**The concept of Big Data and Predictives was launched five to six years ago. After initial technical and implementation challenges, several airlines now have a few years of experience with the system and are producing tangible results in improved reliability, predicted maintenance, and cost savings.**

# Airline results of using Big Data & Predictives

The use of Big Data analytics and Predictive Maintenance in the aviation industry has developed over the past five years. The main objective is to capture detailed data about the performance of aircraft components and systems, and use it to predict when they will start to malfunction and why. Potential benefits include planning the removal of components and reducing the problem of no-fault found (NFF), with the result of reducing maintenance costs and improving the reliability of operations.

Several airlines and original equipment manufacturers (OEMs) have now implemented Big Data and Predictive Maintenance, and have achieved positive results. Moreover, case studies are showing a reduction in maintenance costs and an improvement in aircraft operation.

## Main objectives

The main objectives behind the use of Big Data and Predictive Maintenance were to achieve a detailed picture of the performance of every component and system on an aircraft. This requires a large increase in the number of sensors on the aircraft's systems, and data output to be recorded from every sensor for every second of an entire flight.

The quantity of information generated would make it possible to follow and monitor in detail the performance of every parameter of every component and system on the aircraft. This offers the possibility of replacing the traditional diagnostic and troubleshooting techniques that are used to locate the source of a malfunction from the limited data provided by traditional health monitoring systems.

Such detailed data, when analysed correctly with the appropriate algorithms and data-processing capability, would make it possible to first detect when a malfunction was developing, monitor the progress of the malfunction, and then recommend an optimum time in the aircraft's operating schedule to fix the part. This can also extend to detailing a repair or rectification for the issue.

Such a system would ultimately make it possible to change from a traditional maintenance system that is based on fixed maintenance intervals, to an on-condition and reactive maintenance system. While current aircraft maintenance programmes are based on system, structural and zonal maintenance tasks, many inspections involve testing components and systems to check for functional and operational integrity. These fixed interval inspections could be replaced by monitoring collected data to determine when maintenance is actually required on an on-condition basis.

Fixed interval maintenance would still be required for structural and zonal inspections.

The ability to accurately monitor every parameter of every component and system on an aircraft would save costs in several categories, including: elimination of expensive aircraft-on-ground (AOG) events and their associated costs; a reduced rate, or even the elimination, of no-fault found (NFF) events related to removed components and the associated costs; reduced line maintenance costs; reduced maintenance turn times, and reduced rotable and component inventory. All of these combined would deliver a significant reduction in aircraft maintenance costs.

## Aircraft data

Realising the potential of all these possible objectives relies on the amount of data generated by the aircraft, the ability to download it inexpensively, and process it in a timely and useful manner.

Older aircraft types have limited aircraft health monitoring (AHM) and engine health monitoring (EHM) systems which generate data from a small number of components and systems. The data is collected at snapshot points during the flight, and are not sufficient for Big Data analytics and Predictive Maintenance.

These small volumes of data do not provide nearly enough information for the trajectory of the long-term and operational health of a particular parameter to be accurately or closely followed. Moreover, the number of sensors and parameters followed are insufficient for any detailed information to be derived about the health of a component or sub-component.

New generation aircraft types are those with a number of sensors that are a multiple of the number used on older aircraft. The increased number of sensors allows thousands of parameters to be monitored. These are used on types that include the A380, A350, 787 and A220. These types also continuously monitor parameters, components and systems, so they generate thousands of times more data than the older generation aircraft.

"An example of the difference between aircraft generations is that our A320ceo aircraft generate about 20 megabytes (MB) of data per flight from a few selected systems and at snapshot points in the flight," says David Vasquez, programme manager of big data and predictive maintenance, at Air France Industries. "In contrast, our A380s generate 2.0 gigabytes (GB) of data per flight. Similarly, the A350, which we are introducing into service in November 2019, is expected to generate the same amount of data.

*Air France has used its Big Data and Predictives system Prognos to pinpoint particular technical faults and defects. Positive results include avoiding high cost AOG events that could have affected its largest type, the A380, at long distance outstations.*

"We have a mixed fleet of 222 aircraft. Of these, 203 are old generation types, and so generate small amounts of data. We also have 19 new generation A380 and 787 aircraft, which generate much more," adds Vasquez. "Overall, the whole fleet generates about 18 terabytes (TB) of data per year. This will gradually increase as the older types are replaced with new generation aircraft. We have 28 A350s and up to 60 A220s on order."

The large differences in data volumes reflect the number of sensors in the aircraft. "The A320ceos have about 3,000 sensors, while the A380 has 30,000. The A350 and 787 have about 100,000 sensors," says Vasquez. "The number of parameters that can be monitored is similar to the number of sensors. The large number on the 787 and A350 mean that not only can just about every component and system on the aircraft can be monitored, but also every parameter relating to that component or system."

It is also possible to retrofit older generation aircraft with a large number of sensors and so increase their ability to generate Big Data for use in Predictives. "Our partner KLM is working with Delta Airlines to add parameters on the 737NG fleet," says Vasquez.

Delta Air Lines has a similar issue. Its fleet of 911 mainline jets is a mix of old and new generation Airbus and Boeing types. The new generation aircraft are represented by 23 A220s (of 90 on order) and 13 A350s (of 25 on order). The older fleets include large numbers of MD-80s, A320ceos, 717s, 737NGs, 757s, 767s and 777s.

"At one extreme, the MD-80s are the oldest generation types we operate, and they generate a few kilobytes (Kb) of AHM/EHM data per flight," says Shawn Gregg, general manager of predictive technology engineering, at Delta Air Lines. "At the other extreme, the A350 which has recently entered service, generates several GB per flight. We started implementing Big Data capability on airframes in the 2014-2015 period."

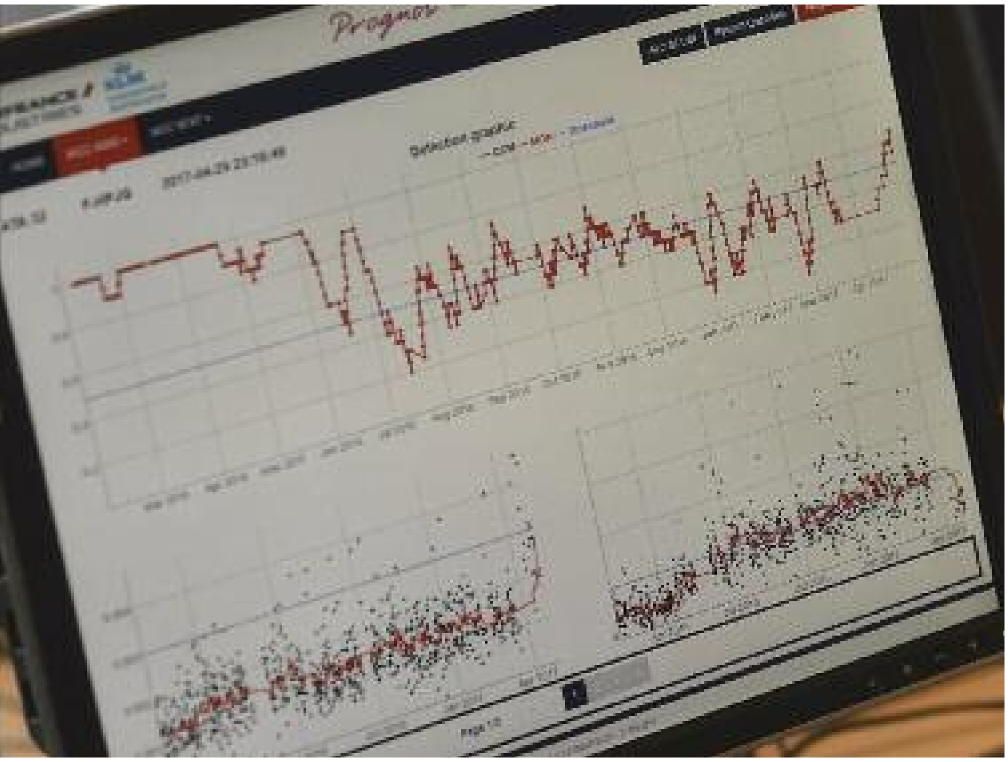
After the generation of data by the aircraft, the next process required in the chain is the storing and downloading of data to ground systems for processing. Data on older generation types is essentially flight operations quality assurance (FOQA) data. This has been stored on the quick access recorder (QAR) of most older generation aircraft types.

Modern aircraft types have been configured with an integrated modular avionics (IMA) architecture. This replaces individual avionic boxes used for individual functions with a single cabinet in the avionics bay to perform all avionics functions. Aircraft that use such IMA architecture included the 777 family. Nevertheless, initially several aircraft types with IMA design did not have QAR functionality included, and so needed a separate unit to provide the QAR function.

More modern aircraft types hosted the QAR function or software on a server in the avionics suite. Airbus used the FlySmart system on the A330 and A340, and the A380 had the option of hosting the QAR function on the server.

Similarly, Boeing introduced the on-board network server (ONS) on the 777 and 747-8. The 787 uses a system referred to as CoreNet, which has some functionality similarity to the ONS.

The quantity of data that has to be downloaded from the QAR is too large for it to be downloaded economically via the aircraft addressing communication and reporting system (ACARS). Teledyne Controls thus developed the wireless QAR, which transmits the data using cellular



*After implementing Big Data and Predictives, Air France says the system is yielding savings in the order of $300,000 per aircraft in its fleet.*

signals. Some QARs also use WiFi signals. The quantity of data downloaded is large compared to that sent via ACARS, but is small compared to the GB and TB of data generated by new generation aircraft types.

Aircraft servers, such as Boeing ONS and the aircraft network server unit (ANSU) on the newer Boeing types, have the functions of recordings and transmitting Big Data generated by the newest aircraft types. The latest system introduced by Airbus is the FOMAX system. This is a line fit option on the A320neo and A330neo.

These platforms have WiFi and cellular transmission systems. Older aircraft types can also be fitted with avionic units, either on the production line or later in operation. These effectively provide Big Data functions, although the volumes of data are smaller than the latest aircraft types. Examples are the Teledyne Controls Wireless GroundLink Comm+. Two-thirds of the jetliner fleet are now estimated to be fitted with wireless transmission systems.

Despite these technical developments, the transmission systems on the aircraft are considered to be capable of downloading only a small portion of the Big Data generated by modern aircraft types for processing by on-ground systems at a reasonable cost.

While it is conceivably possible to increase the amount of data an aircraft generates and transmits, it is not a trivial undertaking. Some air carriers have elected to retrofit older aircraft with newer data acquisition and tranmission systems to provide for increased data flow. A few air carriers have gone so far as adding their own sensors and wiring to increase the amount of data the aircraft generates. One such carrier is Delta Air Lines.

## Practical examples

With the development of Big Data and Predictives and analytics systems over the past four years, there is now an increasing number of examples where airlines are showing positive results from the system.

## Air France

The A380, A350 and 787 are Air France's most modern types, and generate GB volumes of Big Data from tens of thousands of parameters for processing.

"We have configured the Big Data system to not only collect data from tens of thousands of parameters from the aircraft, but also to monitor all steps of aircraft components in the full cycle of operation, removal, test and repair, and reinstallation on the aircraft," says Vasquez. "This includes information being provided by the repair shops about the maintenance being performed. This type of information helps target the correct component removals in the future. That is, the system makes a correlation between the components' health parameters while they are in operation on the aircraft, and their past maintenance history. Algorithms can therefore be developed to predict which components are deteriorating and at what rate."

"We started developing our Big Data and Predictives system about three years ago, and it had to provide definite reliability and maintenance cost reductions," continues Vasquez. One example is an improvement we have had with the A380. An example is the aircraft's fuel transfer pump system. There are four pumps in the system, to transfer data from the fuel tanks to the engines.

"The number 1 pump is the primary fuel transfer system, so it is categorised as a no-go item," continues Vasquez. "The other three pumps are standby pumps, and any one of them can be used to take over the function of the number one pump. These three are categorised as 'Go' items, so they do not have to be operable at departure. The number one pump feeds all four engines, so failure during a flight towards an outstation or on the ground would result in a lengthy delay while it is removed and replaced."

In December 2015, shortly after Air France had implemented its Big Data system, the number one pump was about to fail in flight, so operation was swapped to pump number four. A few weeks later, it was found, through predictives, that the number one pump was due to fail when the aircraft would have been on the ground at Shanghai. Vasquez explains that this would have caused an expensive AOG situation, since the aircraft would have had to be flown back to Paris as an empty ferry flight, while a replacement aircraft would have had to be flown to Shanghai to pick up the passengers. The whole process would clearly have been costly, and would have negatively impacted passenger goodwill.

Big Data analytics have prevented other expensive maintenance events, such as detecting fuel leaks on the A380. "A leak was detected in the tube feed system between the fuel tanks in the aircraft in 2018," says Vasquez. "The detection was made possible by analysing the various fuel flow rates in the fuel transfer system tubes. Pinpointing the source of the leak by analysing fuel pressures in different parts of the fuel transfer system was done very quickly. The architecture of the fuel transfer system is very complex, so this would have been impossible without the analytics system."

Despite only being in operation for a few years, Air France has established several benefits from its Big Data and Predictives system.

The first of these is a 60% prediction rate. This is combined with 200 or more component removals having been the result of recommendations from the Predictives system. There is also 100% accuracy with removals. That is, after being removed the components were found to have been removed correctly, and so there was no incidence of NFF. Moreover, all

*Delta has implemented a Big Data system for its entire fleet that exceeds 900 aircraft. Some of the first results are a reduction in rotable component inventory and a large reduction in the incidence of no-fault found (NFF).*

components that were removed as a result of Predictives were confirmed as being faulty by the component OEM.

Another level of the accuracy that Big Data and Predictives provide resulted in Air France having advance warning and alerts of impending technical problems for 30-50 flights. The result of this has been to improve flight safety and operational reliability, and consequently reduce flight cancellations. Overall, Vasquez estimates that the system is generating savings of about $300,000 per aircraft in the fleet.

## Delta Airlines

Delta Air Lines, which has a diverse fleet following its merger with Northwest, implemented its Big Data and Predictives programme in 2014-2015. "Delta has avoided more than 2,000 delays, cancellations and operational disruptions in each of the past two years because of our predictive maintenance efforts," explains Gary Hammes, vice president engineering, quality, & safety at Delta Air Lines. "Our alerting process is 95% effective at identifying the appropriate maintenance action to avoid a operational disruption."

Delta's Big Data journey began decades earlier. "We implemented an engine condition monitoring (ECM) programme in the late 1980s, which evolved into Engine Health Monitoring (EHM). In the early 2000s we started using the SmartSignal system to process engine data. In 2015 we began upgrading our aircraft to unlock flight data for aircraft health monitoring purposes," says Gregg. "One of the goals of our Big Data and Predictives system is to move away from the snapshot data system of the traditional AHM and EHM programmes, and move to data captured for the full flight of each aircraft. That is, data that is captured every second from every monitored parameter. The volumes of data generated are too large for it be transmitted via ACARS."

The data acquisition systems that Delta operates vary by fleet. It is possible to update the equipment on the aircraft, and this will increase the data storage capacity and improve the processing capability. As an example, it has retrofitted its older types, such as the 737s, with Teledyne Controls' Digital Flight Data Acquisition Unit (DFDAU) avionic box.

"Our modern Airbus types, the A320 and A330, will use the Airbus FOMAX and Skywise system," continues Gregg. "The FOMAX is an avionic unit that performs the data acquisition and transmission via a wireless groundlink. Once the data has been transferred to a ground system it is analysed and processed using Airbus' Skywise product."

The A350 is the newest and latest generation type in the fleet. "It produces a lot of data, and has its own system for data acquisition and transmission via the Information Management Air-Ground Communications System (IMACS)," says Gregg. "We will then use Skywise to analyse the data generated by the A350."

About 50% of Delta's mainline fleet of 911 aircraft have a wireless download capability. Data is downloaded over a cellular network after each flight when the aircraft is at the gate.

"In addition to Skywise being used to process data from the three Airbus types we operate, the system can also be used to process data generated by the A220 as well as other aircraft manufacturers. We are planning to use Skywise for all the airframe and engine types in our fleet. Having a single platform is far more practical compared to the option of using a different system for each airframe and engine OEM.

"Ultimately we plan to use 100% of the sensor data generated by the aircraft, but this requires a system to download all the data, and a large processing capability," continues Gregg. "The Skywise platform has predictive algorithms developed by Airbus to analyse data from Airbus aircraft. A user can also develop their own algorithms and create predictive alerts for data processed from other aircraft types all in the same module. This will provide us with a single-pane-of-glass solution for all aircraft and engine types.

"Delta's plan is to use Skywise to process data for thousands of parameters across their varied aircraft and engine types. "The system gives us the ability to follow just about any parameter we want because of the large number of sensors on the aircraft," explains Gregg. "One particular advantage is that we are able to analyse components and various aircraft aspects that were not previously monitored with an AHM system, and required manual investigation following a write up in a tech log or cabin log report. One example is the air conditioning health management system in the cabins of the 737NG fleet. We were getting a lot of complaints about air conditioning issues in the cabin because of problems with the system. We developed a suite of sensors to characterise the air conditioning system and retrofitted our aircraft so we could detect technical problems. This new data allows us to pinpoint the sources of the impending air conditioning issue before our customers have an uncomfortable cabin experience. The number of complaints has declined to a low level as a consequence." Delta holds a patent and the Supplemental Type Certificate (STC) for this sensor suite, the key to their Air Conditioning Health Management System (ACHMS).

There are other examples Delta gives as a result of its predictive maintenance program. "We use our predictive system to inform the maintenance department of an impending problem along with directions on how best to address it which cuts troubleshooting time significantly." says Gregg. "Ultimately, the goal is to use predictive analytics to issue prescriptions that detail actual fixes. This requires a lot more information than just the source and cause of the problem. For example, it also requires detailed information relating to the maintenance and operational history. Overall, we are aiming to move from manual to digital processing."

Another example of a particular issue fixed through Predictives is a problem with split engine throttle level settings on the A320 flightdeck. Throttle lever positions should be symmetrical for equal engine power ratings. Their position, however, has to be manually adjusted to provide the required power as denoted by engine power instruments on the flightdeck. "There are several reasons why the throttle lever would have to be moved to an asymmetrical position, and there are many factors that affect the readings of the various engine dials," says Gregg. "Either the throttle lever or wiring could have a malfunction, as could the full authority digital engine control (FADEC) unit on the engine. There are also several components and systems that are used to generate the engine power setting on the flightdeck instruments.

"Using full-flight data, our predictive system identified the PS12 line, which is a pressure line on the engine inlet that measures inlet pressure, was leaking," continues Gregg. "Consequently, the pressure being fed to calculate engine power was incorrect. It was possible to pinpoint this problem quickly because the PS12 pressure was monitored continuously throughout the flight, rather than using snapshot data. Moreover, it is very difficult for engineers and mechanics to replicate the problem of incorrect inlet pressure measurement on the ground when the aircraft is not flying."

Another benefit has been a reduction in the incidence of NFF. There are two main causes of NFF. The first is that a part or component is incorrectly diagnosed as the source of a problem and subsequently removed from the aircraft. The second is that an adequate test does not exist to identify the fault in a component that was the source of a problem on the aircraft. Using a feedback loop in their predictive maintenance programme provides a mechanism for component repair technicians to obtain test and repair results and findings. These findings, in turn, are provided to the line maintenance technicians that originally carried out the predictive maintenance action, thereby fully closing the loop.

Gregg claims it is possible to reduce the rate of NFF by 90-95% by better tying flight data and component history to component shop workscopes. There are several advantages to this, chief of which is improved component reliability, which leads to consequent reductions in the quantity of rotable component inventory that needs to be held.

"We now want to expand the system to increase the number of alerts that address major reliability issues in the fleet," says Gregg. "The overall effect of this would be to prevent operational disruptions. This sets the stage for another large benefit, which is ultimately migrating from a traditional maintenance programme of fixed inspection intervals for system tasks that relate in any way to component function and operation, to a maintenance programme based on removing components at the best time before they are predicted to fail."

In addition to developing its Big Data analytics and Predictives for its own use, Delta is also forming a joint venture with two large aerospace OEMs to offer this system as a third-party service to other airlines.

## Lufthansa Technik

Lufthansa Technik and Lufthansa Industry Solutions developed its Aviatar system to offer third-party solutions for Big Data analytics and Predictive Maintenance. Lufthansa has started using the system on the A350, which has now been in


*The A350 generates several giga bytes of data per flight. Lufthansa has introduced its Aviatar system for Big Data and Predictives, and the A350 will be the first type to use the system.*

operation for more than a year.

The data on the A350 is stored on the Full Flight Data (FFD), and the Aircraft Condition Monitoring System (ACMS) is used for Predictives and condition monitoring. The data is transferred to the ground via ACARS in flight, or WiFi signal or on a USB stick.

The Aviatar system offers a suite of Predictive Maintenance, Condition Monitoring, and Reliability Management solutions. The volume of the data therefore varies according to the suites chosen by the operator.

Aviatar does not have any limit on the number of parameters that are monitored on the aircraft. This is because Aviatar is a cloud-based platform.

Aviatar has begun to produce results. The system has been able to reduce unscheduled component removals by more than 60% due its Predictives capability.

## Pratt & Whitney

In addition to whole fleet services, some OEMs, especially engine manufacturers, provide Big Data and Predictives. These are essentially an evolution of the original EHM systems provided by engine manufacturers.

Pratt & Whitney (PW) provides a Big Data service for operators of its engines. "We have about 11,000 engines in service, and can provide Big Data services for about 80% of them," says Eva Azoulay, vice president of commercial aftermarket at Pratt & Whitney. "We use the advanced engine diagnostics and monitoring (ADEM) program. Through ADEM, airlines can access the monitoring of their engines via a web-based application. About half the engines we provide data services for are followed in this way. The other half are monitored by Pratt & Whitney.

"The issue with data services is that as engine technology has evolved, the number of sensors has increased, and the speed of data transmission has also risen," continues Azoulay.

As an example, the V2500 has a fully automated full authority digital engine control (FADEC) unit. "This records certain parameters, mainly as snapshots," says Azoulay. "Jump forward to the PW1100G, and this has 40% more sensors. Many of these sensors record full flight data, and this means about four million data points are captured for each flight. We also use our electronic Full Flight Data Acquisition Storage and Transmission (eFAST) system. eFAST allows users to get the full flight data for the engine. That is, the data for every second of the flight. The data is then transmitted either in the air via ACARS, or on the ground with a wireless groundlink."

The quantity of engine data for the PW1000G series is about 100MB per flight for the A220 and A320neo. By comparison, the V2500 generates a few KB of data per flight.

The data is captured and stored in the PW1000G's FADEC unit, and then downloaded, usually post-flight. The eFAST technology is a standard specification for the PW1100G powering the A220, and a customer option on the PW1500G powering the A320neo. It is now also an option on the V2500 for the A320ceo, and can be retrofitted to all V2500-A5 engines.

"We have about 11,000 PW engines in service under maintenance contract," says Azoulay. "The Big Data system helps with engine shop visit maintenance workscoping. Clearly accurate trends in performance parameters such as temperature and vibration can be followed, but certain maintenance actions can also be pre-empted. This means we can prevent an unscheduled removal, as well as AOG situations at remote outstations. Through the use of eFAST, the number of AOG events we have pre-empted and prevented has grown exponentially. The system has an accuracy of about 90%.

"Another key advantage of eFAST is that the system can recommend certain maintenance practices," continues Azoulay. "We have engines operating in many areas of the world, which provides us with a large volume of data. In turn this generates a large data matrix to help us make accurate predictions. Additional data makes it possible to build a lot more algorithms, and so in turn make more accurate predictions of engine behaviour and performance."

PW uses the Predictives tools to get the optimal times to remove engines for maintenance. The PW Engine Wise engine management and maintenance package programme includes eFAST. "Airlines can also use eFAST as a standalone service, if they are not using Engine Wise," says Azoulay. "Airlines are therefore doing their own engine health monitoring and management."

eFAST is only being used for the A220 fleet, but can also be used on the V2500-powered A320ceo fleet.

## Summary

Big Data and Predictives systems are beginning to show solid results and ultimately financial benefits for airlines. These have to be weighed against the cost of using the system. The overall practice is still in its infancy, and the remaining challenges are devising systems to download a larger portion data from of the fleet data, develop a larger number of algorithms to analyse and monitor a larger number of parameters, and have the commensurate processing capacity. AC