Broadband connectivity systems for flightdeck transmissions and the development of Cloud-based analytics platforms will make it possible to analyse large volumes of aircraft data during or soon after operations. This has the potential to transform traditional airline operations.

Big data analytics: are airlines entering a new era of operations?

The traditional process of transmitting limited volumes of flightdeck and health data in real time from the aircraft for operational purposes is on the verge of being transformed into a more complex and highly capable system. This will be partly through the transmission of larger data volumes, which can be used to both improve an airline's daily operations through the utilisation of accurate and detailed real-time data, and to accurately predict component and system failures.

Flightdeck data

The volume of flightdeck and technical data that can be sent economically in real time is increasing by large multiples *(see The real time transfer of operations data during flight, Aircraft Commerce, December 2015/January 2016, page 38)*. The traditional system of using VHF and HF radio, and L-band satcom flightdeck connectivity systems to send small ACARS messages in flight is beginning to be replaced by broadband connectivity systems. These include the passenger cabin Ku-band and swiftbroadband (SBB) systems.

Because traditional flightdeck connectivity systems have limited data volumes sent during flight, the majority of quick access recorder (QAR), flight data management (FDM), engine health monitoring (EHM), and aircraft health monitoring (AHM) data has been downloaded post-flight. This was first downloaded manually with the use of disk drives, and later wirelessly on younger generation and retrofitted aircraft with WiFi and cellular on-ground systems.

The traditional method that flight operations, maintenance control and line maintenance departments have used to deal with technical issues that occur on an aircraft during flight has been limited by the small volumes of data that are transmitted in flight. Aircraft have been limited to sending central maintenance computer (CMC) fault codes via ACARS in flight. These are sometimes accompanied by flightdeck effect messages, written by flightcrew, which can be sent from an electronic technical log (ETL) used by a small number of fleets. The two are then diagnosed by maintenance control and line maintenance departments to prepare corrective action before the aircraft lands, when corrective line maintenance can be performed.

This process has many limitations. One significant issue is the lack of detailed information contained in a CMC message that is only up to 150 bytes. A CMC fault code is often only a numeric code that then has to be found by a line mechanic in a fault isolation manual (FIM) or troubleshooting manual (TSM). Flightdeck effect messages may add some description, and can be chosen from a menu on an ETL.

This system basically provides a limited and manual process of diagnosing faults with limited information, and requires a lot of human interaction.

Enhanced fault diagnosis

Some AHM products have grown in sophistication to speed up the process and increase accuracy of the fault diagnosis. Airbus's aircraft maintenance analysis (AIRMAN) system has evolved for this purpose. "Our AIRMAN system started in the late 1990s, and first operated on using system fault warning and CMC messages sent during the flight," says Philippe Gourdon, vice president of business information at Airbus Customer Services. "AIRMAN is an IT solution that displays the received fault messages to the line mechanics in the maintenance control and line maintenance departments. The system helps them troubleshoot and diagnose the CMC fault codes and associated maintenance messages.

"AIRMAN is used together with an electronic version of the TSM," says Gourdon. "We have also developed additional capabilities for AIRMAN. These include a database of a full history of each aircraft's technical faults, and related statistics for AIRMAN users to use the system more effectively."

In 2000, Airbus developed an additional product for the A380, known as Airbus real time health monitoring (AiRTHM). AiRTHM's capability starts with the same process as AIRMAN. AiRTHM has additional capability for analysing critical defects that cause the biggest operational problems and delays, and therefore require the most diagnosis and troubleshooting. "We have created a database of all issues and information relating to the most critical defects," says Gourdon. "AiRTHM software can also request additional information and parameters from the aircraft. This is done by the line mechanic user interrogating the aircraft for additional information. The system is, therefore, bi-directional in terms of communicating with the aircraft.

"We have also acquired further diagnostic capability by developing an interface between AiRTHM and the aircraft condition monitoring system (ACMS)," continues Gourdon. "The ACMS is the source of data that feeds the QAR, which in turn is the source of the majority of aircraft health data that is downloaded and analysed post-flight. The ACMS can be interrogated by AiRTHM in real time, and data from the

A small number of airlines have started to use broadband connectivity systems for flightdeck transmissions. Together with Cloud-based diagnostics platforms, airlines are entering an era where it will be possible to perform more detailed and faster analysis on larger volumes of operational and health data. The combined effects should lead to significant gains in operational efficiency.

ACMS is sent to the ground for more detailed analysis. The additional system data and parameters that come to the ground allow a better anticipation of failures that are about to happen. AiRTHM, therefore, has a prognostics capability."

A main benefit of AIRMAN and AiRTHM is that they work on an automatic process where software performs this analysis and sends interrogation requests for data. The parameters that AiRTHM requests are pre-determined by Airbus, and are known to be problematic systems.

"Several airlines wanted to have the capability to interrogate the aircraft for further parameter data and information themselves, and so have incorporated AiRTHM in their maintenance control and line maintenance departments," says Gourdon. "AiRTHM is now a module of AIRMAN, and it has started to be used for the A380, and will later be available for the A350. We are also developing the system for other types."

Post-flight analysis

In addition to the traditional limited and enhanced systems of real-time CMC fault code diagnosis, there is also the post-flight downloading and analysis of the majority of aircraft system and component QAR and FDM data.

Only a minority of AHM and EHM data is downloaded in real time during flight. Airlines have, therefore, decided what fault and warning data and parameters are essential to transmit in real time. The vast majority of data that is not regarded as being necessary to transmit in real time is downloaded post-flight. The process of analysing this data is to ultimately provide diagnostic information on aircraft systems and components. That is, to analyse what caused a failure after it has occurred.

Analysing health and operational parameter data has limitations, however, since, although there are large volumes of QAR and health data, the analysis is performed manually. This starts with engineering departments manually selecting which parameters to analyse, trending them and manually scrutinising the results. Some of the data analysis therefore assists an airline's engineering department to compile data and statistics for its reliability programme.

"We have typical technical and reliability problems with certain aircraft systems, and we trend data and use the reliability programme to generate soft times for component removals," says Rob Saunders, head of engineering cost management and business improvement at Cathay Pacific Airways. "We have made full detailed analyses of particular aircraft systems to reveal what the problems have been, but doing this manually has been very time consuming, laborious and expensive."

The main difficulty with traditional QAR and reliability analysis is that much of the data processing work is carried out post flight and looks back at trends. Not only has this always required many steps with a lot of human intervention, but it does not predict future system and component failures and problems. It also does not analyse any correlations between different parameters. The system is based on diagnostics, or a historical analysis of events. The analysis has not been designed to predict future technical issues.

The main issue of QAR and health monitoring data analysis is that, while it is a legal requirement for airlines to have an FDM analysis system in place, much of the aircraft system and operational data is not analysed. This is because of the lack of analytic systems, and the laborious nature of analysing the information manually. Even using analytic systems to analyse post-flight data requires a large manual input.

Future systems

Two main developments will stimulate a fundamental change in the use of aircraft system and health data. The first, as described, is the possibility of transmitting larger volumes of data from the aircraft. This is not only during flight, but now will also be on the ground when the aircraft is between flights.

The second is the automation of processing large volumes of flightdeck and health monitoring data post flight. Further to this, new analytics applications can be developed faster to evolve and improve the analysis of the data to provide more detailed insight. This is made possible by Cloud computing. This provides the tool sets required to analyse much larger volumes of data on an automated basis.

"Cloud computing platforms, provided by large vendors, such as IBM and Google, mean that the analytic systems can be developed much faster and in a more consistent fashion," says Mark Goodhind, vice president Aerospace Business at Rolls-Royce Controls and Data Services. "Because the analytics can be run quickly, it is also possible to frequently tweak the designs and so improve the analysis of aircraft health data. This can include analysing possible correlations between additional parameters, which can be added to an analytical process in a short time.

"The other main advantage of Cloud computing is the ability to scale up and down computing power," continues Goodhind. "As an example, it is possible to send an algorithm to the Cloud to add it to the analytics process. An analytics, network and storage system can also be infinitely scaled. The Cloud is a place to host everything, and an airline will, therefore, not require any internal infrastructure, implementation or associated up-front investment. The airline only has to pay on a consumption basis, so very quickly the ability to analyse large volumes of QAR and health data and parameters, becomes possible."

Modern aircraft types generate data for 250,000-400,000 parameters. This compares to 15,000-30,000 parameters for older types, like the A320 and A330. Cloud computing and analytics platforms will therefore make it possible for airlines to automate the process of analysing health monitoring data for not only a larger number of parameters, but also fleets of aircraft to provide an overall view. The overall objective is to provide more detailed insight into the actual causes of technical issues with aircraft components and systems. This is because related and associated parameters and systems can be analysed together for possible correlations.

General Electric has introduced its Predix system as an industrial cloud solution for this purpose. Predix started with the purchase of Austin Digital, which had a platform for analysing FOQA/FDM data. Austin's platform was expanded to analyse fuel burn data more efficiently.

Predix has existing analytics solutions that were previously developed by Austin Digital for several industries. Airlines now generate terabytes of data, so a large capacity of processing power is required, so that customers receive the analysis very quickly.

One benefit of Predix is that as more volumes of data are processed, and more are added, the overall cost of processing the data and information is reduced. GE points out that one advantage of viewing the whole fleet is that this provides a lot more visibility with respect to which components and systems are operating normally and which are not.

Predix processes and analyses both real-time and long-term post-flight QAR data. The first major change that Cloud platforms allow is a change to the way in which the data is analysed. Each airline user of Predix can use the system to custom-build solutions for its own purposes. These can be warnings for any particular aircraft system an airline has with a particular fleet type. An example is that the system can be configured to self-report on specific component serial numbers or part numbers that have reliability problems.

Predix is now about five years old, and it will become available for release to airlines and the general industrial ecosystem as a Cloud platform later in 2016. Some airlines have already started to use the system, but most are not familiar with it. The basic analytical processes in the system are the same platform used for other industries. Additional capabilities are then added immediately, because they are already available.

"The previous technique of manually analysing data for a particular system will transform to a situation where the process can be automated, carried out for an entire fleet, and carried out quickly," says Saunders. "It will also be possible to analyse and correlate trending and AHM data. Examples of correlated data can be oil or lubrication levels and the reliability of mechanical components such as flap screwjacks and other flight controls. Another example is the bleed air system. A large and detailed analysis can reveal if there is a possibility for reduced fuel burn by changing the amount of bleed air taken from the engines. The effects of flight controls or even weather on fuel burn performance can also be analysed. Not only can thousands of flights be analysed very quickly for an entire fleet, but it will also be possible to do this at a lower cost than previously possible."

Airline departments that have functions in the day-to-day operational functions of an airline include aircraft scheduling, flight operations, dispatch, maintenance control, line maintenance, and engineering. Cloud platforms and the availability of detailed aircraft performance data in real time will drive the need for airlines to implement total mission management systems. These will coordinate the flow of data and information between these departments.

Airline operations

Airline departments connected to the day-to-day operation and short-term planning of managing a fleet include passenger handling, ground operations, flight operations, aircraft dispatch and flight planning, maintenance control, line maintenance, engineering, and aircraft scheduling. Their roles are linked, and include the preparation of aircraft for service, monitoring progress of flights, scheduling crews to specific flights, submitting flight plans, handling delays and technical issues, performing routine line maintenance, and allocating aircraft to specific routes.

The main issue that affects these departments is that, while they work together and often use some of the same information, the coordination and exchange of information is often manual and paper-based. The traditional system of dealing with technical faults as described has been for maintenance control and line maintenance to use CMC fault messages from the flightdeck to diagnose faults. Operations can be delayed because a fault is relayed to all other affected departments manually, and late.

The ability to download larger volumes of flightdeck data in real time is expected to streamline the activity of these departments. The other element will be total mission management systems, which will coordinate the transfer of relevant information to each department, removing the need for manual coordination and communication.

"While flightdeck connectivity systems are now making it possible to transfer larger volumes of data in flight, the bigger issue is what exactly can be done with these larger volumes of data," says Tulinda Larsen, vice president of commercial operations solutions at Global Eagle Entertainment (GEE).

The main issue is that, so far, few airlines are aware of all the different ways that day-to-day operations can be improved. A few examples of what will be possible, and what the subsequent results could be, are examined below.

"One example is that very accurate aircraft position data is now possible because of the way flightdeck and cabin connectivity systems work," says Larsen. "This means that it is now possible to improve operational efficiency through having accurate total flight and arrival times. This and other data can also be used to produce key performance indicators (KPIs) of airline operations.

"An accurate time of arrival has several implications for daily operations," continues Larsen. "This includes assisting passenger handling and ground operations with flight connections. This is in the case of having more time to re-schedule passengers from late flights onto new connecting flights, or delaying connecting flights. It can also be used for a variety of other uses. An example is allocating gates and various servicing vehicles, and reallocating scheduled ground equipment and crews to different flights. Conversely, if a flight is due to arrive early, it can be asked to slow down by flight operations if this will help save fuel.

"There are many other operations criteria that can now be followed with a larger number of flight operations parameters being followed," continues Larsen. "We are creating a dashboard that will use many flight operations parameters to monitor multiple operational statistics. Another utilisation of operations parameters is basic information, such as exact tail number of each aircraft, its location and status. Ground-handling departments do not have this information until an aircraft has landed. This problem is that catering equipment and catering carts and trolleys vary with each sub-fleet, since each one has different galley configurations. Ground-handling will be able to make better preparations with detailed tail number, accurate arrival time, and aircraft location information."

Flightdeck and aircraft health monitoring data does not only have to be sent from the aircraft while in-flight. There are a large number of aircraft parameters that need to be monitored while an aircraft is on the ground between flights. "This is especially true of the pre-flight phase," says John Schramm, chief executive officer at I-Jet Technologies. "The FDM and QAR data are only captured when the engines are running, and so start from pushback. There is no pre-flight data recorded or monitored with current QAR systems. Most airlines do not know anything about an aircraft's status when it is at the gate between flights. Examples are the status of each door, and the auxiliary power unit (APU).

"I-Jet Technologies has built an application to inform the operations department of the aircraft's on-ground status," says Schramm. "The application can be customised to an airline's requirements. The idea of the application is to provide visibility of the status of an airline's complete fleet. An example is Delta Air Lines, which uses a fleet of pickup trucks at Atlanta Airport. These are used to drive behind parked aircraft at the gate to physically view if the APUs are running on aircraft and, therefore, consuming fuel. This is necessary because flightcrews can leave APUs running after they have left the aircraft, to provide air conditioning or heating, although the aircraft can also use ground power. A running APU will also accumulate hours and cycles, leading to maintenance expenditure. We have created an application to monitor the APU, and turn

KLM is in the process of developing a prognostics platform to analyse large quantities of QAR data. The system will process the data automatically, and it is intended to predict and pre-empt component and system failures.

it off remotely if it has been left running by mistake. This negates the need to operate pick-up trucks, or send someone to the gate to board the aircraft. Overall, we can create a ground management application to monitor a large range of parameters relevant to the aircraft's on-ground status."

One big advantage is that it is now possible to accurately monitor and transmit the fuel on board an aircraft. "The fuel on board is taken into account when refuelling prior to a flight, and is currently estimated," says Larsen. "The estimates will become more and more inaccurate after each flight of the day, so more fuel than required is often loaded on, which will increase fuel burn. More accurate on-board fuel data from detailed flight parameter information will lead to fuel savings."

Another element of daily operations is maintenance and engineering issues. The maintenance status and technical fault information of aircraft is often inadequately shared between airline departments, leading to inefficiencies. "An example of this is that aircraft tail numbers are assigned to flights by the scheduling department about 48 hours before flight," says Larsen. "The schedulers are informed of a pool of aircraft that are not in hangar maintenance, and so are available for assignment to the schedule."

There will be difficulties in scheduling if line maintenance and defects issues relating to each aircraft and, therefore, the related delays, are unknown to the scheduling department. It is easier for schedulers to allocate aircraft tail numbers if there is coordination of information among engineering, line maintenance and scheduling departments. That is, schedulers need to be aware of which aircraft require extended downtime for non-routine maintenance, while the line maintenance and engineering department can better plan corrective maintenance if they have an accurate schedule for each aircraft. This will aid in the positioning of mechanics, equipment and materials. This is one example where total mission management or integrated data systems for operations, aircraft dispatch, maintenance control, and scheduling will improve the efficiency of an airline's day-to-day management.

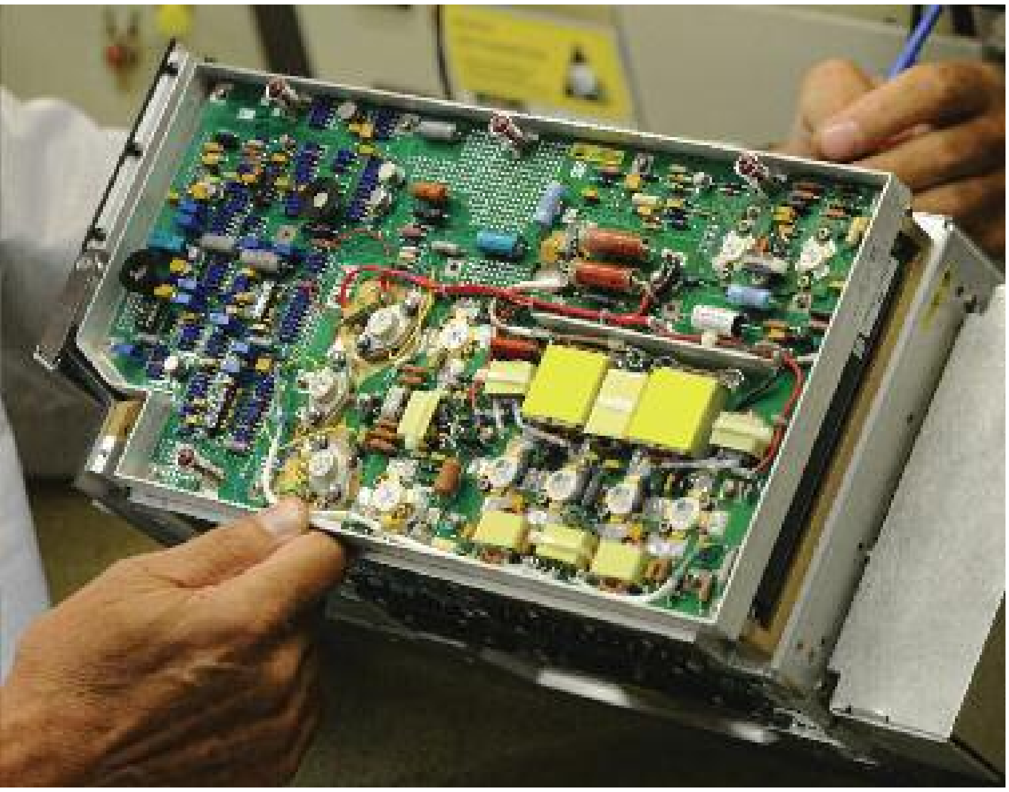
There are many examples of where detailed maintenance-related parameters can improve operational efficiency and save costs. "An example is where under the current alerting system only spikes in engine parameters when they are out of limits are sent as alerts to maintenance and operational departments," says Schramm. "A spike or sharp rise in exhaust temperature or vibration, for example, can lead to a requirement to remove an engine, or at least take the aircraft out of operation to the engine run-up area and perform a ground run test. It may be possible to avoid this if more related parameters are monitored. Examples are the sensor detecting the spike and the engine instrumentation on the flightdeck, either of which may have a fault and so result in transmission of a false EHM alert message. With a much larger number of parameters being monitored, it can be determined what actually led to the EHM alert being sent, thereby avoiding the cost and inconvenience of removing the engine or taking the aircraft out of service to perform a test run in some cases."

Schramm also makes the point that while there are applications that analyse QAR data post-flight to improve fuel burns and flight operations, there is no application that compares the actual flight operated and the intended flight plan. Such an application can be used to improve operational efficiency. "An analysis of data for the past few months' flights, followed by a comparison against all the flight plans filed, would provide a lot of interesting information," says Schramm. "The first stage in improving or making better use of flightdeck and operational data is to have a thorough understanding of an airline's infrastructure and its systems. This includes how the systems for each department and how the departments are organised. An understanding and appreciation of the data storage and processing system and architecture on the ground is also required. In terms of analysing and effectively utilising flightdeck and aircraft health parameter data in real time, there are only a few airlines that understand what they want or could have. What is or will be possible will gradually become more apparent to more airlines as new systems develop and experience is gained."

Prognostics

A main development that analysing all health monitoring data will bring is the change from diagnostics to prognostics. Diagnostics is the analysis of health and parameter data to determine what went wrong after a fault has occurred. Prognostics is the analysis of data in an attempt to predict a failure or the start of a component malfunction in advance.

"New platforms now make it possible to compare and analyse data across



There are several objectives for utilising a prognostics platform for analysing QAR and aircraft health data. Particular advantages will be the avoidance of expensive delays caused by technical issues, a reduction in the cost of repairing failed and damaged components, and the increase in the portion of maintenance performed on a predictive rather than hard-time basis.

thousands of flights," says Goodhind. "The platforms now make it possible to mine QAR data and look for problems with systems and components, and correlations between systems and components. Until now it has not been possible to look for pre-cursors or indications of looming problems, but this is changing. There will therefore be an overall change in philosophy of how to use QAR data downloaded from the aircraft. Rolls-Royce did a project to look at the benefits of transmitting large volumes of data in flight. It actually turned into a project to analyse how to minimise the cost of transmitting existing volumes in real time. Most of the benefit comes from deeper analysis of data that is downloaded post flight.

"In the future we expect to be able to analyse parameter and performance trends to indicate when a system is starting to deviate away from how it should work," says Saunders. "The idea is to predict system failures, and move a large portion of maintenance away from fixed interval inspections to on-condition and condition-monitored maintenance. It is even possible that an airline will eventually be able to customise its maintenance programme to suit its own operation, based on the analysis provided by prognostics. Going even further, there are likely to be developments that have not yet been considered."

KLM of the Netherlands is in the process of developing its own prognostics platform. The overall objective is to analyse core parameter data to predict system and component failures, rather than analysing them after a failure has occurred.

"We are developing our own system to analyse the QAR data downloaded from the aircraft post flight. So far we are not interested in increasing the amount of data sent during the flight," says Marco Kwikkers, avionics and aircraft IT master engineer at Air France Industries KLM Engineering & Maintenance. "The 787 and A350, which we and Air France have just started operating, generate a lot of data from a large number of parameters compared to older types.

"We are going to use prognostics to predict failures. This requires fast analysis of data after downloading, and a feed of the data into a ground-based system," continues Kwikkers. "The analysis will then be done automatically. We have trialled the system, and tested it on problematic systems and components. We are trying to predict upcoming failures, which requires a technical analysis of the system and component normal operating parameters. As an example, one technique is to examine the operating data from each of the engine integrated drive generator (IDG) units from an aircraft, and any related parameters. This way it is possible to build a database of how all the part numbers on an aircraft behave, as well as how each serial number has behaved. From here it is possible to build in indications of when components and systems are not behaving properly."

Kwikkers adds that the platform will need to have filters and alerts built in to indicate when a particular parameter has increased by 1%, is out of its normal range of operation, is trending faster than normal, or has reached a ceiling value at which the component needs to be removed. The platform will also consider weather parameters and the phase of flight. "Prognostics requires an understanding at a deeper level, which is an understanding of all related factors and aircraft systems," explains Kwikkers. "We have the advantage of having a lot of expertise on our own fleet types, whereas an independent system vendor or maintenance provider does not.

"Prognostics will, therefore, provide a big step forward compared to the traditional reliability programme," continues Kwikkers. "A reliability programme is trend-based and only shows spikes and problems. The original component and system manufacturer determines the modification and improvement for the component after airlines have submitted data. Prognostics will be superior in that it will change the system from being reactive to providing pre-planned maintenance for components and systems. Overall, it will allow airlines to plan the repair and replacement of problematic components.

"This system will have various benefits," continues Kwikkers. "One of these will be that components can be removed as they are beginning to malfunction. This avoids removing components after failure, in which case they may have deteriorated so much that they have very high repair costs or are beyond economic repair and so have to be replaced. Prognostics should result in components being removed at a stage where the resulting repair cost is not high."

Component maintenance will therefore be managed on a predictive basis rather than a reactive basis. One change to the system of component management will be the need to communicate with repair shops. This will require data relating to the change in a component's function and operation, rather than its absolute failure. It will also require an analysis to see if the predictions were correct. Airlines that develop and build up prognostics data for their own fleet types will be able to offer this as an element of engineering and continuous airworthiness management to smaller operators. AC