Following the mandate from ICAO for airlines to establish a flight data analysis programme, and the growing volumes of data being generated by new generation aircraft, high-capacity storage and downloading systems are required. The evolution of systems and those available is examined.

Connectivity systems for downloading FDM/FOQA data

Storing and downloading flight data monitoring (FDM) or flight operations quality assurance (FOQA) information is an element of an airline's safety management system (SMS). FDM is the term used by European airlines, while FOQA is a term used in the US. FDM or FOQA data originate from aircraft operating parameters.

The International Civil Aviation Authority (ICAO) mandated a requirement for airlines to establish and maintain a flight data analysis (FDA) programme to analyse FDM/FOQA data as part of the SMS for all aircraft with a maximum take-off weight (MTOW) of 27,000kg (59,400lbs). This mandate is an annex to the Chicago Convention, and airlines have had to comply since January 2005.

FDM/FOQA history

FDM or FOQA data are downloaded from the aircraft's various systems, collated and analysed post-flight.

"Collecting FDM data started in the 1960s with the development of category III landing on the Hawker Sidley Trident for British European Airways (BEA)," explains Eddie Rogan, sales and marketing director at FlightDataPeople. "The objective then was to prove the accuracy of the Trident's landing by analysing its operating data post-flight. FDM grew from this point, with the collection of an increasing number of an aircraft's flight operations parameters.

"A large number of parameters was monitored through data collection, collation and analysis," continues Rogan. "This was initially conducted voluntarily by some airlines to analyse how well aircraft were being flown. This included the anonymous monitoring of pilots."

The objective of collating and analysing FDM/FOQA data is to identify both one-off and recurring events that could affect safety. "This is achieved through a reactive process, but the data can also be used proactively," says Rogan. "The data are analysed to see what percentage of flights are operating within or at the correct parameters. The data from all flights are analysed to get a statistical spread, and thousands of parameters can be monitored once or several times per second.

Examples of the most basic parameters are altitude, airspeed, heading, flap and landing gear configuration, engine power, aircraft attitude, and autopilot settings. The UK civil aviation authority (CAA), for example, details 32 parameters.

Examples of engine-related parameters that may be recorded are: cabin pressure; various hydraulic system health indicators; brake pressures; autopilot and FMS settings; and the operational or failure status of avionic components.

The number of parameters has grown with modern generation aircraft types to several hundred, and even as many as 2,000.

"It is now possible to monitor and record up to 1,000 parameters on the most modern types like the A380 and 787," says Peter Clapp, operations director at FlightDataPeople. "An airline would typically use fewer than 100 for the FDM programme."

The data used can be sub-divided into several categories, including: FOQA, which is flight operations-related data; engine health monitoring (EHM); and aircraft health monitoring (AHM) data. Many of these EHM and AHM parameters are safety-related, and may have to be transmitted to the ground while the aircraft is in the air. Other AHM and EHM data are analysed over the long term, and used to anticipate technical issues arising. Clapp says there are up to 50 EHM parameters, and another 50 AHM parameters. About 20 are used in monitoring fuel consumption.

There is also maintenance operations quality assurance (MOQA) data. Clapp explains that MOQA data are a sub-set of FDM data that relates to the parametrics of aircraft systems and its maintenance status.

MOQA data are used to assist an airline's maintenance and engineering department in troubleshooting and monitoring systems. "The collection and analysis of MOQA data has not really taken off," says Rogan. "The overall FDM/FOQA system monitors aircraft systems to pre-empt system and component failures, while a sub-set of FDM/FOQA data is used to monitor fuel efficiency. The business case for having an FDA programme, before it became mandatory, was that analysis of detailed EHM data, for example, can prevent a catastrophic engine failure. This can save costs by avoiding a large and expensive engine shop visit, and other related expenses caused by the interruption."

FDM data should not be confused with fault data, which reports the actual malfunction or failure of an aircraft system or component. This is sent in real-time by most airlines. Clapp explains that FDM, FOQA and MOQA data are

The main vendors of TWLU WiFi groundlink units are Rockwell Collins, Honeywell, Teledyne Controls, Miltope and Avionica. Teledyne Controls first, second and third generation TWLUs had WiFi connectivity only. Its fifth generation unit provides both WiFi and cellular on-ground connectivity.

parametric data, and explain why a fault has occurred or could occur.

ICAO mandate

As described, the ICAO mandate requires airlines to have a system in place for maintaining an FDA programme for all aircraft with an MTOW of more than 27 tonnes. All airlines operating in the 191 member states that are signatories to the Chicago Convention have to comply with the mandate, with the exception of airlines in the US, where the programme is voluntary, and the data referred to as FOQA. About 50-60% of US flights are currently monitored. The countries that are mandated to have an FDA programme refer to it as FDM collection and analysis. The aim in Europe is for all flights to be monitored.

"Operating an FDA programme can be sub-contracted to a specialist third party, but the airline still takes overall responsibility for the operation and maintenance of the programme," says Mark Goodhind, vice president aerospace business at Controls and Data Services. "An FDA programme is non-punitive, and also has adequate safeguards to protect the source of the data.

The MTOW threshold of 27 tonnes and above for all aircraft to record and analyse FDM data seems arbitrary, as there are many regional aircraft below this weight involved in commercial passenger and freight operations. A document published by the European Organisation for Civil Aviation Equipment (EUROCAE) specifies the parameters that are mandatory on the aircraft's flight data recorder (FDR). The FDM programme, however, is based on what parameters are available from the aircraft. While it is mandatory to have a programme, its content can be tailored to suit the airline's operational requirements.

"ICAO has standards and recommended practices (SARPS) for operating an FDM analysis system, but they are not legally binding," explains Mark Collishaw, business development director, flight data analysis & investigation solutions at Teledyne. "Each state may notify ICAO of differences between its own regulations and practices, and those recommended in SARPS.

"Despite SARPS, the acceptable levels of safety are determined by the regulatory authority in each state," continues Collishaw. "This means that each airline has to satisfy its regulator, not ICAO. Most national regulatory authorities follow the ICAO SARP 27-tonne MTOW criteria. States are free to make their own decisions, however. Some countries use a 20-tonne threshold for implementing a FDA programme."

Despite the 27t and 20t thresholds, many regional aircraft operated by airlines with lower MTOWs have an FDA programme in place. For example, many corporate jet and helicopter operators have voluntarily adopted FDA programmes.

Aircraft parameters

The number of parameters monitored by the FDA programme is not specified by ICAO. "We provide an FDM service for the C-130 for just seven parameters, and monitor up to 2,000 parameters for some Airbus types," says Goodhind.

The issue of which parameters are monitored was clear when all safety-related factors were recorded by the FDR, otherwise known as the black box. The operational parameters that have to be monitored depends on the risks that have to be identified. FDM system vendors will sometimes offer airlines a service that states which parameters will be monitored. In other cases airlines create dataframes to ensure that certain parameters are included.

The number of parameters recorded by the FDR is minimal, while a larger number are recorded by the aircraft's other avionic units. "The distinction is blurred these days, and the number of parameters monitored depends on the aircraft's age, size and manufacturer," says Collishaw. "It is then up to the airline to organise the capture of the maximum amount of data. There is a latency between data being captured and it being processed, and this should be reduced as much as possible."

The data are captured in the aircraft's avionic units according to various ARINC standards. On aircraft with avionics built according to ARINC standards, flight parameter data were transferred to avionic units via databuses. "The acquisition system is programmed to collect the required parameter data from each aircraft system, and package it for recording," says Collishaw. "This data capture normally occurs between engine start and engine stop. Each parameter is captured within 'frames' of data, and many thousands of flight data frames are captured and transferred to a single flight data recording system. This is accessed by line mechanics whenever possible, ideally after each flight."

Data recording units

As described, the FDR in the tail cone of most aircraft types captured and recorded the first aircraft parameters that were monitored. The first FDRs used tape to record parameters, and airlines were able to download the FDRs manually with ground equipment. "The problem with this is that the FDR is not easily accessible, because it has to be damage-proof in case of an accident," explains Rogan. "The flight data acquisition unit (FDAU) is an avionics box in the avionics bay under the flightdeck that captures and records all parameters. The data are captured and transferred from the aircraft's systems and components to the

FedEx is one of a few airlines that has installed its own WAPs at its Memphis homebase to use WiFi to download FDM/FOQA data from its aircraft. The airline installed Teledyne Controls's third-generation TWLU unit on its fleet. This works together with its TITAN aircraft network.

FDAU via databuses in the case of many older types.

"The datastream from a few flight operational parameters is therefore recorded by the FDR, while the datastream of most other parameters is recorded by the quick access recorder (QAR). The QAR is usually easily accessible on most aircraft types. The QAR was developed in the mid-1980s to make it easier for mechanics to regularly remove recorded data. The early QARs used magnetic tape as a recording medium. The QAR usually records the same parameters as the FDR, and up to several hundred or even thousands of others," continues Rogan. "The QAR records a larger number of parameters, but its location means it is not crash-proof. The QAR records and holds the FDM/FOQA data. As new generations of aircraft enter service, and the capacity to record and hold data increases, the number of FDM/FOQA, MOQA, AHM and EHM parameters, and the quantity of data, are increasing."

All aircraft types have a separate FDR, the black box safety recorder. The A350 and 787 also have a separate FDR, although data is now recorded in a new standard format. The problem with FDRs is the practical difficulties of downloading data from them, which had to be done manually at least once a year to verify that the system was operating properly. "This quickly led to a requirement for an easier way to download increasing volumes of data," says Willie Cecil, director of business development at Teledyne Controls. "Some airlines started using QARs in the 1980s. The QAR was introduced so that it was easier to access, which is why most of the aircraft's parameters are recorded on the QAR, and not the FDR. Magneto-optical disks were introduced in the 1990s to make it easier to download the data. Magneto-optical disks have a capacity of 230 mega bytes (MB). These were about 10cm square in size, and less than 10mm thick. They fitted into a slot in the front of the QAR unit, making them easy to remove.

"The idea of using on-ground, wireless connectivity came much later," continues Cecil. "Most types of aircraft had QAR units. QARs using removable PC cards came out in 2002, replacing magneto-optical disks. These were similar to the cards that could be slid into the side of a laptop. New generation QARs therefore used PC cards, and these were more reliable because they were solid state and did not have any moving parts. The FDA programme therefore operated on the basis of removable recording devices being taken by line mechanics after each flight or a series of flights. The data would then be downloaded from the disk onto the airline's flight operations IT system for analysis as part of its FDM and SMS programmes."

From the mid- to late 1990s Airbus and Boeing began delivering new aircraft with a data acquisition unit (DAU) that included an integrated QAR function. The QAR in the DAU still required data to be manually downloaded and collected. "The DAU is located in the aircraft's avionics bay," says Cecil. "Many aircraft types today have DAUs with a slot for PC cards, but some do not have a DAU with a built-in QAR function, so they needed a separate QAR unit.

"Some aircraft types, however, have integrated modular avionics (IMA)," adds Cecil. "This involves a change in the design of the avionics bay. Instead of each function having a separate box, each with its own power supply and hardwired to other avionic boxes, IMA is a system with a single cabinet in the avionics bay. The cabinet has a common power supply. Most of the avionic functions are provided by a series of circuit board cards mounted in the cabinet. Some avionic functions, however, are still provided by individual boxes that are interfaced with the cabinet."

The 777 family and Embraer E-Jets have such an integrated modular design and approach to avionics. These had the need for a separate unit to act as a QAR, because the integrated avionics system did not include a QAR function. Such aircraft types therefore have spaces in their avionics bays for an optional QAR, should airlines want to install them. More recently the concept of QAR software hosted on an aircraft server has been introduced. The Airbus FlySmart system, designed as an option for the A330 and A340, was one of the first to support QAR recording on a server. The A380 also supported QAR as an optional function on the server.

Boeing has introduced an on-board network server (ONS) on the 777, 747-8 and 737. The 787, however, uses a network system called CoreNet, which has some functional similarity with the ONS.

"Avionic functionality is continually being consolidated, and functionality such as the QAR is being incorporated into the other avionic units," says Clapp. "A separate QAR has limited functionality on new-generation aircraft, and is now essentially a memory device that can easily be incorporated into another avionic unit. The 787 and A350 have QAR functionality built into other avionic boxes, so the FDM data are downloaded through the TWLU cellular or WiFi gatelink system. Nevertheless, some airlines may still install a separate QAR."

Data volumes

The quantity and volume of data that have to be downloaded from the QAR are constantly increasing in correlation with the increased sophistication of modern aircraft types.

The QARs of modern generation aircraft now generate up to several hundred MBs of data per month, and

Emirates is another airline to instal a WiFi access network at its main hub; Dubai. The airline has also installed WiFi groundlink transceivers on its A380 and 777 fleets.

even up to a few giga bytes (GB) of data per month. Airlines therefore have to consider what systems they use for downloading the data from the aircraft.

Besides manual downloading from a PC card, there are a few other options for most older generation aircraft types. There are several flightdeck connectivity systems that may be considered.

The aircraft communications addressing and reporting system (ACARS) is the most widely used connectivity system among airlines, but it has the slowest rate of data transmission. "It has a transmission rate of 2.4-31.5 kilo bits per second (Kbps)," says Cecil. "ACARS sends a total of 1-10MB per month from an aircraft, and the ACARS data volumes from most aircraft types are closer to 1MB per month. ACARS is used to send fault code information and messages from the aircraft's CMC and health data in real-time. These messages are small like text message. ACARS is still the most widely used system for sending data for operations and maintenance, including EHM and AHM; for example Airbus AirMANWeb and Boeing AHM. The ACARS bandwidth and network capacity, however, and cost of transmission mean it is not suited for QAR or FDM transmission."

By the mid- or late 1990s aircraft were generating about 1.5MB per flight hour of QAR data. This has now increased to 5.5MB per hour for the latest generation aircraft types. Cecil estimates that the 787 generates up to 8MB per flight hour.

The majority of QAR data, which has been increasing in volume, is now used more broadly than the basic health monitoring uses. The use of QAR data has evolved into big data analytics. While some health monitoring data relates to faults, and needs to be transmitted in real time, most QAR data are not fault-related, and so can be economically downloaded in larger volumes when the aircraft is on the ground. Considering the large volumes and that the data does not need to be downloaded in real-time, an on-ground connectivity system with a high data transmission rate and low transmission cost is the most desirable.

Typically, QAR data are processed and used by airline flight safety departments to support FDM or FOQA. Increasingly data are used for maintenance and operations, and most recently even for business intelligence. Some airlines are using big data analytics to assist with this.

QAR data when collected manually with PC cards takes anything from a few days to a fortnight to be processed. QAR data collected wirelessly is often processed within minutes of landing. This can make the data more useful, not only for flight safety, but also for maintenance and operations. Due to the timeliness of the data, some airlines are using their QAR data and FDM system to provide data for health monitoring, rather than sending the same data in real time during flight via the more costly ACARS links.

Modern download systems

"Despite the different types of avionic configurations of various aircraft types, all aircraft where QAR data are recorded on PC cards have adequate data storage capacity," says Cecil. "The problem, however, with manually downloading data using a removable disk is that it is logistically difficult and time consuming. It also means that it takes several days for the data to get looked at. An electronic system to automatically and wirelessly download the data is therefore required, especially if the airline wants to analyse the data from every flight."

When considering wireless systems for downloading QAR data there are two alternatives for airlines to consider: WiFi and cellular connectivity systems.

WiFi connectivity

A WiFi connectivity system requires the availability of an active WiFi network near the aircraft when it is on the ground. This means a wireless access point (WAP) transceiver has to be installed at least at every other terminal gate at the operator's main base airport.

FedEx, for example, has installed a WiFi network at Memphis. Emirates has installed WiFi at its Dubai hub for its A380 and 777 fleets.

The cost of installing and maintaining all related WAP infrastructure at an airport is high, however, and few airlines have opted for this system. One solution, however, is for an airline to buy a WiFi service from a provider that has already installed the infrastructure at an airport. Rockwell Collins provides ARINC GateFusion, while SITA provides a similar gatelink service called AIRCOM IP. Rockwell Collins and SITA have contracts with different airports, and sell the service to airlines. Airlines need a WiFi service at least at their main operating bases.

Where airlines have opted to use WiFi, the aircraft has to be fitted with a terminal wireless lan unit (TWLU). The TWLU only provides connectivity, however, and has to be interfaced with the aircraft's server or QAR.

Providers of TWLUs, to provide a wireless WiFi connectivity system, are Miltope, Honeywell, Rockwell Collins, and Teledyne Controls. TWLU devices were the first on-ground wireless connectivity system to be standardised by the industry and adopted by aircraft manufacturers.

Miltope's TWLU system with WiFi connectivity has a range of 100 metres (300 feet) from the aircraft, compared to a range of up to 2 kilometres (1.2 miles) for Wi-max. This capability may be needed for aircraft parked at remote areas of an airport, for example.

Teledyne Controls has expanded the

The 787 was fitted with a Honeywell WiFi on-ground connectivity system as standard. More than half 787 operators, however, also wanted their aircraft to be fitted with cellular on-ground connectivity units. The aircraft's QAR function comes from its CoreNet system.

capability of traditional TWLUs, and provides what it now calls an aircraft wireless lan unit (AWLU). The first-, second- and third-generation Teledyne units only provided WiFi connectivity. The third-generation unit provided a combination of a TWLU and a cabin wireless lan unit (CWLU). "We sold this system to FedEx, which retrofitted it to its aircraft fleet with its TITAN aircraft network," says Cecil. "This AWLUg3 had to be interfaced with the aircraft server's QAR function to download the FDM data to the Gatelink ground systems."

Cellular connectivity

The alternative to WiFi is transmitting data from the aircraft through cellular networks that are already in place at airports for personal and domestic use. This has proved more popular than some expected.

Airbus and Boeing are offering the A350 and 787-9 with cellular equipment connectivity solutions.

Teledyne Controls's fifth-generation AWLU has two variants. One of these provides just cellular connectivity.

Miltope is finalising development of a cellular connectivity system called the cTWLU. Miltope says the cTWLU increases the applicability of the system by an order of magnitude. The system can operate on either 3G or 4G networks.

Rockwell Collins provides a terminal ground cellular unit (TGCU), and Avionica provides a mini-QAR.

Combined WiFi & cellular

The other variant of Teledyne Controls' fifth-generation AWLU offers a combined WiFi and cellular on-ground connectivity system. Teledyne Controls is the only provider of combined on-ground connectivity, which has only been available for the past three years. The variant with both WiFi and cellular connectivity first tries to connect using WiFi after the aircraft has landed. It then switches to the cellular network if it cannot connect to the WiFi network. The system can also be configured to work the opposite way at airports where cellular is less expensive than WiFi service.

The AWLU can be fitted to later-build 777s and 737NGs that have an ONS installed, to provide WiFi and/or cellular groundlink connectivity. The ONS was an option for several years on the 777, but is now standard fit on the latest-build 737NGs, 747-8 and 777. These ONS-equipped aircraft may have a QAR function loaded onto the ONS as an application. The aircraft therefore just need a WiFi and/or cellular wireless system to transmit the QAR data. In the case of the 777, the only choice is Teledyne Controls' AWLU. Today about half of the 777s coming off the production line have the AWLU option installed.

Similar to the 777, the 787 can now be configured with WiFi and cellular connectivity. The 787 has been fitted with a Honeywell TWLU, providing WiFi, as standard. More than half of 787 operators also wanted cellular connectivity, however, so there is now the option of installing or retrofitting a Terminal Cellular Unit (TCU). This is functionally very similar to the cellular AWLU used on other Boeing types. The TWLU and TCU therefore provide the 787 with WiFi and cellular connectivity. The aircraft's QAR function comes from its CoreNet system.

Combined connectivity & QAR

"An issue with transmitting QAR data to the ground is that in terms of aircraft architecture, connectivity systems are kept under Air Transport Association (ATA) chapter 23, while QAR and FDAU systems are under chapter 31," says Cecil. The fact that these two were separate meant a physical link was needed between the two. "Teledyne Controls broke the mould in 2001 with its Wireless GroundLink (WGL) product, which combined cellular connectivity technology and the QAR function in a single unit. This provided the necessary hardware for older generation aircraft that have a legacy QAR with manually-removed disks and do not have a server or TWLU wireless groundlink system.

Teledyne Controls does not manufacture a combined WiFi and QAR unit, however, because the uptake and use of cellular on-ground communications has proved to be more popular than WiFi.

"The GroundLink is installed on a large number of older 737NGs, older 777s, 747-8s, A320s, A330,s A380s, Embraer E-Jets, and Sukhoi SSJ100s," continues Cecil. "The GroundLink is installed as an option on almost two-thirds of all aircraft on the Airbus and Boeing production lines. Including those installed as retrofit via a service bulletin or STC, there are about 6,500 aircraft equipped. Used by more than 150 airlines, the system is by far the most popular and most widely used wireless QAR data collection solution in the industry."

Older-build 777s were delivered with legacy QAR units. Operators have two options to configure the aircraft to wirelessly download FDM data. One was to retrofit a GroundLink unit, which provided both the QAR and the cellular connectivity for FDM data download, but not other functions.

The other option includes retrofitting an ONS, which would include virtual QAR functionality, and installing an AWLU. This provides full e-enablement of the aircraft and many more functions, since the ONS is connected to multiple aircraft systems. AC