On-board maintenance systems have evolved from simple sensors to full maintenance suites and dedicated maintenance terminals. Their purpose is to simplify line maintenance and improve the efficiency of maintenance control & aircraft operations.

The evolution of on-board maintenance computers

The increasing level of technological sophistication used in commercial aircraft over the past 30 years has included the development of on-board maintenance computers. These were first introduced because of the increasing system integration in the aircraft (avionics systems) and the advent of two-man flightdecks. They have developed into maintenance aids that are intended to reduce the time and manpower required to locate and deal with technical faults and defects. How they have evolved and contributed to simplifying the line maintenance process and streamlining aircraft operations is examined.

Fault analysis

Aircraft develop technical defects and faults in operation. While the design of aircraft systems over several decades has aimed at improving system component reliability, technical defects and faults are inevitable. Many of these defects and faults affect line replaceable units (LRUs), which are rotables related to aircraft's systems.

Faults and defects have traditionally been reported and analysed manually. Pilots make pilot reports (PIREPs) and technical logs of faults or problems manually on paper, which are passed to line maintenance mechanics. Line mechanics and maintenance control departments then have to analyse and isolate faults, symptoms and problems using manuals. This is done using fault isolation manuals (FIM) or troubleshooting manuals (TSM), which are used to look up fault codes.

Prior to initialising any troubleshooting, the personnel in these departments first use the minimum equipment list (MEL) to determine if the problem is a 'go' or 'no go' item. That is, whether or not the aircraft can continue to operate with the fault. Faults that are 'go' can be deferred while an aircraft continues to operate.

There are also time limits for how long a fault can be deferred before being cleared. Line maintenance departments therefore have to make arrangements for rectifying defects and reducing or totally clearing the list of outstanding defects.

Early development

The increasing complexity of aircraft required the automation of some of this manual process. The requirement was for an aircraft system that would detect faults and defects occurring, and warn that there was a problem. The first aircraft to have some sort of automated failure reporting capability were the A310 and 757/767.

Early aircraft in the 1950s and 1960s used analogue signals for systems to communicate with each other. Aircraft developed in the 1970s started to use digital data buses to increase sophistication.

Early aircraft types used basic equipment to analyse and troubleshoot systems to isolate problems and faults. A built-in test (BIT) was developed to detect improper operation. Mechanics still relied on voltmeters, PIREPs and manual techniques to analyse faults, however. These fault detection monitors were utilised to aid the detection, troubleshooting and isolation of faults.

The fault code system was developed in the 1960s, and in the case of Boeing aircraft evolved into fault report manuals (FRMs). The FRM was used by the flightcrew to generate a fault code or 'maintenance message' following a particular malfunction. This was done on the flightdeck using a fault tree. These codes were then recorded by the crew into their technical logs, which were then handed to line mechanics after the aircraft had landed. The fault codes were used by line mechanics who manually went through the FIM to troubleshoot them.

The advent of digital aircraft meant that LRUs now had built-in test equipment (BITE). The BITE on each LRU produced and displayed maintenance messages on light emitting diodes (LEDs) on the front of the LRUs, many of which were avionics in the lower bays of the aircraft. The LRUs could also be interrogated, using a push button, to get a fault code, which was then analysed. The fault data were not stored, however, and if they were not read by the line mechanic within a set period of time, the information was lost.

The LRUs could also send messages on a system fault to a central display. In the case of Boeing aircraft, the 757 and 767 were some of the first to have such central displays, and had the engine indicating and crew alerting system (EICAS). The EICAS showed messages in text relating to a system fault. These were known as flightdeck effects (FDEs).

This system was still cumbersome in that the line mechanics had to physically open the avionics bay and climb inside for inspections after each flight to get the fault codes from the LRUs. These had to be recorded manually and listed, and compared manually with the EICAS messages.

Centralised display

The shortcomings of this system were soon appreciated. The number and complexity of systems continued to increase and the use of front panel displays on each LRU differed and so became ineffective.

This led to the development of a centralised display on a terminal on the flightdeck, which was first featured on the A310.

The evolution of on-board maintenance systems has reduced the number of stages involved in isolating and rectifying a technical fault. The next generation of on-board maintenance systems will involve dedicated on-board maintenance systems that could see the complete bypassing of maintenance control centres in many cases.

The main feature was that the aircraft had the capability to test some BITEs from the flightdeck, and display their maintenance messages.

The A310 also showed FDEs on the electronic centralised aircraft monitor (ECAM). This is similar to the EICAS on the 757/767.

The ECAM includes a control panel on the centre pedestal and two screens in front of the throttle quadrant. These can display comprehensive warning messages, and the control panel is used by the flightcrew and mechanics to select the system for which the information is required.

Messages on the ECAM are recorded manually by the flightcrew in technical logs and PIREPs, and these can be followed up together with the maintenance messages by line mechanics. Maintenance and fault messages can also be printed on the flightdeck printer. From here line mechanics would isolate faults using the FIM and other manuals.

First generation

The first generation of centralised on-board maintenance computer capability came on the A320. The aircraft had a centralised fault display system (CFDS), which provides a common display that communicates with all BITEs. It acquires and provides a report of maintenance messages from most or all of the systems on board the aircraft, and prevents line mechanics from having to go to the avionics bay to test individual LRUs.

The CFDS is used to select the system for which information is required, and then maintenance messages for that system are sent to the multi-function control display unit (MCDU) display. This basic structure of this system was also used on the A330/340.

“We developed a CFDS that uses a centralised fault and display interface unit, which is a computer for acquiring maintenance fault messages,” explains Christian Fremont, head of avionics systems within Airbus Customer Support. “There is also the ECAM warning that has an operational impact in flight, and these are displayed to the pilots. There are many types of failure that do not affect the operability of the aircraft. These are recorded for later information for line mechanics, but do not need to be displayed to the pilot. These messages are still acquired by the CFDS.

“Line mechanics need to collect all failure messages, and they check the technical logs and PIREPs after flights, as well as the post-flight report provided by the CFDS,” adds Herve Auffret, on-board maintenance system engineer at Airbus. “Line mechanics then have to correlate the two. The CFDS prints the report on the flightdeck. With the evolution of the A300 to the A320, the A320 acquired a centralised system that can send standardised fault messages in plain English, but also with an Air Transport Association (ATA) chapter identity. This is a six-digit code listed in the troubleshooting manual so that corresponding troubleshooting procedures can be identified.”

The A320 CFDS also has an interactive mode, in that it allows line mechanics to retrieve system BITE memory content as well as launching tests. Auffret explains that the two MCDUs are situated on either side of the pedestal. They are interactive terminals that link with both CFDs and the flight management system, among others. The MCDU is the pilot’s and line mechanic’s terminal for reading maintenance messages.

The A320’s centralised system provided line mechanics with a list of maintenance messages, which have to be analysed manually together with ECAM messages by the line mechanics.

The A320 has the ability to use an aircraft communication and reporting system (ACARS) to transmit maintenance messages to ground stations. These messages can then be fed into maintenance software systems for automatic analysis.

The advantage of transmitting maintenance messages to the ground is that line mechanics can receive maintenance messages in real time while the aircraft is in flight. The first obvious advantage of this is that line mechanics do not have to wait for the aircraft to land before going on to the flightdeck to use the MCDU to get messages. They can therefore save time by starting to analyse messages and isolate faults, so that preparation to rectify ‘no go’ failures can be made before the aircraft lands.

Central maintenance

Up until this stage, on-board systems only provided a list of maintenance messages. These were not correlated, so when a malfunction in one component or LRU caused malfunctions in others, several maintenance messages were often produced, regardless of the fact that the malfunctions had occurred at the same time, and were related to the same problem. Fault reporting systems had so far not correlated these, and this had to be done manually by line mechanics. A correlation function for fault messages is standard on the A320.

The 747-400 was the first Boeing aircraft to have a centralised maintenance system. The CMC received the maintenance messages and EICAS information or FDEs from most of the aircraft systems, and correlated them. These data and information were then shown on a common display unit (CDU).

Eduardo Borges, quality manager at Louro Aircraft Services, explains that the 747-400’s two CMCs consolidate maintenance messages, determine the source of the fault and correlate this with the fault indication on the flightdeck

Boeing introduced the maintenance access terminal (MAT) on the 777. The MAT replaces the CDU used in previous generation on-board maintenance systems and is a dedicated terminal specifically for viewing maintenance messages and FDEs. The 787's system will include a full suite of electronic technical manuals, which will be interrelated.

EICAS. "The CMC can display these results on the MCDU, or downlink them to ground stations via ACARS," says Borges. "The CMC also provides an integrated user interface to perform ground tests on all connected systems. The experience used from this system on the 747-400 led to the development of the next generation of on-board maintenance computer."

Second generation

A second generation of CMCs were developed as a consequence of the lessons learnt from the first generation systems. "The 777 uses a central maintenance computing function (CMCF) to detect faults as they occur, and an airplane condition monitoring function (ACMF), which collects data to try to predict problems in advance of them occurring," explains Borges. "The 777 has a system which drives fault processing and ground tests to display fault information in plain text to the maintenance technician. These reports can then be stored on mass storage devices on board the aircraft, and are then downlinked via ACARS."

The 777 also has a maintenance access terminal (MAT) on the flightdeck. This replaces the CDU terminal on the pedestal on the 747-400 with a maintenance terminal located behind the pilots' seats. This is a display specifically for viewing maintenance messages and FDEs that have been correlated by the CMC. The MAT is basically a bigger and more powerful CDU.

A portable MAT can also be used on the 777 via an access panel underneath the aircraft, so that line mechanics can view maintenance messages without having to enter the flightdeck.

Automated fault code analysis

As described, fault codes have to be analysed manually by line mechanics using printed FIMs, the MEL and other technical documents. These manuals are now produced electronically, allowing a more automated approach to analysing fault codes.

PIREPs and technical logs can still be made manually or recorded electronically. There are also several types of maintenance software available that can analyse fault codes automatically by using electronic versions of the aircraft technical manuals.

Fault codes and messages can be entered into these software systems electronically via electronic logbooks, PIREPs, technical logs, or ACARS.

The data are then transferred to the systems for automated diagnosis using the FIM. Some of these systems also provide line mechanics with tablet computers so that relevant pages of the FIM, troubleshooting manual, illustrated parts catalogue (IPC) or aircraft maintenance manual (AMM) can be looked up on line while the aircraft is being worked on. The systems also transfer open defects to the maintenance production system so that task cards may be written. These have pages from various manuals attached and are then sent electronically to the line mechanics so that they can proceed with the rectification.

ACARS eliminates the need for line mechanics to manually record codes and then enter them into maintenance software. Cathay Pacific, for example, downloads all its codes via ACARS into the Ultramain software. PIREPs and technical logs also have to be fed into maintenance systems, and have to be reconciled with the fault codes sent by ACARS.

There are many software systems available for airlines, and Airbus has developed AIRMAN for this purpose. As described, maintenance data can be transmitted via ACARS to line mechanics and maintenance control departments during flight. "AIRMAN receives these codes automatically and has algorithms to provide troubleshooting recommendations," says Fremont. "This means that there is time for the line mechanic to analyse faults, make a decision about deferring them or rectifying them when the aircraft is on the ground, and prepare a rectification with all relevant manuals, job cards and spare parts in time for when the aircraft lands. AIRMAN also produces hyperlinks, which the line mechanic can click on. These lead to the relevant pages on the electronic manuals that provide a procedure for fixing the problem."

Not only does this mean that the preparation of fault fixing can be done in flight, it also means that problems can be more quickly isolated during daily, weekly and A checks.

Future developments

The second generation of on-board maintenance computers correlated maintenance messages and FDEs, but then relied either on manual recording or ACARS to get these codes into manual or automatic fault diagnosis systems and FIMs. The third generation of on-board maintenance computers will automatically link maintenance messages and FDEs with electronic technical documents such as the FIM.

The first generation system, as used on the 747-400, received FDEs and maintenance messages from systems and BITEs, and correlated this data. The line mechanic was required to manually look the codes up in the FIM.

The second generation system on the 777 provided the MAT to display all data and messages that were correlated. These data still had to be analysed manually by line mechanics if automatic systems were not in place.

The A380 and 787 will use third generation on-board maintenance systems. In the case of the 787, the MAT used on the 777 will be replaced by a dedicated laptop computer. This will be plugged into the aircraft to provide access to the data in the CMC. The same laptop will be able to receive this information via ACARS while the aircraft is in flight.

The laptop will receive correlated FDEs and maintenance messages. The laptop will display a button that when pressed by the mechanic will automatically go to the relevant FIM page in the electronic FIM stored on the laptop. All technical documents are interrelated, so that having gone to the relevant page in the FIM, the line mechanic will find that the fault isolation process will follow on automatically to the other relevant pages of the relevant documents, such as the AMM or IPC. Ultimately the mechanic will be taken to the part that has failed.

From here, it is possible for job cards that are required to effect a repair to be produced, although this requires a link to another software.

The laptop computer on the 787 can be wireless, so that the line mechanic can receive maintenance messages and FDEs when walking in the vicinity of the aircraft. This will allow the line mechanic to start work on isolating faults and identifying failed parts within minutes of an aircraft landing. While this can already be done with ACARS, the third generation of on-board maintenance systems eliminate many of the steps in the traditional process of manually recording FDEs and maintenance messages, taking them to maintenance control, analysing them manually with paper manuals to make decisions with respect to deferring or fixing the problem, and looking through manuals to create a fix. The overall benefit of this is to increase the efficiency of maintenance control and line maintenance, and reduce the time and resources spent resolving faults, thereby increasing the reliability of the aircraft's operation.

The A380's on-board maintenance system will provide direct access to electronic manuals and documents while on the aircraft. "The system will allow the entire process to be done on the aircraft, from issuing a maintenance message all the way to identifying a fixing procedure," says Jerome Lavainne, group manager of on-board maintenance systems at Airbus Industrie. "The centralised maintenance function will be hosted on a server on the aircraft. The aircraft will have a dedicated station in the flightdeck for line maintenance, known as an on-board maintenance terminal (OMT). The OMT will have direct access to all the electronic maintenance manuals, while the ECAM will still display FDEs that affect the operation of the aircraft. The A380 will continue to use AIRMAN so that problems can be dealt with in flight. AIRMAN also maintains the list of outstanding defects on each aircraft in the fleet."

The A380 can also have an electronic logbook, so that access to all PIREPs can be made in real time, and sent to AIRMAN. Although this is not yet available, it is proposed that this will be standard on the A380.

Dedicated on-board maintenance systems will be to cut out the number of steps taken in rectifying faults. AC