The use of Big Data analytics and predictive maintenance by airlines is in its infancy. One main issues holding back development is the lack of an affordable system to download the large volume of maintenance-related data from new generation aircraft.

Coordinating aircraft and M&E systems for big data & predictive maintenance

The issue of big data (BD) analytics and predictives, including maintenance and flight operations, has received a lot of attention over the past few years. The reality is that Big Data is a new name for something that already existed, and now the technologies to increase its utilisation and application are maturing.

Aircraft operational and health data is already being downloaded from aircraft, and BD is an enlargement of the data volume and aircraft parameters that will be downloaded in the future. The overall objective of BD analytics and predictives is to monitor the operation and performance of aircraft components and systems more closely, by using data from a larger number of parameters with a larger number of sensors that has previously been possible. "It means that the deterioration of a component's or system's operation can be detected and followed earlier and in more detail compared to the traditional approach of detecting faults and malfunctions," says Willie Cecil, director business development aircraft data services, at Teledyne Controls.

"This changes things. The identification of a malfunction is no longer reliant on pilots reporting it, or systems on board transmitting real-time alerts or fault data to maintenance staff," explains Cecil. "This 'legacy' approach involves waiting for malfunctions to arise, and performing unscheduled maintenance in a reactive way which can disrupt flight operations and cause delays. In contrast, predictive maintenance allows proactive monitoring and problems to be detected earlier, enabled by a prediction that a failing component or system needs to be investigated, repaired or removed and replaced before it ultimately fails causing an unscheduled maintenance event. Resolution can therefore be planned into scheduled maintenance at the most convenient time and place where there are resources and parts available, for example an overnight stop at a main operating base."

The technologies and capabilities to make predictive maintenance work have been developed. The process is in its infancy, and has only started to come into practical airline operation in a small number of cases over the past two years.

Big data collection

Downloading data from aircraft began with the development of new generation aircraft in the early 1980s, such as the A300-600, A310, 757 and 767, followed by types such as the MD-11, 747-700, A320, A330/340 and 777. All of these aircraft types used BITE to send sensory data from their components and systems to provide maintenance error and fault messages on the aircraft's CMC, and health monitoring data.

In parallel, aircraft systems have been providing data to supply the required mandatory aircraft operational data for flight operations quality assurance (FOQA) analysis.

The system of using and delivering aircraft data has evolved so that health monitoring data from engines and some vital aircraft systems are sent in snapshots from each flight in real-time via the aircraft communications addressing and reporting system (ACARS). ACARS is also used to send information on component and system faults and failures in real-time from the CMC so that the engineering department can analyse technical problems reactively as part of the traditional unscheduled component and system maintenance.

The ACARS system is limited, however, to the quantity of data it sends and the transmission rate of that data. This applies to the transmissions being sent via VHF or HF radio, or via satcom.

The use of ACARS for transmitting aircraft data has been expanded as more data gets generated by the aircraft and engines, but also as aircraft health monitoring (AHM) and engine health monitoring (EHM) programmes develop. First, AHM and EHM programmes have gone from being managed by airline engineering departments to being provided by third-party specialists. This in particular relates to EHM programmes that are offered by engine original equipment manufacturers (OEMs), and as an element of their maintenance cost per the hour (MCPH) services they provide to airlines. Rolls-Royce (RR), General Electric (GE) and Pratt & Whitney (PW) and others all have EHM programmes. These have gradually been enlarged by the OEMs as the number of engine parameters monitored in real-time has grown, thereby increasing the volume of data being sent by ACARS in real-time. The increased number of parameters and quantity of data sent in real-time is included in the OEMs' MCPH contracts.

In addition, airframe OEMs and other providers have gradually introduced AHM programmes. The number of aircraft parameters and quantity of data being sent via ACARS in real-time has

One of the main issues of big data is that modern and new generation aircraft types monitor more aircraft component and system parameters than previous generation aircraft, and consequently generate up to several hundreds time more data.

also steadily increased. As a result, modern aircraft types are sending larger quantities of data via ACARS, with the effect of increasing an airline's data transmission costs. This has reached the point with certain aircraft types, such as the 787, where the volumes of ACARS data being sent has overloaded the ACARS networks.

The data sent via ACARS, both to airline engineering departments and to AHM/EHM providers, is a small example of the type and quantity of data in BD and Predictives.

The data downloaded from the aircraft for FOQA programmes is different, and has a different use. The systems for downloading FOQA data from the aircraft are nevertheless for a high volume of data. Various technologies have evolved to transmit data from the aircraft to the operator's flight operations and engineering departments.

Originally data was collected manually with PC cards and other devices. Modern wireless systems soon evolved. The first of these were WiFi units on the aircraft, but also require a wireless access point transceiver at the airport. The alternative system of cellular devices generally proved more popular.

The device for collecting FOQA data on aircraft is the quick access recorder (QAR),which receives inputs from the Flight Data Acquisition Unit (FDAU). QARs started with systems similar to computer discs, and later developed into solid state discs. In the early 2000s, Teledyne introduced the first Wireless QAR, which transmits data automatically post-flight using wireless cellular technologies. Since then some QARs also transmitting the data off the aircraft via airport gate WiFi links, but deployment of this has been limited because they never offered global coverage. The quantity of FOQA data that is downloaded periodically from aircraft is very large compared to the data sent via ACARS, but it is still relatively small compared to the GB or TB of data that is generated by the latest aircraft types.

Use of aircraft avionic connected platform servers, such as the on-board network server (ONS) on new Boeing aircraft or the aircraft network server unit (ANSU) or FOMAX box on new Airbus aircraft now record and transmit BD, including QAR data. These platforms have cellular or WiFi transmission units as standard, which can download larger volumes of data than the aircraft's ACARS system can support. The wireless systems can transmit BD and QAR data at a fraction of the cost of sending small text message data via ACARS.

There also avionic units installed as line-fit options on some aircraft types, and that are retrofitted on older generation aircraft, that provide similar big data and wireless functions of the OEMs' avionic platforms. Examples include the Wireless GroundLink Comm+ system by Teledyne Controls. These units have gradually been fitted to a growing number of aircraft. Clearly not all older aircraft will have such avionics units fitted, considering their age and probable number of years until retirement. Cecil estimates that two-thirds of the 25,000 plus jetliner global fleet are now fitted with wireless transmission systems from the airframe OEMs, Teledyne and other vendors. Within five years we can expect nearly all of the global fleet will have such wireless systems transmitting BD.

Besides big data generated by aircraft, there is additional BD necessary to enable predictives. A fundamental approach of predictive maintenance is to examine past component failures and then to establish signatures in the archives of aircraft sensor BD. These signatures are used in analytics models that predict future failure of the same component. Enterprise system data such as flight operations data from flight operations IT systems and maintenance history records from MRO IT systems are therefore critically useful. Contextual data such as weather and turbulence data are also useful to refine predictives.

Data volumes

New generation aircraft are known to generate large volumes of data compared to older aircraft types. "For example, a 767 can generate about 15MB of FOQA data, while a 787 can generate about 60MB of FOQA data per flight," says Chris Reed, managing director at Trax. "The 787 will, however, generate several hundred Gigabytes of maintenance data. If BD and Predictives are going to provide a worthwhile service for airlines, data needs to be downloaded at a reasonable cost, and in a reasonable amount of time, without disrupting flight schedules." Data of this size has to be collected by laptop or portable maintenance access terminal (PMAT) downloads."

The volumes of data are so large for new generation aircraft that it is not yet possible to harvest all the data they generate, and therefore the data cannot be used for BD analytics and Predictives. "Most health monitoring and flight operations applications used by airlines

A low-cost system for downloading all maintenance-related data from new generation aircraft is not yet available. A lot of data is still being transmitted from the aircraft in real-time during flight. A fraction of all maintenance-related data is downloaded when the aircraft is on the ground.

today still utilise data that is transmitted from the aircraft via ACARS. The quantity of data a 777 transmits per flight is about 10 times that of a 767. In turn, the amount of data generated by a 787 is about 10 times the amount generated per flight by a 777, but this is not big data" says Cecil. "The simple truth is that the vast majority of the data generated by modern aircraft is currently not downloaded, and so is not available for predictive maintenance."

Modern and new-generation aircraft types can clearly generate volumes of data that extend into terabytes (TB) per day. All of this super high volume data is not being downloaded from the aircraft, because the transmission technology for quick downloads at a reasonable cost does not yet exist. That is, existing cellular and WiFi systems or even the latest high speed Satcom systems are inadequate for the purposes of collecting such high volumes of big data that could be consumed by BD analytics. "The current approach for downloading the largest volumes of data, for example from an aircraft engine to support intensive analytics by an engine manufacturer, is via a portable maintenance access terminal (PMAT) or laptop used by a line mechanic," says Cecil. "This a big burden on line maintenance during aircraft turnarounds so it is typically only performed periodically which means only a fraction of the large data volumes is collected."

Big data processing

There are several subsequent steps in the BD analytics and Predictives services. The first of these is storing and processing data. "The first issue is that most airlines do not have the capacity to store the data in-house, so Cloud storage is required," says Reed. "In many cases data is transferred to a local data centre or the Cloud. Raw data is then accessed by processors for conversion into a format that can be analysed by specialist processors."

This is a large element, since processing data includes the use of algorithms, developed by data scientists, to detect a component and system malfunction that ultimately leads to the alerting of a problem. The first consideration, however, is downloading and storing the data.

The amount of data that modern types such as the 787 and A350 can generate is up to several hundred GB. "This comes from on-board sensors if all possible components and systems are taken into consideration," says Wayne Enis, vice president Middle East, at Flatirons Solutions. "When one aircraft's operation and rate of utilisation is taken into consideration, it can generate up to 330 TB per year. This has to be considered in relation to the typical cost of a mid-range server hard disk, which is about $75 per TB. The cost of storing data from just one 787 for a year is therefore about $25,000."

It is for this reason, and several others, that data generated by the aircraft's systems does not go anywhere. The implications of this are that only a small percentage can be downloaded, and subsequently processed. This means that airlines have to be selective about which data parameters are downloaded.

"Although a single new generation aircraft may generate hundreds of TB in a single day of operations, I estimate that the data applied for most health monitoring and flight operations applications amounts to less than a quarter of one TB. This is not for one aircraft or one day, but for all commercial aircraft in the world combined for an entire year," says Cecil. "In contrast, most airline flight safety departments benefit from 'full flight' data recordings wirelessly transmitted that contains over 1,000 times the ACARS data available to airline maintenance and engineering. This higher volume data is often held exclusively for safety data analytics, even though it contains rich sensor data ideal for predictive analytics. With routine downloading of this data now universal, and airline safety departments starting to release this data, the future for predictive maintenance is bright."

While most airlines still lack the capacity to download all BD from an aircraft, engine OEMs have been using BD and increasing the number of engine parameters and large data volumes to drive engine maintenance. "This has come from the increased scope of EHM and engine MCPH programmes," says John Stone, vice president of product management at Ultramain. "Airlines have various choices when it comes to data storing and processing."

BD analytics providers

The first option for airlines is the airframe and engine OEMs. The engine OEMs have expanded their data storage and processing capability. GE's Predix product is an example. Airbus started offering its FOMAX, which includes the downloading and storage of data, and transfer to its Skywise system for processing and providing Predictives services. Boeing offers its AnalytX products, including airplane health monitoring (AHM) and self-help analytics that will ingest QAR big data.

Another group of providers are airline engineering departments. This includes Lufthansa Industry Solutions that has engineered the data downloading and processing service, and Lufthansa Technik which processes data for airlines and provides Predictive Services. The product provided is Aviatar.

Air France Industries KLM Engineering & Maintenance offers a similar product called Prognos, comprising two elements: Prognos for ENGINE and Prognos for AIRCRAFT. Prognos for AIRCRAFT uses BD to give A380 operators early warnings and failure monitoring software for the aircraft's components and systems. There are similar systems being developed for the 787. The system ultimately aims at reducing schedule disruptions as a result of unscheduled maintenance events.

Other aerospace OEMs, including Honeywell, UTC Aerospace and Teledyne Controls, are also offering services. Teledyne Controls offers its Flight Data Analytics (FDA) service. Other data storage and processing providers include independents such as IBM, Tata Consultancy Services and Capgemini.

While BD analytics and Predictives is still in its infancy, some services offer the possibility of increasing data volumes, or making it more attractive to airlines to download larger volumes of data. The FOMAX data extraction service provided by Airbus is free, with the condition that data does straight to Skywise for processing and providing a Predictives service. The alternative option is to use FOMAX to transmit the aircraft QAR data direct to the airline, and for the airline to use it with their own chosen predictives provider. In this case the airline pays the data transfer fees.

Lufthansa Industry Solutions, which is part of the Lufthansa Group, separated from Lufthansa Systems about five years ago. Lufthansa Industry Solutions has developed the architecture for downloading maintenance data from the aircraft, and transferring it to Lufthansa Technik in Hamburg, where the data is processed using algorithms. A good example is the maintenance data downloaded from Lufthansa's A350 fleet, which it introduced into service in December 2016. "Much larger volumes of data are downloaded from the A350 compared to older types," says Bernard Kube, vice president of technology consulting at Lufthansa Industry Solutions. "Lufthansa Industry Solutions built the data processing systems, and our data scientists wrote the algorithms to process the data and analyse the cause of technical problems. This concept was started about five years ago, and the first stage was designing the architecture of the data processing and Predictives system, which became the whole Aviatar system. Two years ago we implemented the first productive use of the Predictives capability, and the first results in terms of providing a solution to a technical problem.

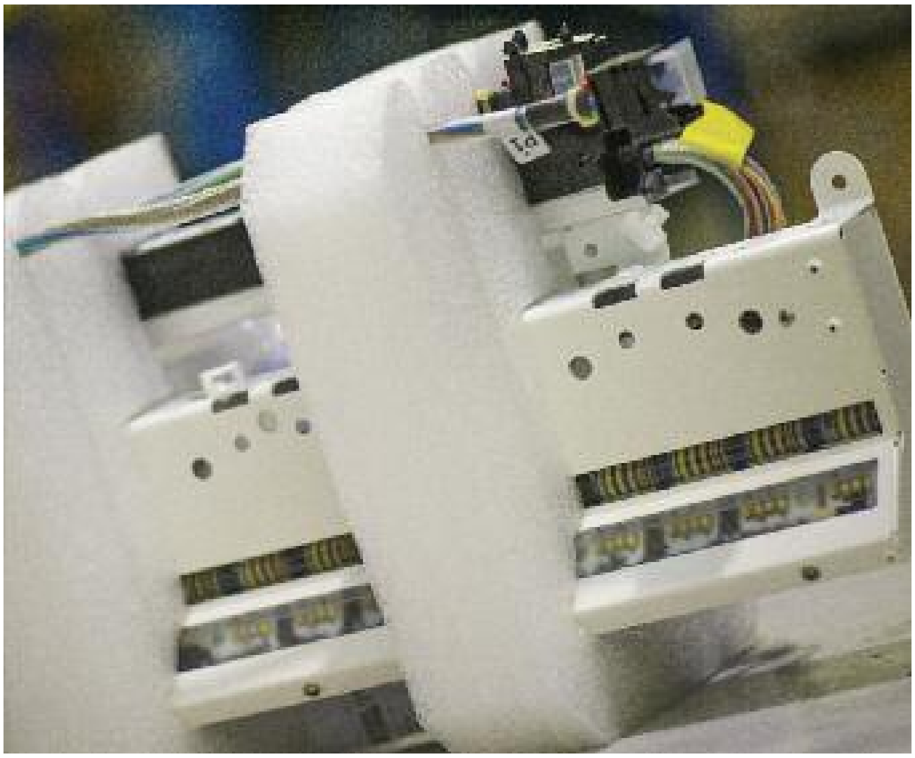
"In general, data scientists can find answers to questions that previously did not exist," continues Kube. "That is, with the data processing and writing of algorithms, we can solve a problem in a way that was not previously thought of. As this has developed we have ended up providing an exploratory service. That is, we can develop new ways to investigate the cause of technical defects and component or system malfunctions. In some cases we are finding that we need more sensor data, because we need more values and data from a larger number of parameters to pinpoint a problem, and detect it earlier than before. We can now answer more questions if required, and so need more sensors to be placed on certain systems on the aircraft. This is performed as a modification by the aircraft OEM."

In addition to the basic services of data download, storage and processing, other techniques are being used to provide detailed information about the cause of technical issues. GE has developed a system of digital twinning as part of its Predix system.

"GE builds a digital model of the aircraft or engine being monitored," explains Reed. "This is so that when performance data is downloaded and analysed, the operation and flight of the aircraft or engine can be simulated. This allows GE to see how certain faults and system malfunctions develop, and how hardware deterioration has occurred."

Airframe maintenance

The evolution of EHM services



One of the ultimate aims of big data and predictives is for airlines to be able to refine their rotable component inventory requirements.

offered by engine OEMs, and the development of MCPH services in parallel over the past 20 years or so has seen the engine OEMs gain a large share of the engine aftermarket.

The arrival of BD and its analysis with respect to airframes raises the issue of airframe OEMs gaining a share of the airframe aftermarket with an increased level of MRO through power-by-the-hour (PBH) programmes. This would be aided by their BD processing services. "There is a risk that airframe OEMs could use BD to control the airframe aftermarket," says Stone. "This may happen because BD processing gives the airframe OEMs the full loop of the aftermarket, since they would be involved in every step of the airframe maintenance and aftermarket support process. BD is key to controlling almost the entire maintenance package on the aircraft, except for the engines and a few heavy components such as landing gear, or wheels and brakes.

"There are already some examples of OEMs making entry into the airframe aftermarket," continues Stone. "One is Heavy Maintenance Singapore Services (HMS Services), which is a joint venture between Singapore Airlines Engineering Company (SIAECO) and Airbus. HMS Services will provide heavy maintenance for the A350 and A380."

There are several obvious candidates for this type of MRO provider, including low-cost carriers. The maintenance and engineering (M&E) departments of major airlines are likely to enhance their third-party maintenance services with the use of BD. One target area where this can be effectively used is in the assessment of what rotable inventory is required to support a fleet, and also managing several aspects of fault detection, component removal and replacement, component test and repair, and overall logistics processes.

The concerns about OEMs gaining an increased share of the airframe MRO market via PBH programmes and control of BD has been voiced by high profile figures, including the chairman of Lufthansa Technik, who said that if OEMs run and control aircraft data it will destroy the freeflow of aircraft data, and this will eventually kill the aftermarket. Boeing, for example, has said that it is entitled to own the all the 737 MAX data.

It remains to be seen what will happen with regard to the issue of data ownership and control. Some believe that airlines will ultimately refuse to accept handing control of data generated by their fleets to the OEMs. When airlines collect this data they usually do not want to share it all with everyone. They may be willing to send certain data to the OEMs, and certain other data to their MRO provider or engineering and maintenance departments. This may illustrate the need for data filtering.

Using processed data

Downloading and processing aircraft operational and maintenance data is just one step in the complete BD and Predictives process.

There are six main steps. The first of these is the initial collection of data using sensors from the aircraft systems and components. The second step is the transfer of data to the on-board servers, and its subsequent storage.

The third step is downloading the relevant pieces of data, subject to the cost of downloading it being low enough. This data harvest will be widened as the cost of downloading data declines.

The fourth stage is pre-processing or cleaning and decoding data. The fifth stage is analysing the data with predictive analytics algorithms and the sixth step is making use of the recommendation or insight provided by the predictive. This process is gradual, since development by data scientists of use cases and predictive algorithms takes time.

Moreover, they are developed one by one, or at least in groups since there is not enough capability to produce algorithms simultaneously that analyse and detect every type of technical and reliability problem on every aircraft type.

This is one of the two main factors that limits providers' progress in being able to offer a full BD and Predictives service for aircraft maintenance. The maintenance data that is downloaded from the aircraft on-board server is therefore limited to those parameters that can be analysed using algorithms.

"Predictive maintenance in the airline industry is in its infancy," says Cecil. "Teledyne is adding and expanding the number of aircraft data parameters acquired and collected from aircraft to support both OEM and airline predictive maintenance initiatives, and we are helping with both aircraft coming off the production line and airlines' in-service fleets. The data acquisition hardware that captures full-flight data on most in-service aircraft is capable of capturing much more aircraft system and maintenance-related data, and the volume can be expanded significantly and often without replacing hardware or modifying the aircraft."

There are ways to expand the number of parameters in one go, and so increase the amount of data captured from aircraft databuses and systems, continue to download all the data, and then gradually make use of the expand the number of parameters for key component reliability issues to be resolved.

Airlines have to consider the issue of diminishing returns. That is, the technical issues that cause the largest number of, or the most expensive, unscheduled maintenance events would be dealt with first, and the cost of developing algorithms and all other related processes can be justified. As technical problems

Some of the benefits of big data and predictive maintenance is being able to anticipate and plan for non-routine maintenance tasks, and so reduce the downtime to complete base checks.

with smaller consequences are dealt with, the related cost is more likely to be questioned.

M&E system function

The final step in the whole BD and Predictives process is to send information to an airline's or maintenance provider's M&E IT system.

With traditional maintenance, aircraft faults are reported by fault messages via ACARS or by pilots and the repair actions are driven by these faults and pilot reports. The faults and rectifying actions and parts replacements are recorded in the M&E MRO IT system. With the introduction of predictives there is a need to transfer the output of the analytics into the MRO IT system so that maintenance takes action based on problems that pilots may not yet be aware of. Typically an airline's engineering technical service organisation will perform a triage function where they review predictives outputs and recommendations before work orders are raised in the MRO IT system.

"There are now some Ultramain customers that are getting processed data back from the specialist data processors," says Stone. "This data comes back in extensible mark-up language (XML) format, which can be used in Ultramain to provide instructions. For example, this will be correlated fault data to identify the system or component that is causing a problem. It can also be information that instructs the engineering department to perform a test or troubleshoot a component or system on a particular aircraft within a particular timeframe, or to remove and replace a component within a certain time limit. It could also be a work order for a particular repair of a component. Planning engineers can then include these actions in scheduled maintenance visits, such as daily or weekly checks."

Stone points out that this basic capability has actually been available for several years, and that it is in the past few years that the whole capability and process is being expanded.

This final step in the complete BD and Predictives process cannot be performed, however, without the data processor first having key data and information. This will include each aircraft's component and system configuration, the serial number (S/N) of each component, the date that each component on the aircraft was installed, the total time in FH and FC the component has accumulated on the aircraft since installation, and the component's repair history. This will all have to be sent from the airline's M&E system to the data processor, before the data processor can send back data relating to maintenance Predictives. A two-way link and data transfer is therefore required between the M&E systems and the data processors. XML is the most commonly used format by M&E systems. This process has begun to be implemented, and Airbus' Skywise Predictives product is an example. "Trax has an interface with the RR system so that it can be informed of problems with individual engines as they develop," says Reed. "An example is a message being sent by RR to Trax if, for example, a generator is not performing correctly. This can include a recommendation to change the part, bring forward its removal, or even change the component's maintenance interval."

There is not yet a data standard, however, and Reed makes the point that this will be needed. "The OEMs will have to accept that they will be interfacing with a large number of different M&E systems," continues Reed. "It looks like there is no standard, but this will be useful in the future. It will almost certainly have to be developed. Another issue is the need for a bigger connectivity capacity to send data along all the various paths in the entire process."

Enis explains that few changes to M&E system functionality and configuration are required. "This is mainly because M&E system vendors are not making use of data yet, and within the scope of MSG-3 logic there is not much you can do to improve the maintenance processes with data," says Enis. "This is why the OEMs are the drivers in big data and the subsequent use of predictives. This raises the issue of whether or not the M&E system vendors will have the capital to invest in new capabilities and upgrades to their systems."

Stone explains that Ultramain has a flexible data schema, and a data import and export engine. "The system does already have some BD processing and predictives capabilites," says Stone. "So far this is data that relates to the execution of maintenance, so it does not compete with the OEMs and external suppliers at the moment. This data is used by Ultramain to reduce the ground time used for maintenance tasks. For example, as non-routine maintenance tasks arise, there is a need for optimisation and predictive capabilities.

"There are some benefits of BD and predictives that are coming clear," adds Stone. "These include the continual process of driving down maintenance costs and improving operational reliability. Airlines are also planning to use BD to extend maintenance intervals and refine rotable component inventory requirements." AC