**New generation aircraft such as the A380 and Bombardier CSeries have introduced a new generation of on-board maintenance systems. These have enhanced functionality to diagnose and rectify technical faults on the aircraft, and ultimately reduce the cost of line maintenance.**

# Rectifying faults with new-generation on-board maintenance systems

Line maintenance, and the diagnosis and correction of faults and defects that occur randomly in flight, account for a high percentage of total aircraft maintenance costs. Over the past three decades, on-board maintenance computers have evolved to make it faster and simpler for line mechanics to diagnose and correct technical defects, thereby reducing aircraft downtime and the cost of routine and non-routine line maintenance.

## Technical faults

Traditionally, pilots would give handwritten pilot reports (PIREPs) and technical flight logs to line mechanics after a flight. They would cover all faults, defects and flightdeck effects that occurred in flight, including: warning indications from flight instruments; problems and malfunctions with the aircraft's systems and their related line replaceable unit (LRU) and rotable components; and failure messages from the centralised maintenance system (CMS).

An aircraft's systems include: the auto flight system; communications; cabin systems; fire protection; flight control; fuel system; pneumatics; hydraulics; electrics; air conditioning; recording & flight warning system (FWS); landing gear; lights; navigation system; oxygen system; water waste; onboard network system; onboard maintenance system; information system; doors; auxiliary power unit (APU); and engines.

Fault messages are also sent from the aircraft's major components such as the wheels and brakes, landing gear, thrust reversers, and the (APU).

Faults and malfunctions in aircraft systems and LRUs all had to be analysed manually, by line mechanics examining PIREPS and handwritten technical logs, and consulting paper documents and manuals like the minimum equipment list (MEL), troubleshooting manual (TSM), fault isolation manual (FIM), illustrated parts catalogue (IPC) and the aircraft maintenance manual (AMM).

## On-board systems

The first on-board maintenance computers provided fault codes from the aircraft's central maintenance computer (CMC) via built-in test equipment (BITE) on each of the aircraft's components. These were displayed on a centralised display unit (CDU) on the flightdeck of types such as the 757, 767, A310 and A320. The mechanics then interpreted the codes using the paper manuals.

On-board maintenance systems introduced in the late 1980s on the A320 family and 747-400 correlated and consolidated all fault messages that were related to the same fault in a CMC. These were printed off in a single report by the mechanics conducting line maintenance.

"On types like the A320 and A340, the aircraft's CMC is accessed via the multi-purpose control and display unit (MCDU) screens on the centre pedestal," explains Christian Dieckert, manager of A380 maintenance at Lufthansa Technik. "The printed list of fault codes is taken to an office or a van where a computer is used to access electronic versions of the various maintenance manuals. The fault codes must be manually entered into the computer to find the relevant manual as the first stage in fixing the faults. Also on the A320/330/330, fault messages are sent to the ground via ACARS after each flight and are accessible to the operator's maintenance control centre (MCC) by using AIRMAN. Aircraft manufacturers have developed software to diagnose fault codes electronically, which reduces a mechanic's workload. Airbus has developed a set of applications for this purpose: AIRN@V for aircraft maintenance documentation; and AIRMAN for Airbus fleet monitoring. The software provides analyses and troubleshooting recommendations. AIRN@V produces hyperlinks that lead to the relevant pages of the FIM, TSM, IPC and AMM. Depending on company policy, a current flight report can be sent in flight via the aircraft communication and reporting system (ACARS)."

In contrast, earlier on-board maintenance systems simply listed all fault codes. As one of the first stages in diagnosing a fault, line mechanics had to manually correlate all the fault codes that came from several LRUs that were related to the same problem and malfunction.

Later-generation CMCs, on types like the 777, were on dedicated maintenance terminals on the side or the rear of the flightdeck. They also included access panels on the side of the aircraft so that the CMC could be accessed using a portable maintenance terminal; a device similar to a laptop computer.

Fault codes and flightdeck effects can also be transmitted from aircraft in real time by ACARS to a ground station. ACARS allows mechanics to diagnose and prepare corrective action while the aircraft is still in flight.

Once received by the ground station, the fault codes can be fed into the airline's maintenance and engineering (M&E) IT system. PIREPs and technical logs also have to be fed or typed into the M&E systems. Mechanics then reconcile them with the fault codes sent by ACARS.

## New generation

The latest-generation aircraft, which

*The A380's flightdeck has two ITs and one OMT, and the aircraft central maintenance function can be accessed through these. The OMT is also used to access the aircraft's electronic logbook and post-flight report which lsist all the faults and their codes that occurred during the flight.*

include the A380, A350, 787 and Bombardier CSeries, have on-board maintenance systems that further simplify the diagnosis of technical faults and flightdeck effects. This will reduce the aircraft's line maintenance requirements and improve technical dispatch reliability.

The on-board maintenance system on the A380 and A350, for example, has been configured so that all fault codes can be viewed on dedicated maintenance terminals, on the flightdeck or at various points around the aircraft. The fault codes are hyperlinked to the relevant pages of the appropriate maintenance manuals and documents on computers on the aircraft to provide faster and more accurate analysis of faults and defects. Mechanics can make a diagnosis and take corrective action without having to make as many trips between the aircraft and ground stations, such as the airline's maintenance control centre (MCC).

## A380 system

The A380's flightdeck has a single on-board maintenance terminal (OMT) and two on-board information terminals (OITs).

The OMT is a dedicated maintenance computer on the flightdeck, between the two jump seats. "The OMT is the main station on the flightdeck and is a laptop that allows the user to access the aircraft's maintenance applications, such as the central maintenance function (CMF)," says Dieckert. "The OMT is also used to access the aircraft's electronic logbook, the post-flight report (PFR) as part of the CMF, the aircraft systems report and test, the circuit breaker manager, and all electronic maintenance documents and manuals. Access to the electronic circuit breakers via the OMT means there are only a few electromechanical circuit breakers on the A380, in the upper and lower avionics compartment. There are some reset switches on the overhead panel on the flightdeck with a circuit breaker look and feel, but no real circuit breaker function. About 90% of circuit breakers on the A380 are electronic.

"The two OITs are mainly dedicated to displaying information from the electronic flight bags (EFBs), and are located to the side of the main flightdeck screens for each pilot," continues Dieckert. "The OIT has a pull-out keyboard and built-in mouse, which slide out below the main screens, so they are visible to each pilot. The OITs are used to access the same functions as the OMT."

The OMT and OITs can also be used to access PIREPS and PFRs, maintenance manuals and documents, and the aircraft condition monitoring system (ACMS). PIREPs are documented in a technical logbook only.

The OIT and OMT will eventually be able to use and access an electronic technical log (eLogbook). This has yet to be operationally deployed on the A380, but is now available with the latest NSS/OIS standard delivered in 2012. The eLogbook will replace the paper technical log, which must still be written, given to a mechanic and filed as a legal requirement.

Although the eLogbook is available on the A380 as a basic function, it is not yet used by Lufthansa. The A380 is equipped with the eLogbook, but it is not just an aircraft application. A dedicated ground software interfaces to the airline's maintenance IT system. A proper ground network is required.

"All flightdeck effects, messages, warnings and malfunctions still have to be recorded in the handwritten technical log for viewing by mechanics and our MCC. They can also be sent to the MCC while in flight via an ACARS telex, and so be seen earlier. The flightcrew can also send an ACARS telex," says Dieckert.

"The aircraft's CMF can also be accessed through nine plugs at various points around the aircraft with a portable maintenance access terminal (PMAT)," says Jean-Marc Tragin, head of on-board information systems for the A380 at Airbus. "The PMAT is a secured laptop, similar in appearance to the OMT. The access plugs are both inside and outside the aircraft, including the nose and main landing gears, the APU, fuelling station, various points in the cabin, near the electronic bays and in the cargo zones."

The connection with the PMATs allows the mechanics to perform the line maintenance functions at the appropriate location, rather than having to constantly visit the flightdeck.

In addition to the OITs and OMT, the A380 also has the ACMS. "The A380's ACMS is an aircraft health-monitoring system that follows about 6,000 parameters," explains Dieckert. "These include the sensor monitoring the nose wheel alignment, fuel quantity indication, wheel brake temperature, and flight control positions. The ACMS does not provide messages to ECAM. The ACMS collects pre-selected aircraft parameters and builds a report. These reports may be sent to the MCC using ACARS."

The ACMS provides the maintenance and engineering teams with additional information to the flight warning system (FWS) messages and alerts. The ACMS notifies, via the OITs and the OMT, if a monitored parameter is reaching or exceeding pre-defined thresholds and requires maintenance attention or action.

## A380 fault diagnosis

The configuration of the A380's CMF and maintenance terminals removes many of the manual processes a line mechanic has to follow when diagnosing faults and defects on aircraft prior to the A380.

Fault codes and defects that occur in flight are displayed on the ECAM screens, and summarised in the PFR on the OITs and OMT at the end of the flight. "Fault

*When a fault code listed in the A380's PFR is clicked on, hyperlinks take the mechanic to the relevant pages of the electronic technical manuals to allow faster fault diagnosis. This is aided by AIRN@V, a software developed by Airbus. Fault codes are also transmitted during flight via ACARS, and diagnosis can start on the ground.*

codes are transmitted to the ground stations via ACARS every 15 minutes," explains Dieckert.

"The A380 automatically classifies fault codes at six levels. Class 1, the highest severity, is potentially a 'no-go' fault, although not all are. It is just a dispatch-critical item, which has to be analysed against the MEL, and can be deferred, depending on MEL criteria," continues Dieckert. "Class 2 is reserved for the future system on the A350. Class 3 is a cabin fault. Class 4 is a timer fault, so it has a time limit to be rectified. If the fault is not fixed it automatically becomes a Class 1 fault (ECAM Warning 'Maintenance Limited ITEM') Classified as MEL C, which means it has to be rectified within 10 days. Class 5 is a pending fault, and will only become a Class 1 fault if an associated fault occurs. Class 6 is a fault that can be deferred."

The fault codes will have been automatically transmitted via ACARS to the airline's MCC, which will use a fault diagnostic tool, such as AIRMAN, to diagnose and interpret the codes.

In the meantime, the current flight report (which includes the actual fault codes in flight) and the PFR (list of all fault codes that have appeared during the flight) are sent to the MCC via ACARS.

The MCC's software is similar to the OITs and OMT, so it can use hyperlinks to diagnose faults.

"In addition to a fault code being issued, there is a flightdeck effect in some cases," says Dieckert. "An example is a malfunction with an avionic LRU that is related to autopilot function. A fault code will be generated by the unit's BITE, and transmitted to the ground by ACARS. At the same time the pilot will get a message warning of an autopilot malfunction on the ECAM warning display. Based on one or more fault codes, the FWS logic generates a related flightdeck effect. This must be handwritten in the technical and flight logs, but can also be sent to the MCC by the pilot, using the eLogbook on the OIT (if used by the airline). Again, the message will be transmitted by ACARS."

When a fault code is generated by the LRU's BITE it is sent to the CMS and FWS. The CMS records the fault in its database. The FWS generates a related ECAM warning, failure flag or warning light. On the A380, the CMS sends a summary of all recorded fault codes every 15 minutes via ACARS. At the end of the flight the CMS generates the PFR, which summarises all failure messages from the last flight leg. The report is stored on the aircraft server and sent to MCC via ACARS.

Both the fault codes and the flightdeck message from the pilot's log can be correlated and diagnosed by line mechanics in real time while the aircraft is in flight. AIRMAN gives a hyperlink for each fault code, taking the mechanic to the relevant pages of the electronic maintenance manuals and documents.

The faults, their associated fault codes and the eLogbook entries can be viewed by the mechanics on the PFR via the OITs or OMT.

"Automatically transmitting fault codes every 15 minutes from the aircraft means that 95% of faults are sent while the aircraft is still flying," says Dieckert. "The mechanics only have to wait for the aircraft to land before viewing the other 5% on the OITs and OMT."

The current flight reports (every 15 minutes) support maintenance by giving a clear picture of the aircraft's health status during flight, to prepare maintenance action before arrival. At the end of a flight the line mechanics will check the PFR with the summary of all faults that occurred during the flight.

"The first steps are to troubleshoot a problem on a system as it arises," explains Tragin. "The fault codes and messages are summarised at the end of the flight in the PFR, accessed through the OITs or OMT. Each fault is described, and there is a highlighted fault code in the electronic documentation."

If clicked on, the procedure for diagnosing and dealing with the fault opens up in AIRN@V. "AIRN@V is a documentation manager tool, and its manuals and documents include the AMM, TSM, IPC, wiring diagrams, schematic manuals and others," says Dieckert. "AIRN@V has further hyperlinks to relevant pages in the electronic manuals and documents. These give the mechanics the instructions to deal with the faults and defects."

Another feature is that the faults are linked to the MEL, which can be consulted in-flight. Whether the fault has to be cleared and dealt with when the aircraft lands, or can be deferred, can be decided as soon as it occurs. This is aided by the A380's ability automatically to classify each fault according to severity.

The same fault classification is transmitted to the ground, where mechanics analyse the severity of the fault in more detail, and consider it in relation to all other outstanding faults, upcoming planned maintenance events, and plan when to rectify the fault accordingly.

If the fault is dealt with on the ground after the aircraft has landed by the mechanic consulting the OMT and the electronic manuals, a fix must still be prepared manually. "This is because there is no continuous electronic connection between the aircraft's CMF and the M&E IT system," explains Dieckert. "The mechanics must therefore follow the same procedure as for types like the A320 and A340, where further steps, such as sending a material order and organising tools, are taken at the MCC or in a van by the aircraft. Since most fault codes and flightdeck effects are transmitted during flight, these manual steps are unnecessary in most cases."

The A380's system also gives access to the aircraft's eLogbook. "The eLogbook standardises flight reports and PIREPS written by the flight crew," says Tragin.

*The Bombardier CSeries will have an on-board maintenance system with similar functionality to the A380. This will have hyperlinks to the electronic maintenance manuals. Bombardier is also developing a smart fault isolation manual. This will allow the mechanic to run remote dispatches via a laptop or tablet computer.*

"It allows information to be shared between the pilots and mechanics electronically. The information is first entered by the pilots, via the OITs, and by cabin crew using their own system.

"These are similar to traditional paper logs, but the information can be shared and used at several locations," continues Tragin. "Instead of pilots reporting flightdeck effects and problems in their own style on handwritten paper logs, the eLogbook has a standard format for making reports and messages, which come from a menu. This avoids confusion and misinterpretation by ground crew."

However a fault or defect is dealt with, mechanics must still manually correlate and associate the fault codes and the flightdeck effects. This is done by the CMF, and is already available on the A320/330/340. The A350 is expected to extend the functionality to automatically correlate the flightdeck effects and fault codes, further reducing the time to diagnose and rectify a fault or defect. The A350 will also have a feature, known as a dispatch message, to correlate flightdeck effects and fault messages with the MEL.

## System tests

One major task of line maintenance is to run system tests. On older generation aircraft this has been done via the AMM.

Once an LRU or rotable is replaced, the AMM instructs the mechanic to run a system or BITE test to confirm correct function. "The OMT describes how to run the test, and the mechanic clicks a button on the AMM page to go to a hyperlink to run the test," says Dieckert. "The test can be run with just a few mouse clicks on the OMT. This is much faster than following the manual process on the MCDU and circuit breakers of the A320 or A340 flightdeck."

The many steps in running system tests involve pulling several circuit breakers prior to a test being run.

On the A380, the OMS interfaces with the electronic circuit breakers. These can all be pulled electronically with a click when a test is run. This starts with a hyperlink within AIRN@V, and the test is run automatically. Afterwards the electronic circuit breakers can be re-engaged through the same interface. The entire process is quicker than the manual system on previous generation aircraft.

The aircraft's OMS then tells the line mechanics that the test has been run, gives results and findings, and confirms full functionality after the test has been run. It will indicate a test result, rather than give an indication for dispatch. This automatic test process is another feature that allows faster diagnosis and treatment of technical defects and system faults, during a power-up sequence or taxi-out, after landing, or automatically after operational hours with the aircraft on the ground. The result of an automatic test may lead to a flightdeck effect and a CMS failure message.

## Bombardier CSeries

The Bombardier CSeries, which is due to enter service in late 2013, has an on-board maintenance system that promises to offer similar functionality to the A380's, and some additional features.

"We will introduce an aircraft health-monitoring system (AHMS) on the CSeries," says Shahan Helvadjian, director of CSeries customer services and support at Bombardier. "The AHMS will monitor aircraft systems, and transmit data to the operator's ground stations, as well as to Bombardier.

"The aircraft will have an on-board maintenance system (OMS) with a health management unit (HMU)," continues Helvadjian. "This will have three basic functions. The first is line maintenance diagnostics, to generate a message if a fault occurs, which will be transmitted to the ground via ACARS. The second main function is data recorded in the HMU, to analyse the aircraft's flight operations profile. Parameters will include speed, descent and ascent angles, and fuel consumption. The third main function will be data for analysis of aircraft system data and component function. The data will be trended and monitored, and alerts will be automatically generated if a component or system failure is possible."

The aircraft's OMS will have electronic versions of all the aircraft's technical and maintenance manuals, and will generate and display EICAS messages, PFRs and maintenance documentation. It will also have the AHMS and, if required by the operator, an electronic technical logbook. "The OMS will provide hyperlinks between the fault messages and the relevant electronic manuals," explains Helvadjian. "Once a hyperlink is clicked on, the mechanic will be taken to the relevant pages of the technical manuals.

"We are also developing a smart fault isolation manual (FIM)," continues Helvadjian. "This will not be on the aircraft, but will be available on a laptop or tablet computer, such as an iPad. The mechanic will link directly to the aircraft, either via a physical connection to the ethernet or a wireless connection. This will allow a mechanic to run remote dispatches, and give them the authority to perform remote maintenance and sign the aircraft off for dispatch. This cannot be certified for several years, however, so a mechanic must continue being at the aircraft to initiate tests. The smart FIM will allow a mechanic to run system tests electronically with a connected or wireless computer device, so that the circuit breakers do not have to be physically pulled and re-stowed before and after the test."



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