The evolution and development of high bandwidth flightdeck connectivity systems is continuing. Applications for these include the use of live, graphical weather information to be used together with flightpaths and plans on EFBs. These are already delivering additional benefits of large fuel savings.

The evolution of high bandwidth flightdeck connectivity systems

Flightdeck connectivity systems have evolved over the past 15-20 years to give pilots and flightcrew more information, so that they can operate differently to traditional procedures.

Legacy connectivity systems

Initial developments in flightdeck connectivity systems provided methods for transferring relatively small quantities of information and data to and from the flightdeck. This was in addition to voice communications over radio.

These developments include the advent of the aircraft communication addressing and reporting system (ACARS) in the late 1970s, digital very high frequency (VHF) and high frequency (HF) radio transmissions for data and digital ACARS messaging, and controller-pilot datalink communications (CPDLC) to replace voice over radio and satellite transmissions. ACARS messages are sent from the aircraft's communications management unit (CMU) or air traffic services unit (ATSU) to the connectivity system being used.

These developments have allowed only relatively small volumes of data to be transmitted, because existing connectivity systems have low data transmission rates. One limiting factor is that many flightdeck transmissions are air traffic service (ATS) messages, and so require connectivity systems that are not susceptible to interruptions, such as attenuation by water droplets. To date, all of these have low data transmission rates, which limit message size.

ACARS messages conform to ARINC protocols, and originally were analogue messages referred to as plain old ACARS (POA) or character oriented protocol (COP) messages. POA/COP ACARS messages are transmitted over VHF, HF and Classic Inmarsat and Classic Iridium satellite communication (Satcom) systems. Data transmission rates for POA/COP messages over VHF and HF are 2.4 kilobits per second (Kbps).

Second generation ACARS messages were binary files, known as bit-oriented protocol (BOP) messages, that have more information than POA messages. These require connectivity systems with higher rates of transmission. They have to be sent by VHF digital radio or VDL mode 2 (VDL M2), or by digital HF datalink (HFDL). These have a data transmission rate of 31.5Kbps. There are a small number of VDL M2 receivers in the world, and most are based in Europe. These receivers can be used for BOP and POA messages.

In addition to analogue and digital variants of radio, Classic Inmarsat and Classic Iridium satcom systems started to be used by corporate and civil aviation in the late 1980s.

Inmarsat Classic is an L-band system, and transmits digital messages and transmissions approved for ATS messages. They can be used for POA/COP ACARS messages at a rate of 2.4Kbps. A BOP digital ACARS message that gets sent over VDL M2 VHF at 31.5Kbps will get sent over Inmarsat Classic at 2.4Kbps. Iridium Classic has been used since 2011 for safety-related POA/COP messages. Like Inmarsat Classic, data transmission rates for these ACARS messages are limited to 2.4Kbps.

Flightdeck applications

There are four categories of flightdeck transmissions *(see The applications of flightdeck connectivity systems, Aircraft Commerce, October/November 2013, page 13)*.

The first of these are ATS transmissions. These are all safety-related, and so mainly relate to navigation and air traffic control (ATC) issues between flightcrew members and ground-based systems, in particular the air navigation service providers (ANSPs) and air traffic management (ATM) operators.

There are several categories of ATS messages. The first of these are the voice over radio ATC communications. A lot of information used by flightcrew was provided prior to flight in the pre-flight briefing. This included weather information and flight plans. Information relating to factors affecting the airfield, such as weather and runway(s) in use, was originally provided as a recorded voice message over VHF in the form of an automatic terminal information service (ATIS) transmission. ATIS information can now be received in the aircraft's flight management system (FMS) via a digital ACARS message. Flightplans and pre-departure clearances can also be loaded into the FMS the same way.

Another application of ATS messages is updates to the flightplan, such as change of route or altitude, while the flight is in progress. This can now be in the form of ACARS messages rather than requests being made to ATC controllers by voice.

In addition to analogue and digital

ACARS messages, there has been the development of CPDLC messages. These are sent between the aircraft's FMS and ATC and the ANSPs. They are a set of standard digital text messages, and they are selected by crew from the FMS. They are used in various new systems for ATM and navigation, with the objective of replacing traditional voice messages.

CPDLC messages are a category of BOP ACARS messages, and are sent either when the aircraft is in range of VDRs or via HFDL, Classic Inmarsat or Iridium satcom or when the aircraft is operating over an ocean or sparsely populated area and out of range of VDRs.

CPDLC messages have been developed as part of new navigation and ATM procedures that eliminate all voice transmissions, which increases the utilisation of airspace. CPDLC messages are used in the future air navigation system (FANS) for intercontinental and long-haul markets, in the Single European Skies ATM Research (SESAR) system for Europe, and the NextGen system for the US. The data transmission rate of CPDLC messages via these established connectivity systems is the same as for BOP ACARS messages.

The other three categories of flightdeck messages are airline operational communication (AOC), airline administration communication (AAC), and air passenger communication (APC) messages.

AOC messages relate to a variety of information classes that are used by airline operations departments, including the transmission of: off, out, on and in (OOOI) times; flightplans; aircraft health monitoring (AHM) and engine health monitoring (EHM) data; crew messages; fault codes from the aircraft's central maintenance computer (CMC); uploads for the electronic flightbag (EFB); information and reports sent from the electronic technical log (ETL); and graphical text weather services. Graphical weather service information is transmitted to aircraft on request to superimpose several layers of graphical weather over the flight path on the EFB screen. Graphical text weather service provides weather information in text form on request from the flightcrew. There are several providers.

All these categories of AOC messages can be sent to the aircraft via POA ACARS or BOP ACARS messages over the VHF and HF radio, and Classic satcom systems.

The AOC messages and transmissions that involve some of the largest quantities of data relate to uploads of information to the EFB, and downloads of AHM/EHM data from the ETL.

AAC messages are a smaller category of data. These include crew manifests and occasional chart and loadsheet database uploads to the aircraft's FMS.

APC messages are the infrequent and small messages relating to items of passenger interest, such as gate changes for connecting flights or news updates.

High bandwidth

Most of the transmission types and categories have messages that are relatively small in size. There are several categories, however, such as live weather data and information, and some AHM/EHM transmissions, that have relatively large messages; these could be larger if a higher bandwidth connectivity system were available.

The size of these types of messages is limited by the current flightdeck connectivity systems available. Live weather data and information, and aircraft health and maintenance data are not ATS messages, and are AOC messages. They are, therefore, not limited to the legacy connectivity systems that are approved for ATS messages, which are analogue and digital ACARS messages over VHF and HF radio, and Classic satcom systems.

A new generation of Inmarsat and Iridium satellites has been launched that can be used for flightdeck transmissions, and which have higher data transmission rates than Classic systems. Inmarsat and Iridium Classic satcom systems operate on ARINC protocols. They are not attenuated by water droplets, so their secure nature means that they are approved for ATS transmissions.

High data rate or high bandwidth satellite constellations have been launched by Inmarsat and Iridium.

Inmarsat SBS

Inmarsat has already launched a full constellation of satellites for swiftbroadband (SBB) services. Compared to Classic L-band satellites, these new constellations will have a higher data transmission rate of 432Kbps. This is about 40 times the rate of Inmarsat Classic. The new generation satellites for SB services transmit using internet protocol (I.P.), which achieves the higher data transmission rate.

In addition to the new satellite constellation, Inmarsat has developed a system previously known as SBB, and now called swift broadband for safety (SBS), together with Cobham Satcom. The I.P. transmissions of the new generation Inmarsat satellites are prone to attenuation by water droplets in clouds and other weather systems, so they cannot be approved for ATS messages.

Cobham Satcom developed a system to encapsulate ACARS messages in I.P. packets using an avionics unit on the aircraft called Aviator S for Safety. This unit encapsulates an ACARS message before it is transferred to the aircraft's CMU or ATSU to be transmitted to the ground via the new generation Inmarsat SBS satcom system. The message received on the ground has the enclosed ACARS message extracted, and then fed into the communication channels used for all other ACARS messages. The encapsulation and I.P. transmission process circumvents the low transmission rate of conventional connectivity systems, and provides a high transmission rate system for ACARS messages.

In addition, the system distinguishes between transmissions that have an encapsulated ACARS message and those that are plain I.P. transmissions. While encapsulated ACARS messages are required for ATS transmissions, pure I.P. transmissions are suitable for data being sent to and from the EFB and ETL, and for AHM/EHM data transmissions to the ground from the aircraft.

Iridium NEXT operates in a similar way to the Inmarsat SBS system, and has the same type of potential applications.

These two new high bandwidth flightdeck connectivity systems, therefore, have two categories of possible applications. One is ATS transmissions, with the high transmission rates reducing an aircraft's overall cost of communications. The second is high-volume non-ATS transmissions, especially AOC communications. A high bandwidth connectivity system would allow AOC applications that require high data volumes.

While the Inmarsat SBS system is already approved for non-ATS transmissions, it had to be evaluated, trialled and certified for ATS transmissions. Inmarsat started testing the system with Hawaiian Airlines from March 2015. The system was fitted to eight of the airline's widebody aircraft that are operated on transpacific routes. These were A330s and 767s. The purpose of the trial was to verify that the SBS system could transmit all types and categories of SBS messages, including CPDLC transmissions used in the FANS ATM system. For regulatory authorities to approve the system for ATS transmissions, key issues to be examined were the latency of the transmissions, and their security or susceptibility to interruptions and attenuation by weather patterns.

Iridium NEXT

Iridium is in the process of launching a constellation of satellites to replace its Iridium Classic satellites. These are called Iridium NEXT or Iridium Certis. "We will use these new satellites to provide the same high bandwidth system as Inmarsat SBS. Certis is an I.P.-based transmission, and we will have a unit on the aircraft to encapsulate ACARS messages in I.P. packets to achieve a high data transmission rate," says Michael Hooper, director and general manager of aviation at Iridium. "The Certis system will also put in place the required security so that it can be used to send ATS transmissions. The system will also be used for AOC transmissions, and so make it possible to have live graphical weather updates for use on EFBs. It can also be used to stream operational and maintenance data in real

Hawaiian Airlines tested the Inmarsat SBS system on its A330s used for its transpacific routes. In addition to testing the system for ATS messages, Hawaiian also used SBS as the connectivity system to provide live graphical weather information to be superimposed on flightpaths on its EFB system.

time. Certis will allow an airline to set up several IP flows that will enable a wealth of new services."

In addition to I.P.-based transmissions, the Certis satellites will continue to support legacy devices, and send the POA ACARS transmissions that are sent by Iridium Classic. The Iridium Certis satellites will use multiple wave forms, and the higher wave forms have high data transmission rates. "Certis 100 will have a data rate of 88Kbps to and from the aircraft; Certis 200 will have double the transmission rate of 176Kbps in both directions; and Certis 350 will further double the data rate to 352Kbps both to and from the aircraft," says Hooper. "The two highest systems of Certis 700 will have a downlink rate from the aircraft of 352Kbps, and an uplink rate to the aircraft of 704Kbps; Certis 1,400 will have a downlink rate of 524Kbps and an uplink rate of 1,408Kbps. We have provided these different data rates so that we can offer different costs of transmission to match airlines' data requirements. We will also offer high data usage plans. We expect to make the system commercially available to airlines in 2019."

Iridium is currently undergoing a test and evaluation programme with the US Federal Aviation Administration (FAA). This requires a high degree of confidence, so it will involve about 10,000 messages. "Several of our first customers for the system will have to be part of the FAA evaluation and testing programme," says Hooper. "The use of several airlines and 12 aircraft should make evaluation quicker because of the high volume of messages involved."

New applications

The non-ATS use for Inmarsat SBS and Iridium NEXT is using several applications that require high data volumes, including several applications that have not yet been developed.

Real-time weather

Hawaiian Airlines has primarily been using the SBS system to transmit graphical weather data in real time to the flightdeck for use on the EFB. This can have several consequences for the efficiency of operating flights.

The traditional system for providing weather information is to give it to flightcrews during pre-flight briefings, partly in the form of printed charts. World area forecast centre (WAFC) reports are provided for international flights, and reports from local flight information regions (FIRs) are used for domestic flights. WAFC reports ultimately originate from the National Oceanic and Atmospheric Administration (NOAA) in Washington DC, and the Met Office of the United Kingdom.

The NOAA weather reports cover the regions that include the Americas and the Pacific and Atlantic oceans. The UK Met office reports cover Europe, Asia, Indian ocean and Africa. The NOAA and Met office WAFC reports only provide weather for the en-route cruise section of the flight.

WAFC reports are generated at six-hour intervals, four times per day. The reports are distributed to airlines' flight operations and dispatch departments via distributors and flight planning providers, such as Jeppesen, Scheider Electric, Sabre, Lufthansa Systems and the Weather Co. Some of these distributors also generate their own forecasts and provide additional services, such as providing the terminal area forecasts (TAFs), meteorological actual reports (METARs), and significant meteorological information (SIGMET) reports. TAFs are generated every six hours, while METARS are generated every 30 minutes. The information originates from local meteorological offices, and flight crews use them to provide weather for the departure, destination and alternate airports. SIGMETs are issued when significant weather occurs.

A few weather distributors, such as the Weather Co, also generate their own weather reports. The official weather information from the WAFC, TAFs and METARs have to be used.

There are several inherent problems in generating the WAFC reports every six hours, and providing them in printed form to flightcrews. These include the information being up to six hours old at the time of the pre-flight briefing, and then ageing as the flight progresses. Weather information can, therefore, be more than 15 hours old towards the end of long- and ultra-long-distance flights.

Developments in previous years, and the growing adoption and utilisation by airlines of EFB systems, led to the uploading of WAFC, TAFS and METARs to EFBs in graphical format prior to flight departure, largely via on-ground cellular and WiFi connectivity systems. This system still has inherent disadvantages: the weather data is already several hours old at time of upload; it ages as the flight progresses; and it has to be viewed on an EFB page that is separate to the page displaying the track as provided in the flight plan.

A more desirable system will generate more frequent weather forecasts, transmit data to the aircraft via a high bandwidth connectivity system, and superimpose graphical weather information over the flight track on the EFB page. This would allow relatively young or real-time weather to be viewed on the flight path, and so allow pilots to make informed decisions about changing the flight plan, either in the routeing or cruising altitudes.

"The Inmarsat SBS system has been used in this way by Hawaiian Airlines in trials to assess it for ATS transmissions," says Frederik van Essen, senior vice president of marketing and business development at Inmarsat Aviation. "There are problems with airlines making an initial assessment of a high bandwidth connectivity system, since many still adopt a silo mentality, and do not see the holistic benefits of using such a system. Low-cost carriers are driven by unit cost per available seat-mile efficiency, and so are more inclined to appreciate the overall benefit of this type of system than legacy carriers, which so far seem to have only seen SBS as a low-bandwidth cabin-connectivity system."

A main element of the trial by Hawaiian Airlines was to use SBS to provide live graphical weather data on its EFBs. "Hawaiian found there were several benefits to using the system," says van Essen. The first of these was significant fuel burn reductions and savings, thanks to more efficient flight management. The SBS system and the more up-to-date weather data allowed crews to avoid adverse weather patterns, and also operate more direct routes. This is only possible with real-time weather information. The system has allowed Hawaiian to constantly re-optimise its A330 and 767 transpacific operations while in progress, where previously flight plans were made 24 hours in advance. Over the trial, the system made it possible for the airline to save an average of 2,000lbs of fuel on flights serving Japan and South Korea." This is equal to 300 US gallons (USG) of fuel, the equivalent of about $600 at current spot prices, and $2.40-2.60 per seat on a one-way trip.

"There were some exceptional flights where up to 10,000lbs, or about 1,500USG and $3,000 were saved," says van Essen. "These savings are clearly substantial. When extrapolated over an airline's entire operation, large annual savings in flight time and fuel consumption can be made. Following the trial by Hawaiian, The London School of Economics (LSE) conducted a study in June 2018 to assess the implications of using a real-time weather and constant flight plan re-optimisation system while using the Inmarsat SBS system."

Mark Miller, business unit executive for aviation at The Weather Company, says that there is clearly a move from planning flights in advance and releasing the information, to continual optimisation of the flight while it is in progress. "High bandwidth connectivity systems are key to this," says Miller. "One of our areas of expertise is providing enhanced weather services. This makes true in-flight optimisation possible with continual weather updates. Enhanced weather services improve forecasting capability, and use a combination of traditional weather sources and others that include barometric pressure from smartphones and real-time data from aircraft that are in the air.

"Enhanced weather data has allowed us to increase spatial resolution by a factor of three to five," continues Miller. "The main improvements that result from this are more frequent weather update cycles, which can be as frequent as hourly or even every 30 minutes. This is helped by the use of IBM supercomputers and the Internet of Things (IoT) to collate several other data sources. Traditional weather forecasts have information provided on map grids that are 32km by 32km. We have already reduced this to 15km square grids, and soon plan to have 3.5km grids in higher traffic areas. We also plan to have hourly updates for weather information. In future, the higher resolution of weather data means the grid square dimensions will have 1km spacing. It will, therefore, be possible to have

The use of Inmarsat's SBS connectivity system to provide live graphical weather for use on an EFB system has had the benefit of saving an average of 2,000lbs of fuel on long-range missions operated by the A330-200. This is generates a saving of about $600 per flight. A study by London School of Economics has extrapolated this to an industry-wide annual saving of $15 billion if deployed on all jetliners.

micro forecasts that can pick up the details of the exact scale of a thunderstorm. We will, therefore, have smaller grids with detailed information that is frequently updated. In addition, we will take an array of weather models and look at the probability of the forecast being correct. This means that the future system will differ greatly from the traditional model."

The Weather Company's Pilot Brief application is a system for use on EFBs that receives real-time weather updates. "We recently added a vertical profile to the application," says Miller. "This has the particular benefit of enabling the flight crew to know about possible turbulence occurring in the planned flightpath. Another application we offer is Fusion, which is used on the ground by flight operations and dispatch departments. It is a real-time decision support system that provides weather information and airspace availability, and gives flight planners updates on fuel reports. Overall, the system allows flight dispatchers to maintain the performance of flight plans, by giving them early insights into disruptions and changes. This makes it possible for a dispatcher to re-optimise a flight plan earlier or continuously so that the airline is not penalised as much by incurring additional fuel burn."

Maintenance & ATM

There are additional benefits of a high bandwidth system that can provide airlines with cost savings. The first comes from the application of predictive maintenance. A high data-transmission rate will allow a large volume of aircraft health monitoring data to be transmitted to airline engineering and maintenance control departments in real time. This data can be used by maintenance IT systems to predict system and component failures, and so schedule maintenance and component changes that would otherwise result in expensive flight disruptions and cancellations.

An additional benefit is using a high bandwidth system on the aircraft as an element of new ATM systems and procedures, such as the European SESAR or US NextGEN programmes. The systems aim to increase European airspace capacity, given predictions that passenger numbers will double by 2035. This will require a move to 4-D trajectory in flight operations, and in turn will require a system to tell the aircraft where it needs to be and when. This will involve a high volume of CPDLC messages, and will only be possible with high-bandwidth flightdeck connectivity systems. Van Essen claims that the cost of adding these two capabilities to the SBS system is only incremental.

The conclusion of the LSE study was that the industry has the potential to save approximately $15 billion a year by 2035 if the entire global jetliner fleet were equipped with the system. Van Essen predicts that the cost of transmissions will not explode, despite an inevitable increase in volume, and that the benefit predicted by the LSE study is a net benefit. Moreover, there is only an incremental cost of getting the additional benefits of adding the capability of predictive maintenance and new generation ATM systems to the live weather capability.

Additional systems

In addition to Inmarsat SBS and Iridium Certis, there are several other high-bandwidth connectivity systems that can be used for flightdeck applications. These include air-to-ground (ATG) and Ku-band satcom systems. These are based on I.P. transmissions, and can be used for AOC communications and transmissions. This is the most appropriate category of flightdeck transmissions, since it is EFB and ETL applications that require the highest data rates and bandwidths. Moreover, EFB and ETL systems are I.P.-based.

While ATG and Ku-band satcom systems are primarily used for cabin connectivity to provide in-flight entertainment, these two connectivity systems can have split channels, with one being used to service the flightdeck. Gogo provides its ATG system for overland flights in North America, and its high-bandwidth 2Ku-band satcom system internationally. "Flight operations departments mainly want live graphical weather data, supported by either of these connectivity systems," says TJ Horsager, connected aircraft director at Gogo. "The 2Ku-band system has a high data transmission rate, and can be operated gate-to-gate, and so throughout the entire flight without having to use another connectivity system. There are currently 14 airlines with 700 aircraft operating the 2Ku-band system. These include Delta Air Lines, Japan Transocean Air, Cathay Pacific, British Airways and Air Canada. Air France and KLM also have a commitment to 2Ku-band. Virgin Atlantic, Iberia, GOL, Aeromexico and LATAM Airlines are at various stages of equipping their fleets. Not all 2Ku-band customers are using the system for operational uses, since it mainly depends on the maturity of an airline's EFB programme." AC