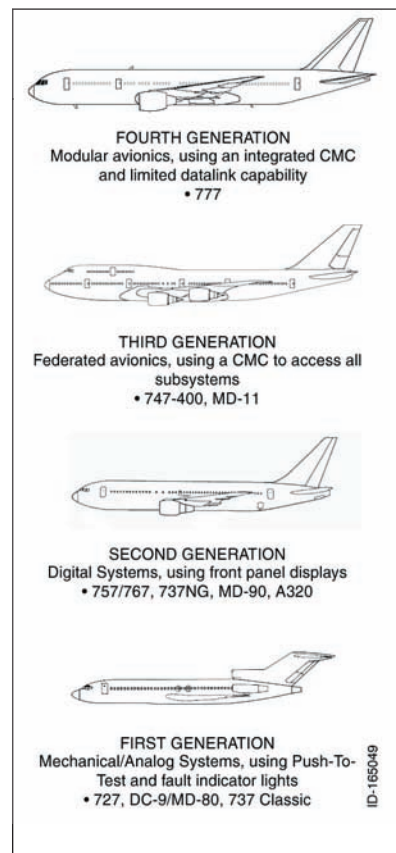
- ▶ Fault detection and isolation philosophy,
- ▶ Optimal sensor quantity and placement guidelines,
- ▶ Standard built-in-test designs and practices,
- ▶ Metrics, e.g., fault coverage percentage or fault isolation accuracy percentage,
- ▶ Verification and validation plans and procedures,
- ▶ Fault modeling guidelines, and
- ▶ Interface standards between subsystems and central maintenance systems.

Coordination and integration of those processes are key to effective vehicle health management. The ultimate goal

was to improve testability, isolate failures, improve system safety and reliability, and reduce life-cycle costs.

Many of today's aircraft employ some type of central maintenance system that fulfills the role of collecting faults from all subsystems, performing some root cause determination and recommending repair actions. In the Boeing 777, those functions are performed by the Honeywell-developed central main-

Vehicle Health Management Evolution for Commercial Aircraft



The development of health management systems reflects the evolution of avionics architectures. From the B727 to the B777, health systems have supported mechanical/analog, digital, federated and modular avionics.

tenance system software. It consists of two portions: the Central Maintenance Computing Function (CMCF), which detects faults after they happen, and the Airplane Condition Monitoring Function (ACMF), which collects data to enable prediction of problems in advance. ACMF capabilities indicated previously in earlier federated systems, but the B777

was the first aircraft to implement them in the same cabinet with an integrated advanced user interface, according to Gautham Ramohalli, the engineering manager of Honeywell Aerospace's Aircraft Diagnostics and Monitoring Systems. This integration provided the ACMF with unprecedented access to aircraft signals and enabled a common, point-and-click interface on the aircraft for both CMCF and ACMF.

As opposed to the logic equation-based diagnostics on the 747-400, the 777 CMCF employs a Honeywell-patented, model-based diagnostics technology to drive fault processing and ground tests, and display textual information to the maintenance technician. The fault model encodes the observable symptoms for each fault condition, based on the modeled effects of each fault condition within the member system and the connectivity of LRUs within the aircraft.

Each system on the airplane is responsible for fault detection and reporting in accordance with a set of Boeing-defined member system requirements. The reporting system communicates with the CMCF, using an aircraft-wide standard protocol that provides for fault reporting, configuration reporting and commanded ground tests.

Model information is contained in a separately loadable database referred to as loadable diagnostic information (LDI). The LDI is created by Boeing, using the Honeywell-developed ground-based Diagnostic Model Development Tool (DMDT), the purpose of which is to collect and validate the fault model for the aircraft.

DMDT is seeded by imports from various sources. These include the airplane interface control database, crew alerting message database, and failure modes and effects analyses. Aircraft system designers enter subsystem-specific diagnostic information and links to complete the basic model. Boeing, as the aircraft system integrator for the 777 and 787, completes the aircraft-level model by performing tasks, including analysis and correction of DMDT proposed propagation relationships and definition of fault isolation relationships for faults reported by multiple systems. This aircraft-level modeling determines

fault consolidation and fault cascade effect removal, and ensures correct flight deck effect correlation.

The aircraft condition monitoring function provides a programmable method for triggering custom data reports. Report triggers can be defined, using interface control document signals combined with logic units, to collect sample data at a predefined rate and time before and after the trigger event.

Resulting reports can be stored on onboard mass storage devices (e.g., the Maintenance Access Terminal hard drive on the 777, and the crew information system [CIS] servers on the 787), downlinked via the airborne communications addressing and reporting system (ACARS) or, on the 787, one of the available broadband communication paths, such as Gatelink (a wireless local area network [LAN] technology), Connexion by Boeing, or Inmarsat's Swift64 satellite service.

Such a capability is key to improving on-time departures because it gives line maintenance staff time to prepare even while the airplane is still in the air. "What that does is extend the maintenance technician's ramp time from 30 minutes to four hours by giving him 3.5 hours advance notice," says Don Morrow, Honeywell's director, New Boeing Platforms.

The user interface employed by the CMCF enforces a common look and feel for all member systems. This reduces the amount of training required for maintenance personnel, regardless of the system they are working on, e.g., landing gear, environmental control system or avionics.

Differences from Previous Systems

Most previous maintenance systems depended on the individual member systems to store the fault data in their LRU/LRM (line replaceable module). To display a system's stored data, a bidirectional command-request protocol is performed to retrieve the data each time a user request is made.

The CMCF uses local fault storage to store the data, which simplifies the fault-reporting interface for the participating systems. The CMCF retrieval of fault data is all contained within the CMCF itself. This speeds up data retrieval while requiring no handshaking or protocol with member



A maintenance technician accesses data using a wireless terminal

systems during the display process.

The CMCF was built upon previous Honeywell maintenance systems that added maintenance message text to maintenance message codes. The objective is to present maintenance message information in clear English text that is usable by the maintenance technician, rather than having a code that requires translation.

Embraer's OMS

The Honeywell Primus Epic® onboard maintenance system, which consists of a CMC and the airplane condition monitoring system, is finding its first 70- to 110-passenger aircraft application in the EMBRAER 170/190 family of commercial jetliners.

Many of the system health management capabilities of the Embraer aircraft are similar to those of the 777 onboard maintenance system. These include the following:

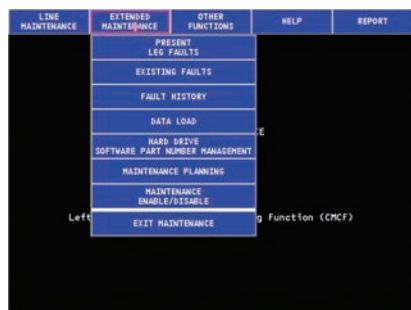
- ▶ Real-time fault monitoring,
- ▶ Integration with the data loading system,
- ▶ Point-and-click intuitive navigation,
- ▶ Comprehensive system coverage—weather radar to auxiliary power unit,
- ▶ Open architecture,
- ▶ Loadable diagnostic information database,
- ▶ Capability to display bus parameters and member status, and
- ▶ Remote terminal connectivity.

"These go beyond having a system that just reports faults to one that quickly gives maintenance technicians a snapshot of all the member systems on the aircraft," says Eric Heinzer, Honeywell's

Customer and Product Support leader for regional OEMs. "A mechanic having to deal with a series of faults now can easily determine what systems are not on-line and start there."

Like the system now being developed for the Boeing 787, the EMBRAER 170/190 Primus Epic system has a separately loadable database, so that loadable diagnostic information can be updated without having to alter the CMC functional code. In addition, the CMC is navigable, with a cursor control device comparable to that on the 777. Another common feature with the Boeing widebody is the ability to query the CMC on the EMBRAER 170/190 with a commercial off-the-shelf laptop.

On the EMBRAER 170/190, the CMC is part of Honeywell Aerospace's Primus Epic integrated avionics system. The



CMC resides on a dedicated module within the Primus Epic modular avionics unit (MAU) and utilizes a commercial off-the-shelf (COTS) operating system. The CMC software stores maintenance data locally on the CMC module in a format that is later downloaded and analyzed with common PC software applications.

Honeywell evaluated the need to bridge airborne embedded software with PC software and made a design decision to use the PC software on the CMC line replaceable module in the Primus Epic MAU cabinet, according to Gary Bird, Honeywell's product portfolio leader, Telematics and Diagnostics. This decision meant that PCs could be connected directly to the CMC module, using COTS hardware and protocols.

In turn, this provided the ability to create a CMC interface console, using a PC instead of specialized hardware. The CMC is specifically designed so that its operational interface in the cockpit requires no

keyboard. The interface is point-and-click and works with a variety of cockpit-mounted cursor control devices.

777 to 787

Boeing's 787, now under development, will also utilize the Honeywell-patented, model-based CMCF and ACMF technology, and in this application, the health management function is part of the crew information system/maintenance system (CIS-MS). The CIS-MS provides a networking infrastructure that enables airborne functions to interact with ground components and a computing environment capable of hosting RTCA/DO-178B, Level D and Level E, software applications. Hosted by the CIS are various standard



B777 OMS menus, including higher-level page and (right) flight deck effects correlation page.

applications, including the maintenance system, electronic flight bag (EFB), data loader, flight deck printer and terminal wireless LAN unit (TWLU).

The preceding systems provide interfaces to airplane communication systems, airline applications and information systems in an open architecture that can be extended and adapted. Maintenance system control and display are available through several user interfaces. Web-based technology is used for the primary interface, and ARINC 661 is provided as a backup.

The primary interface to the maintenance system is a commercial off-the-shelf PC that uses a typical Web browser interface. Unlike the Boeing 777, these devices are not certified or installed

in the airplane, and an operator may choose to stow a laptop computer on the airplane for convenience. If a laptop computer is not available, the cockpit multifunction display is equipped to provide the minimum CMCF display functionality necessary to prepare the airplane for dispatch.

Basic to the 787 airplane is the terminal wireless LAN unit, which provides the airplane side of the Gatelink connectivity and lets maintenance technicians electronically access the airplane when it is located at the gate. An optional crew wireless LAN unit (CWLU) provides the ability to use a wireless laptop computer in the proximity of the airplane to perform all of the available maintenance system control and display functionality. The CWLU system provides necessary security and allows for multiple simultaneous users.

Easy Access

With this wireless capability, maintenance technicians will not have to fight their way through departing passengers to get into the cockpit or even have to hook up their computers to external connections on the tail or engines to access troubleshooting data. They can access data while roaming freely around the exterior of the airplane. Up to four remote terminals can be connected to the CMC at one time, allowing for a faster aircraft build in the Boeing factory, as well as expedited return to service in airline maintenance operations.

In addition, the maintenance system will provide links to the electronic airplane maintenance manuals (AMMs), allowing access to detailed maintenance and troubleshooting procedures without leaving the airplane. "By auto-linking to electronic documents on the 787—something that was not available on the 777—we're creating an essentially paperless and media-less airplane," explains Bird.

How soon can 787 operators see the benefits of Honeywell's crew information system/maintenance system? The new Boeing aircraft's first flight is scheduled for August 2007, with certification in March 2008 and first deliveries by May 2008. There were, through January 2006, 291 orders for the twin-aisle Boeing 787.