The 787 has now been in operation for about four years. Although it encountered some initial service-entry problems, it remains one of the most technologically advanced airliners available. A summary of the aircraft's on-board fault detection capabilities compared to one of its earlier predecessors, the 747, is offered.

The 787's on-board fault diagnosis & line maintenance capabilities

The 787 family signifies the introduction of new generation, long-haul aircraft to commercial operations. The 787 is designed to embody an increased reliance on technology, displaying an ability for the aircraft to capture and feed back reliable, real-time data to its ground and air crew almost all the time. This is a major feature that allows its operators to reduce in line maintenance costs and related downtime compared to older generation aircraft.

The 787 first entered service in October 2011. Key airlines that operate the type include British Airways, Virgin Airlines, Qatar Airways, Air New Zealand and Air India. Thomas Cook is also due to take delivery of an initial order of 787s in the next two years.

Across the family there is the 787-8, -9 and -10. About 1,100 787 orders have been placed by airlines, and nearly 320 have been delivered to date. The fleet can be powered by two separate engine options: the General Electric GEnx-1B; and the Rolls Royce Trent 100. These are new generation engines designed to promote lower fuel emissions and overall increased efficiency.

The 787's leap in technological progress meant that its entry into service had its share of difficulties, including electrical fires, battery issues, and multiple system messages while in operation.

The 787 also generates large volumes of aircraft health monitoring (AHM) and engine health monitoring (EHM) data, compared to older types. These large data volumes, which an aircraft can pick up and alert flight and line maintenance crew to, suggest that more problems, defects, or 'faults, are inevitably going to be detected.

Flight operations and maintenance personnel therefore need to be trained in how to analyse which faults or observations made by the on-board central maintenance computer (CMC) are urgent, 'hard' or 'latched' faults, so which ones cannot be deferred, and those that can. Mechanics need to be made aware of faults that cannot be deferred and must be addressed before the aircraft flies again, and those that can be deferred until the next significant line check or the next base check.

The 787's fault and defect diagnosis processes have been designed to ensure that downtime used to analyse and rectify faults is minimised, and safety and reliability are maximised.

This article explores how the flightdeck and its related maintenance systems analyse and diagnose faults and defects arising mid-flight. It then further illustrates how this information is fed to flight crew and mechanics receiving the data for decisions to be made in relation to rectification. Comparing the 787 to an old generation game-changer, such as the 747-400, puts the differences that define a next generation aircraft into context.

The 747 family

First developed and tested in the late 1960s, the 747 has been one of Boeing's longest running and well known aircraft. New variants of the aircraft entered commercial operation in the decades that followed: the 747-200 in the 1970s; and the -300 and -400 in the 1980s. Each variant was equipped with upgraded avionics compared to its predecessor.

The 747-400 remains the most popular 747 variant to date. It was the first Boeing aircraft that represented an evolution from analogue to digital technologies. There is now a 747-8 variant, with a longer fuselage, in commercial operation. The 747-8 shares much of the flightdeck technology and computer systems also seen on the 787.

Using the 747 family as an example, one can understand how complex it once was to diagnose and source corrective action for a fault after it arose during flight. Pilot reports (PIREPS) on older aircraft were handwritten by flight crew and handed over to the line mechanic on arrival, together with handwritten technical logs.

The PIREP would detail any faults or defects that were observed during flight, for manual analysis by the mechanic. To diagnose faults, line mechanics, and the line maintenance and maintenance control departments, referred to large printed manuals and documents, such as the fault isolation manual (FIM), aircraft maintenance manual (AMM), the troubleshooting manual (TSM) or the minimum equipment list (MEL). This was both time-consuming and inefficient for operators, which needed to adhere to flight schedules.

As fault diagnosis processes developed and industry demands grew, however, elements of the troubleshooting process were refined to some degree to assist the line mechanic analysing faults. These improvements centre on the aircraft's on-board CMC systems and servers, which are responsible for the reliable and timely feedback of information to the crew.

Traditional troubleshooting

The 747-400's on-board systems include a CMC, which provides line mechanics with a maintenance overview of the aircraft, via its on-board maintenance terminal on the engine

The 787's flightdeck has on-board CMC systems that are designed to consolidate and simplify fault diagnosis. The fault information can be accessed by line mechanics to then diagnose and analyse faults with electronic versions of maintenance manuals.

indication and crew alerting system (EICAS) screens on the flightdeck.

AFI KLM Engineering & Maintenance (KLM E&M) is based at Amsterdam Schiphol Airport. It can perform component repair, line maintenance and AOG services on the 747 and 787 families. It is able to offer an insight into the synergies and differences between fault detection and defect analysis and rectification processes across the two types. "On the 747-400, the CMC gave the maintenance team visibility of aircraft defects that were processed by the aircraft itself, instead of being recorded by an on-board flight engineer," explains Jeroen Lodewijks, ground engineer on the 747 at KLM E&M. "This contributed to the goal of limiting the workload of two cockpit crew. This information is also presented on the EICAS in the cockpit for flight crew and line mechanics to see". The information given by the CMC includes fault isolation manual (FIM) codes, which are presented alongside the defects on the screen. If defects are detected on major components such as the auxiliary power unit (APU), landing gear, and wheels and brakes these would be displayed here too.

First, the line mechanics would interrogate the EICAS messages, and then the aircraft's CMC to determine the faults detected if the source of the fault was unclear. The 747-400 is able to correlate groups of fault codes, so rather than several individual codes being produced for the same defect, line mechanics receive a consolidated version in a single page report. This can then be printed off at the centre pedestal, and taken to their base for analysis by looking for them on the various printed maintenance manuals. Although the base may be a short walk from the aircraft, the whole process is time-consuming.

Using a desktop computer terminal, the line mechanic may then access on-line or electronic versions of the aforementioned paper manuals to isolate and source the problem that is producing the fault codes. This troubleshooting process involved the mechanic accessing the electronic FIM to manually type in the fault code in question, and then assign a task number to the fault. The FIM addresses the number of possibilities this fault code gives as the actual cause. Getting to the root of these issues, determining the actual cause and appropriate action for the line mechanic, involves using a fault tree analysis on the electronic FIM.

Fault trees are used to ascertain system reliability and safety. They involve a logic tree that connects initial, relatively minor events to a potentially hazardous outcome. By implementing the fault tree analysis, the mechanic or engineer can identify the fault and determine its severity. Once the fault is identified, the appropriate maintenance manual is referred to and corrective action given in the form of a task code, which is fed back into the airline's maintenance system.

This traditional 'process of elimination' can be time-consuming, and may slow the diagnosis of a fault. Airlines operating an aircraft such as the 747 over a long period of time, however, have the benefit of experienced mechanics and flight crew which reduces the need for unnecessary and sometimes lengthy processes.

The ability to receive fault data while the aircraft is in mid-flight reduces the time it takes for a mechanic to diagnose the fault. While voice communications originally were the only option for pilots to outline faults mid-flight to line mechanics, datalink systems, such as the aircraft communicating addressing and reporting system (ACARS), can transmit fault codes directly to a ground station and maintenance and engineering (M&E) IT system for mechanics to access. "An aircraft can also send its data via SATCOM or VHF to ground stations," explains Lodewijks. "All areas can be covered if SATCOM is used for data transfer."

With the introduction of tablets and iPads, mechanics working on a 747 now no longer have to print pages from a PC and then lose further time in manually diagnosing a fault as it arises. A mechanic can now use this portable hardware to access the relevant pages of an electronic FIM or AMM, and assign task codes electronically. The traditional and time-consuming process of troubleshooting has therefore become less and less common, as is the need to use a printed manual.

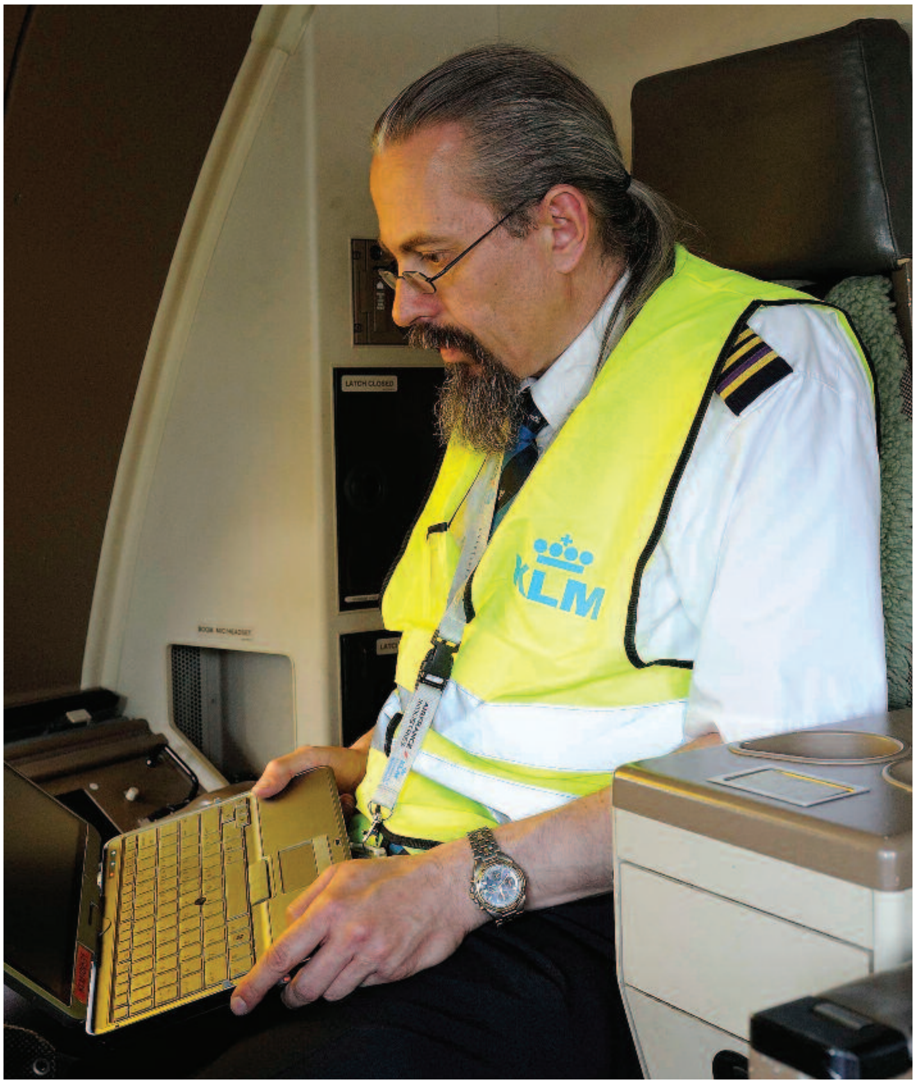
The 787

The 787's on-board CMC systems are designed to consolidate and simplify the procedure that diagnoses faults that are detected by the aircraft's systems. The 787 therefore has different architecture to the 747-400. The systems on board the 787 make it less mechanically complex. It is estimated that complexity is reduced by 50% compared to the 787's immediate predecessor, the 767.

Significantly, instead of the bleed air configuration seen on the 747 (and almost all other preceding aircraft), the 787's main electrical power generation and start system is a four-channel variable frequency system with two variable frequency starter generators (VFSGs) on each of the two main engines. These engine-driven VFSGs therefore provide an electrical generating system for power on-board the aircraft.

The traditional mechanical and electrical generating systems replaced on the 787 with power from the VFSG system include the APU, wing ice protection, environmental control and cabin pressurisation systems.

Adopting this electrically-dominant



Previous generation aircraft presented fault codes in EICAS screens on the flightdeck. These codes then had to be manually analysed by line mechanics using printed maintenance manuals, or electronic versions of manuals on laptop computers.

system saves weight, and eliminates relatively heavy and maintenance-reliant bleed air components, such as regulation valves, ducting and coolers.

The VFSG system also provides power for the on-board systems, so there is a core difference in its fault detection process when compared to older generation aircraft.

The bus power control unit (BPCU) and generator control unit (GCU) control and monitor the VFSGs. While the GCU regulates voltage, the BPCU controls the EHM system, and acts as the electrical power system communication gateway between the other on-board systems and the flightdeck. The BPCU can also provide secondary back-up power, promoting operational reliability.

Rather than the hydraulic and pneumatic driven on-board system that bleed-air provides, the VFSGs are fully self-contained and can be disconnected directly through flightdeck controls if needed. This illustrates how the 787 is more electrically reliant, rather than mechanical. It is therefore lighter, more communicative, and efficient to operate.

Rather than the CMC seen on the 747-400, EICAS messages can be accessed on the primary flight display (PFD). This PFD continuously monitors and displays engine health information. The level of information it displays can be determined by the flight crew operating the aircraft, as long as the engines are working normally and within certain operational parameters. As soon as the operational environment changes, an engine shuts down or has failed, the system will override to show full details relating to the situation. Next to this engine parameter display are the EICAS messages, which will detail warning and advisory messages to the crew in case of abnormal engine behaviour.

Furthermore, as will be expanded on throughout the article, rather than maintenance terminals seen on the 747, line mechanics can view fault codes and maintenance information via a maintenance laptop (ML). "The fault codes and maintenance messages are processed by the ML and electronic flight bag (EFB)," describes Lodewijks. "The ML can be hardwired to the aircraft or wirelessly connected. This depends on whether the operator opted for the crew wireless LAN unit (CWLU)."

E-enabling on the 787

The concept of E-enabling has revolutionised the process by which the 787 Dreamliner produces information and interprets it. The emphasis is on keeping all information in a digital format, to reduce errors arising from manual data entry. E-enabling allows real-time data transmission, so that crew and mechanics can access much of the data as it arises, including during flight. There are various E-enabled systems located all over the aircraft; each integrated with the maintenance system. These systems include EFB displays and servers, ethernet ports on the flightdeck, and a local wireless network unit. E-enabled communication capabilities seen on the 787 include an on-board wireless network, ACARS and VHF Data Link Mods. Combined together, these allow a near constant stream of communication from the air to the ground.

In addition to VHF and HF radio datalink for sending ACARS, the 787 can also make use of L-band satellite communication (satcom), provided by Inmarsat and Iridium, flightdeck connectivity links for sending ACARS messages at a faster data rate and at a lower cost while the aircraft is in the air. Inmarsat also has a swift broadband (SBB) product that encapsulates ACARS messages in internet protocol (I.P.) packets for faster data transmissions. Iridium will be launching a similar product in 2016.

The 787 also has on-ground connectivity systems. These are used for transmitting the large volumes of AHM, EHM and other system-related data that do not need to be sent in real-time while the aircraft is in the air. These are WiFi Gatelink, and cellular connectivity systems. Both can be used to transmit large volumes at low cost. The 787-8 and 787-9 were both fitted with WiFi as standard, while the 787-9 and 787-10 were also fitted with cellular as standard. There is a cellular retrofit option for the 787-8.

Health Management Systems

On-ground AHM & EHM systems are used by line maintenance and operations departments. They are essential to provide real-time operational data. The electrical systems seen on-board the 787 through E-enabling have allowed AHM and EHM to become more

The process for isolating and rectifying faults is known as centralised fault reporting. It is integral to the process of minimising turnaround times.

sophisticated than on previous models, while also being easier to monitor. "The 787 runs continuous BITE information on most systems on-board the aircraft," describes Lodewijks. "All these events can be viewed by the AHM. The capability to perform remote fault monitoring via the AHM gives operators the opportunity to start troubleshooting while an aircraft is still airborne. Therefore, there are no surprises when opening up maintenance logbooks for systems connected to the CMCF. This provides an operational advantage," continues Lodewijks.

The 787's AHM is facilitated through MyBoeingFleet.com, and uses real-time aircraft data to provide enhanced fault forwarding, troubleshooting, and historical fix information for maintenance planners to use. AHM integrates the remote collection, monitoring and analysis of aircraft data to determine its status.

This suggests that a large volume of information can be tracked and monitored by the aircraft's AHM and EHM systems while it is in operation. On the 787, the parameters it measures to detect a fault in its systems total about 140,000 different measurements. It is this information that the AHM tracks, and is then used for root-cause analysis by the mechanics when troubleshooting an error.

In turn, the EHM system is established by the engine's original equipment manufacturer (OEM). The OEM provides a dedicated EHM that monitors vibrations and engine parameters to simultaneously monitor engine maintenance and health status.

One example of the added benefits provided by the AHM and electrical systems on-board the 787 is the monitoring of wheel brakes. The continuous trend monitoring of the brakes eliminates the requirement to schedule visual inspections of the brakes wear and tear in line maintenance checks.

Also, due to the isolation of faults detected as they arise by the central maintenance computing function (CMCF), AHM gives mechanics enough information to focus on the right area of the aircraft, rather than resort to the traditional troubleshooting technique of 'process of elimination'. Moreover, as the electrical system constantly measures the force experienced by the wheel brakes, the brakes can automatically adjust as they cool down, extending part lives.

ACARS over VHF or HF radio or satcom is still present on the 787 for in-flight data transmission, alongside other various higher speed flightdeck connectivity systems that are available, or are coming available, as described. These are used transmit real-time events (RTEs) or faults to the AHM systems for mechanics to access them via a wireless internet connection. Fault codes and routine reports, including tyre pressure, oxygen pressure, hydraulic fluid, APU status, and engine oil levels are transmitted to the AHM, via the aircraft condition monitoring function (ACMF) on the aircraft, at various stages of the flight. Time of transmission depends on the operator's preference, although failure events are automatically transmitted in real-time.

Fault reporting

The 787 is geared towards aiding the line mechanic in his efforts to isolate and rectify detected faults. The process adopted is known as centralised fault reporting. It is integral to the process of minimising turnaround times when the aircraft is on the ground (AOG).

The 787's on-board maintenance system is manifested via an on-board network server (ONS). This manages the uploads and downloads of loadable aircraft software parts (LSAPs). LSAPs are applications which upgrade and modify aircraft system components. This replaces the traditional system of making physical upgrades to system components.

The ONS also includes an ACMF. This supports a diagnostic model development tool (DMDT). The DMDT is a multi-user, ground-based engineering tool used to support the generation of diagnostic-data tables.

The ACMF and DMDT are needed by the central maintenance computing function (CMCF) to allow the diagnosis of faults when parameters are exceeded. This CMCF is also installed on the EFB and ML.

Most of the 747's and 787's rotable components are monitored and maintained on an 'on-condition' basis. Rather than a set repair and overhaul interval for each component, sensors allow operators to anticipate when components need to be removed. It is this information that the engineering department uses to plan component removals and the installation of replacements.

When a fault arises, the built-in test equipment (BITE) sends a flightdeck effect (FDE) signal to the EICAS. These are noted as a crew alert and fault status on the EICAS. This fault information from the BITE, alongside the FDE status from the flightdeck, is simultaneously sent to the CMCF to correlate and consolidate the fault reports using diagnostic data tables. Once this is done, a report is sent to the maintenance control display (MCD) on the aircraft, which can be accessed from the ground via a laptop.

In the meantime, a line mechanic on-

Air New Zealand operates five 787-9s. The airline's maintenance control centre uses the AHM system to view fault information.

board can consult the aircraft's MEL via a laptop or toughpad, by accessing the Toolbox application or MyBoeingFleet.com (MBF). Toolbox can access the fault data and follow the repair/restoration procedures in the AMM or SRM, which are both interactive in Toolbox, and determine whether the fault requires immediate rectification. If not, the fault can be deferred.

When a 'hard' fault arises, the line mechanic can consult the MCD to access the FIM and determine the next course of action. Ultimately, the process is geared towards fault diagnosis occurring much sooner after a defect is raised. "Hyperlinks to the FIM and AMM through the Toolbox software also combine to accelerate the troubleshooting process for line mechanics," explains Lodewijks.

Air New Zealand is headquartered in Auckland and has incorporated the 787-9 into its fleet. The current operational fleet totals five, with another seven aircraft due to be delivered. Current routes flown include Perth, Narita and Shanghai from its Auckland airport base. "The 787 does not have a dedicated CMC as on the 747. Instead, the 787 uses integrated avionics where the CMC is a function of a core system, which is its central maintenance function," explains Tim Broad, 787 systems support engineer, fleet engineering at Air New Zealand. "Fault information is available for us to see via AHM. Our maintenance control centre can then determine the course of action to take," continues Broad. "Any work requests are generated via SAP, which is Air New Zealand's core M&E system."

The fault reporting process appears to be relatively similar, according to Broad. "The basic process on the 787 is very similar to that on the 747. The message hierarchy and how they affect dispatch is exactly the same," continues Broad. "Aside from the 787's different on-board technology, there is no real difference in philosophy. The main difference is that the 787 'talks' a lot more and there are far more systems talking to the CMF to enable more precise troubleshooting." The determined severity of the fault is also similar for the 787 and its predecessors. "The 787's hierarchy is the same as that of other Boeing models, such as the 777 and 747," confirms Broad.

Electronic Flight Bags (EFB)

Rather than an additional element that is physically separate to the aircraft, the 787 has a fully integrated, 'Class 3' EFB that is an integral part of its flightdeck. Since it is connected to the electronic systems and avionics, and its external connectivity systems, the 787's EFB is able to supply a constant stream of information that can be instantly accessed by those in the cockpit and subsequently sent to those with access to the company's M&E system on the ground. EFBs also provide a secondary location in which to review fault and AHM/EHM information.

As mentioned above, traditionally mechanics would have not received sufficient information regarding faults arising during flight until the aircraft had reached the ground. Planning and diagnosing the fault could therefore not have taken place until a mechanic could get on-board. A fully integrated EFB provides a communication channel between flight crew and line mechanics to directly report fault information in real-time, enabling quick decision-making. If an FDE fault occurs in flight, for example, crew can report this via the EFB and its ETL application. This then automatically enters the fault code into the fault recording form. The system is designed to allow the pilot to easily enter the initial fault. Once the aircraft is cruising the crew can further describe the fault via the ETL. As soon as the captain electronically confirms the fault occurrence through an electronic signature, the EFB transmits an accurate fault description to the ground control system in the maintenance control centre (MCC) via the M&E system. The fault is automatically correlated to the fault code, with its status, whether it is a 'hard' fault or one that can be deferred. This allows increased maintenance efficiency. The ETL application already has a list of fault descriptions installed so that crew can quickly select from a list. This further decreases the troubleshooting process for line mechanics.

Boeing has developed its own software via a series of ETL and other electronic logbook applications, which are installed on the EFB and also available to view from the ground, to supply a full end-to-end service for its operators. These applications include:

- The ETL, which is hosted on the EFB. The purpose of the ETL is to allow fault reporting and other logbook items including the flight log, fault reports, maintenance actions, deferrals, release and servicing records. These are all synchronised with a ground database.
- The Cabin Electronic Logbook, hosted on the EFB. This includes a cabin crew fault reporting form for various in-cabin scenarios, such as in-flight entertainment equipment faults. These are then synchronised with ETL. This means that once logged any of these observations over a certain severity are

automatically alerted to the flight crew.

- EFB Ground Module contains full background fleet information, such as logbook history. This module is predominantly used by the MCC on the ground, for the entry of all maintenance actions and subsequent confirmation of each aircraft release to service.
- Mechanic ETL application. This ultimately allows the mechanic to view faults after flight on-board the aircraft. He can then enter appropriate maintenance actions and release-to-service information without having to exit the aircraft and return to a maintenance terminal.

Boeing's customer portal, myboeingFleet.com, enables customers to use this heavily integrated software without requiring substantial back-office integration. Air New Zealand is trialling and integrating the on-board EFB into its day-to-day operations.

Ultimately, maintenance information can be viewed in several different areas of the 787 for line mechanics to analyse. With the rising use of portable devices on the aircraft, flight crew and mechanics alike have more variety to view information and further speed up the troubleshooting process. "The ML can be hooked up to 3 UTP sockets on the aircraft," elaborates Lodewijks. "These can be located in the cockpit, and forward and aft electronic equipment bays. The majority of maintenance information produced via the on-board systems can also be accessed via the EFB screens, which are installed on the captain and first officer's sides.

"The aircraft is designed to accommodate up to six MLs at any one time, including the on-board EFB," says Lodewijks.

Summary

The new detection and communication features displayed on the 787 family are clearly designed to increase the accuracy of the information presented by the aircraft to its crew. "Due to the large increase in message numbers generated by the aircraft, you need to strictly adhere to the troubleshooting philosophy," summarises Broad. "You need to know when to listen and when to ignore the information being sent. Ultimately, more information is better, but you just need to know how to use it."

This system has enabled better planning with regard to repair schedules, limiting an aircraft's time on the ground due to engineering faults and allowing more information flow into an airline's M&E system. Data is arguably put to better use through the modern on-board features, because the information is now timely and more reliable than it used to be. Despite teething problems that were reported in the industry during the early stages of the 787's operation, a little more experience and time have allowed operators to adjust to the differences presented by the new electrical systems seen. "Aircraft troubleshooting has become more effective and more efficient on the 787, but will require a different approach from operators and line maintenance teams compared to other generation aircraft," concludes Lodewijks. "The in-service experience of 787 operators has shown that a strict follow-up of manufacturer instructions is critical, whereas the 747-400 allowed the line mechanic more freedom to manage and fix defects."

The benefits of real-time reliable data cannot be denied, and the weight-saving potential of an electric versus hydraulic system also has efficiency-driven advantages.

An electrical system suggests relative ease to update and improve in accordance with industry processes and regulatory acceptance. This means a cost-effective and logical next step for aviation's relationship with maintenance IT. AC