Rotable support packages allow airlines to avoid capital investment in component inventories and complex management processes. Big Data analytics and Predictives have been introduced to the management process, realising a reduction in AOG situations and airline costs.

Rotable support and technology to streamline management

Total support packages and programmes for inventories of rotable and repairable components allow airlines to avoid high capital investments and enable known and predictable maintenance costs. These total support packages are used by many airlines, but primarily to support small- and medium-sized fleets.

Rotable economics

Operating a complete in-house rotable management and support programme requires large capital investment in three main areas. The first area is the inventory of rotable and repairable components to support each fleet operated. The main issue is the quantity of components that are required to support a fleet. The number needed per aircraft decreases as the fleet size grows and matures due to the implementation of Airworthiness Directives (ADs), Service Bulletins (SBs) and performance improvements during the normal course of business.

"The initial investment in rotable and repairable inventory will be quite high. Depending on the number and type of parts covered under the agreement, it ranges between $80-150 million for a fleet of 150 aircraft of a single type, or $1 million per aircraft," says Al Malecha, managing director EMEA at Kellstrom. "As the programme matures and more removal data is accumulated and increased performance measures are implemented, this investment shrinks to $0.5 million per aircraft, but is only achievable with the addition of other such programmes across similar fleets. This allows the inventory to be used across multiple fleets. This relates to about 600 different part numbers (P/Ns) that are considered for coverage under the agreement, and correspond to about 2,500 parts on the aircraft. These covered parts are usually the most routinely removed parts on the aircraft. They do not include components that are extremely expensive, seldom-removed parts such as structures, and flight control surfaces, because this would make the programme cost-prohibitive for the customer."

Upfront investment per aircraft will be several million per aircraft for small fleets. "Upfront investment is made more difficult by the fact that there is an even higher capital cost for rotables for a new generation fleet, since there is very little used serviceable material (USM) available in the aftermarket and parts must be bought from the original equipment manufacturers (OEMs)," continues Malecha. "Also, the OEMs provide a recommended parts list (RPL) for a fleet when delivered new. This tends to overestimate the quantity of parts required, but this does not become clear until the fleet has been operating for a few years, and it leaves the airline with a glut of unnecessary and often expensive inventory. The parts for a new generation fleet are expensive to acquire, but this changes once an aftermarket for its components is established."

The initial investment by an airline per aircraft will be much higher at roughly a few million dollars per aircraft for very small fleets. It is this high investment per aircraft for small fleets that drives the demand for complete rotable support packages for many of the smaller airlines. This investment rate per aircraft declines, however, as the fleet increases in size and the previously purchased expensive, low-use, no-go material can be used to support a larger population of aircraft.

The second main investment an airline requires for managing components in-house is in extensive test and repair facilities. There is a large number of component P/Ns and of different types and categories. This includes high capital cost and complex components, such as avionic units. The test and repair equipment for these is expensive. Moreover, the variety of components means a range of test and repair equipment is required to support a fleet of any type. This can only be justified for a continuous stream of removed components, which in turn means a large fleet needs to be operated to justify performing all the repair activity in-house. In turn this means the third tranche of investment is for qualified repair technicians.

Small and medium fleets lack the economies of scale that large fleets have, so they will seek support of this type to avoid high upfront capital investments. Airlines that own inventories of rotables and have at least some of the test and repair facilities required to support a fleet can divest in them, and so generate cash.

Rotable management

Alongside the considerations of the capital investments related to rotable inventories, several related management functions have to be performed by an airline's engineering department where rotable inventory management is conducted in-house. These will include: the initial and continuous assessment of the quantity of each P/N required to support a particular fleet size; determining the optimum locations for holding the stock of rotables; tracking each component serial number (S/N) as it rotates around the system; generating component and system reliability reports; managing repair and modification activities; and managing all transport and related logistics services.

All-inclusive rotable support packages therefore also include performing most of these management functions. The appeal for an airline is that all the investment and management functions can be avoided, and the service can be paid for at a predictable rate that often finds favour with airline

Rotable components are complex and have high capital costs. The high capital outlay to support a fleet is the rational behind all-inclusive rotable support programmes.

chief financial officers.

Large airlines have traditionally performed all the related rotable management functions in house. Some medium and large airlines may prefer to continue owning their rotable inventories, while outsourcing engineering management functions to a specialist service provider.

Support packages

Several rotable support package providers offer services that have the same or similar basic structure and functionality, including: an initial assessment of inventory required by the airline's fleet; provisioning a homebase stock of rotable components; providing access to a second inventory of rotable stock held by the provider; and managing all logistics and repair activities.

The provisioning of the homebase stock and pool access is then often paid for on a flat-rate basis to reflect the capital cost of the components. The management of logistics and repairs is paid on a power-by-the-hour (PBH) basis, which takes into account the predicted or planned rate of aircraft utilisation by the operator.

Most airlines take a complete package of all these activities, but may also retain ownership of all their stock, or the homebase position of the inventory.

The fleet sizes that benefit most are 25-35 units of a single aircraft type. "Examples are regional carriers, start-up airlines, and freight carriers," says Malecha. "These are the usual types of airline that have minimal capital available, which is the main factor that attracts such airlines to these types of all-inclusive rotable support packages."

All-inclusive rotable support contracts are also used, however, for larger fleets. For example, easyJet's A320 family fleet of about 300 aircraft is supported by AJW.

Specialist providers often offer packages for a select number of aircraft types, or sometimes just one.

Spairliners is a joint venture set up by Air France Industries KLM Engineering & Maintenance and Lufthansa Technik to provide specialist rotable support for the A380. While the aircraft type has recently been phased out of service by Air France and is being stored long-term by Lufthansa, Spairliners continues to support other operators they have agreements with. Since 2013 the company has been supporting the Embraer E-Jet E-170/-175 and E-190/-195. It has excessive inventory to support its more than 16 exclusive customers around the world and has become a leading component support provider in Europe for the Embraer E-Jet family.

"We support several carriers for the E-Jets, and our two largest supported fleets are KLM Cityhopper and HOP!, with 49 and 32 aircraft. We also support several other airlines with a range of fleet sizes. These include Lufthansa Cityline, Austrian, Air Dolomiti, Kenya Airways, Royal Jordanian and Austral. We also have multiple pool locations worldwide to serve our international customer base. Our most recent addition is a pool location at Miami International airport to serve a group of airlines in that region. We cover more than 1,400 P/Ns for the E-Jets and more than 2,000 P/N for the A380, and so can provide almost every rotable and repairable on these aircraft types. We provide customised solutions for airlines from all-inclusive PBH or fixed-price packages to single event or AOG support." says Cornelius Dalm, head of sales, account management and marketing, Spairliners.

AJW was one of the first specialist parts providers to pioneer, develop and offer all-inclusive rotable support packages to airlines. AJW's support programmes are mainly for the Airbus and Boeing narrowbody families. This includes support for easyJet's fleet of 300 A320 family types. "We also have a significant presence in the widebody market, especially the A330, 767 and 777. AJW's overall rotable stocks mean it can support about 1,000 aircraft.

AJW often supports small start-up carriers with a single fleet type, as well as larger carriers with multiple fleet types. AJW based its support packages around air transport association (ATA) chapters, that relate to different aircraft systems.

Air France Industries KLM Engineering & Maintenance (AFI KLM E&M) can support a range of aircraft types, since its two parent airlines operate large fleets of Airbus and Boeing types. It can provide rotables for the 737 Classic, 737NG, 737 MAX, A320 current engine option (ceo), A320 new engine option (neo), A330, A330neo, A340, A350, 747, 757, 767, 777 and 787 family types. About 55% of the aircraft it supports are new generation types.

AFI KLM E&M has many different airline customers, ranging from those operating just a single aircraft to several hundred. They all benefit from the maintenance & engineering (M&E) departments of its partner airlines and their operational experience, and the economies of scale provided by the large number of aircraft and fleet types. "These provide savings from accessing the pool of common rotables that we share with the customer airlines. This is mainly due to the effects of scale of large fleets," explains Jean-Luc Fattelay, vice president of components customer business at AFI KLM E&M. "We also believe that we can guarantee high operational performance. We use a global network of logistic and repair shops around the world, and so can deal with urgent customer requests."

Inventory assessment

The assessment of the total number of rotables required to support a particular

fleet of a certain size in an airline's operation is a main factor influencing the rate paid by the airline for the service.

Quantity of stock for each P/N clearly depends on macro factors, such as the number of different routes and the complexity of the route network the fleet operates, the fleet size and the average component removal rates. The spread or variation in removal rates and the standard deviation also have an influence.

The industry still generally operates in a reactive way to component malfunction or failure and subsequent removal. It is this random nature of removals that creates most of the difficulties in managing rotables, and causes aircraft-on-ground (AOG) situations when 'no-go' items fail or malfunction. The situation is worse when an aircraft is at an outstation.

Accurate removal interval data across an entire fleet helps simplify how to determine what rotable stock is required, by tracking components with the airline's M&E IT system.

"We support about 180 aircraft with these programmes, and so have access to a lot of supporting technical data from the airlines but also from the repair shop," says Dalm. "This includes several categories of customer data such as removal interval, removal reason, flown flight hours and cycles that come from the customers' M&E systems and which helps us to calculate their inventory requirements. We process the data with our in-house system we developed together with our partner Lokad. This is part of the inventory software 'SPACE' we have designed."

Software supplier ARMAC in Ireland uses its RIOsys platform to assess inventory requirements from a wide range of data, including: component removal and reliability data; component classification with respect to criticality; the cost of each P/N; aircraft configuration; fleet age; and its rate of utilisation.

RIOsys aims to optimise the inventory required, and its capabilities include producing alerts when stock levels of a particular P/N are getting low. The system is used to constantly re-assess and optimise the stock levels required. This is necessary because airlines are constantly making changes to their fleets and operation.

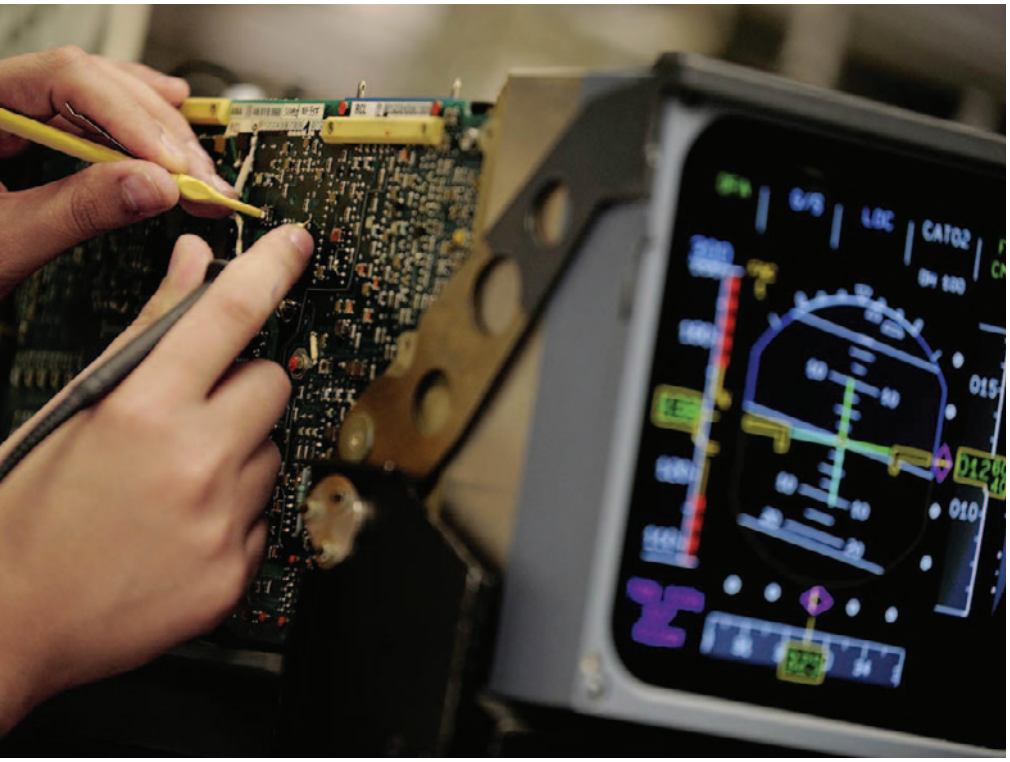
The quality of data used to assess the inventory needed improves with operational experience, especially with a new or young fleet. Attention to detail also helps to fine-tune the assessment of inventory. This will include splitting P/Ns into sub-fleets, by using different dash numbers of the same P/N. Modification of an inventory to using a later dash number of a P/N, or a different P/N altogether will result in the non-use of older components. It is therefore important to continually re-assess the inventory required to support a fleet so that unused components could be disposed of or identified as being surplus to requirements.

Another important factor is changing a fleet or aircraft type on a particular route, meaning that the inventory for that aircraft type is no longer required at the particular outstation. Again, such surplus inventory can be sold or relocated.

The ultimate aim is to establish the quantity of inventory required at the customer airline's homebase and its larger outstations, and then how much inventory it will need to access in the pool. A 'fill rate' of 100% is not possible without the quantity of inventory held being excessive. "That sort of level is cost-prohibitive, because the number of units held will have to increase exponentially from a fill rate of say 95%," says Malecha. "It therefore means that some AOGs are inevitable. The provider needs to decide with the airline how to split the stock between its homebases and outstations, and between the home stock and the access pool. The fill rate of each stock is then decided."

The service levels airlines usually require are 90-98%, depending on the fleet or individual P/N.

"AJW usually asks for a fit list from the airline, as well as any removal data if they have it," says Tom De Geytere, chief sales officer at AJW. "We often ask for



The logistics of transport, testing, repair and managing all associated documentation is another high cost management process that is covered in a predictable and manageable rate in all-inclusive support programmes. Some airlines choose to use just this element from specialist support providers, and retain ownership of their rotable stocks.

three years' worth of data, but recognise that this is not always available. We therefore use our own data for initial stock evaluation. We are now developing an in-house inventory optimisation solution that provides granular detail."

Airline removal data

The rotable support providers themselves have a large database of data for each component P/N and its different dash numbers. The effect of factors, such as average flight cycle length and operating environment, can also be examined to ascertain any correlation with removal intervals and failure rates.

In addition, airlines can supply their support providers with more data. This of course relies on cooperation between rotable support providers and airlines, with the latter allowing their removal data to be used in aggregate with other airlines' data to provide a large source to work from. "Most of our airline support contracts for rotables are on a long-term basis. This puts us in a position to follow component removals and fleet utilisation, which allows us to build up data for use in Big Data (BD) analysis and predictive maintenance solutions," says Fattelay.

Big Data & Predictives

The random nature of component malfunctions, and the difficulties and expense that they cause, can be minimised or even avoided through BD analytics and predictive maintenance, or 'Predictives'.

Until BD and Predictives were developed, the only indication a flightcrew had of an impending part malfunction came from the built-in test equipment (BITE) and the central maintenance computer (CMC) fault code displayed on a screen in the flightdeck. The appearance of a CMC code indicated that a component malfunction had already happened, or that a system was malfunctioning. It did not indicate the exact component that was causing the issue.

Therefore in most cases flightcrews and line maintenance mechanics received little warning that a failure was about to occur. The main principle of BD and Predictives is that there is a larger number of sensors on components and systems compared to the number used for BITE and to generate fault codes.

This increased number of sensors allows more parameters in a large number of places within a component or system to be used, so that a lot of information on a component's health can be acquired. With the appropriate algorithms written to analyse the data, the location of a malfunction can be accurately determined. Moreover, the right algorithm analysing the data can be used to accurately predict the rate at which a part's performance is deteriorating. This health data therefore provides information of sufficient quality for the removal of a component, which is normally maintained on an on-condition basis, to be planned. The main benefits of this are the avoidance of expensive AOG situations, and sufficient time to prepare for the part's removal or maintenance, including time to transport it. This is in contrast to the emergency nature of dealing with an AOG event, and the need for an airline's M&E department to react to an unexpected event.

Several systems have been developed for BD and Predictives, and these are now being used in operation. AJW, for example, has a modern cloud-native architecture designed to process high volumes of complex data. "We leverage Snowflake as our primary database partner, perform our data extractions, transformations, and loads (referred to as ETL) with Matillion and Python, and visualisation tools. The platform allows our data and analytics engineers to deliver robust products to the business, our customers, and our vendor base as a combination of pre-packaged products, as well as self-service datasets.

"BD has therefore allowed us to offer an in-house inventory modelling software that delivers the optimum level of stock to de-risk the operation, while reducing inventory levels," adds De Geytere. "Our biggest airline customers are using BD in the predictive maintenance environment to reduce operational risk."

AFI KLM E&M uses its PROGNOS system for BD analytics and Predictives services. "We combined our experience of operating an airline and a maintenance organisation with the skills we developed producing this new field of BD and probabilistic models to develop PROGNOS for inventory. Managing inventory needs more than just a 'Poisson law', and average or median inputs to optimise rotable inventory," says Fattelay. "We use BD for various inventory types, including rotables. We have seen the benefit in terms of capital expenditure, and the use rate of each component (in terms of consumption versus cost of procurement). It also provides an easy way to make decisions and control our activities."

AFI KLM E&M is also using PROGNOS for those airline customers to which it provides rotable support. It already has agreements with several carriers in the Asia Pacific that operate A320 and 787 fleets, and is negotiating with a North American 777 freight operator.

"With PROGNOS, we can detect a likely failure up to 50 flights ahead, and so depending on the aircraft's utilisation, we can have enough time ahead to schedule the removal and rectification," continues Fattelay. "By setting alerts for component removals 30-50 flights before a fault happens, we have reduced AOG events by more than 95%. Also, out of several hundred component removals there were zero 'no fault found' (NFF) incidents. We

have also decreased the number of parts held on our airlines' minimum equipment list (MEL) by 50% since implementing PROGNOS.

"We have developed a fully web-based solution, which only requires the airline customer to have an internet connection to access PROGNOS for inventory assessment, and have optimised stocks and the supply chain. We can assess their inventory needs for supply chain support, with an airline operational view," adds Fattelay. "We have used PROGNOS to perform complex statistical analysis to produce simulations and prioritised investment recommendations. This can also include making the best investment and divestment decisions, optimising pool distribution, and improving inventory availability."

Spairliners has been investigating the use of BD and Predictives for two years. "Not only do we clearly use historic data to predict inventory requirements, but we also analyse removal patterns and work closely with our repair shops to define algorithms to predict future removals. The goal is to remove a part shortly before it actually fails to keep repair costs as low as possible and to avoid flight disruptions by doing component removal in a scheduled way," says Dalm. "This requires a complex set up. It needs live component behaviour data from the airline to monitor the performance of the parts as well as the correct understanding of the data.

"If a component is removed as a result of using Predictives, then a normal test on the test bench could be innocuous but when it is examined in detail, developing or existing damage can normally be found somewhere inside it," adds Dalm. Spairliners has used BD and Predictives with one of its customers for 18 months.

"Our customer uses BD to trigger certain component removals," says François de Larambergue, head of engineering, AOG desk & procurement at Spairliners. "The repair shop provides the detailed inspection and the actual cause of the removal. As a result, more components are now removed on a scheduled basis, and can be supplied in advance to the appropriate location. This results in smoother operation for the airline, which has a reduced number of delays and cancellations due to AOG events and lower repair costs due to less serious damage to components. We have yet, however, to see fewer component removals, but removals are no longer the main concern. The system is now more scheduled, and there is less urgency. This alone has huge financial implications. It may be possible to reduce the inventory in the long-term."

Spairliners frequently re-assesses the stock of inventory required to support a fleet. "Each customer's homebase stock is re-calculated annually, while Spairliners' own pool stock, which we hold to support all our customers, is continuously assessed on a live basis," says de Larambergue.

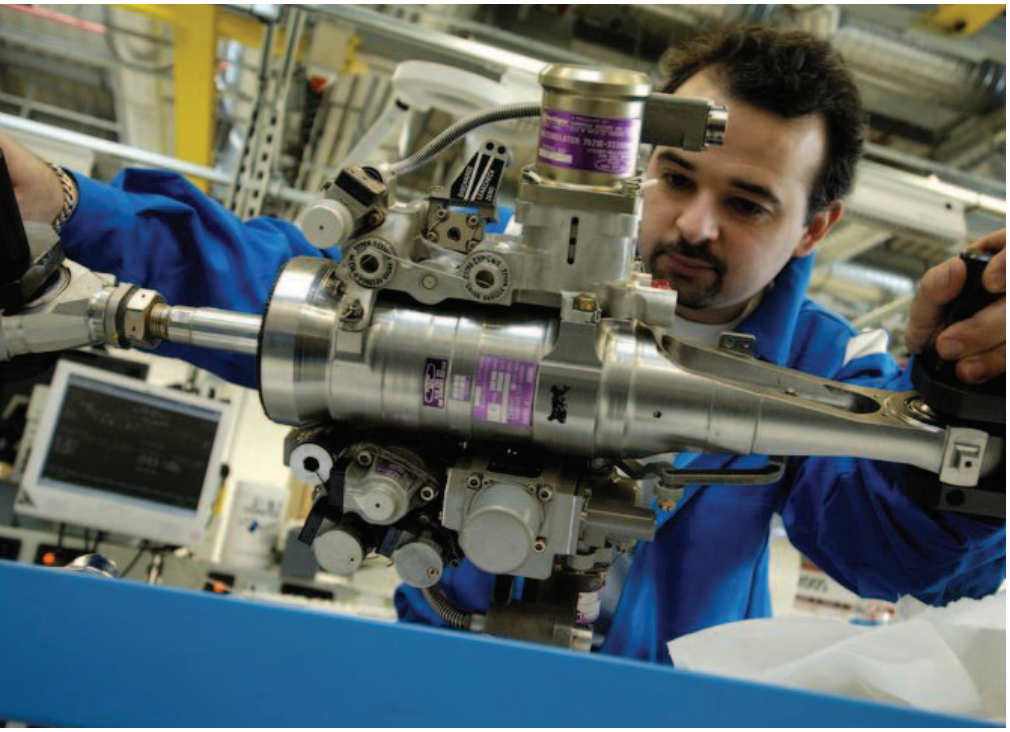
In addition to information relating to historic removal intervals and detailed data provided from BD analytics, electronic technical logs (ETLs) can be used to enhance the prediction of component and system malfunctions. "If we get live data from the aircraft it can aid in detecting the upcoming failure. In this way the ETL is an enabler," says de Larambergue. "That is, it provides an advance warning, and potentially while in flight, we can already start acting on resolving it."

Data interchange

The use of BD and Predictives was clearly intended to make inventory management a more exact process, and remove much of the activity around reacting to component failures. The BD and Predictives process starts with downloading and processing the large volumes of component and system health data from each aircraft.

The first step for a third-party rotable support provider is therefore to acquire this data from the customer airline. This requires an interface between the IT systems of the related parties.

As an example, AFI KLM E&M has



The technology of Big Data analytics and Predictive maintenance has added a dimension to managing rotables by making it possible to plan removals, rather than component failures occurring on a random basis. This has resulted in a large reduction in AOG events for airlines that use this system.

implemented interfaces with several customers. In the case of some operators, M&E system Swiss AMOS has been interfaced using Web services. This uses XML messages to cover the pooling service and the repair management process. "We have one operator that has integrated its SAP system using dedicated Web services. There are also several other integrations, with systems such as IFS Aerospace's Maintenix and Airbus Apsys's Amasis. This communication can be implemented with IT systems that are compliant with Spec 2000. This transfer of data in both directions can be automated," says Emmanuel Lazaroo, EMpower supply chain project manager at AFI KLM E&M.

AJW has an extensive IT system, which has digital engineering capability with mature interfaces with its own enterprise resource planning (ERP) system, Quantum, and the IT systems of its customers. AJW's integration capability is mostly developed with Swiss AMOS and SAP. It is also expanding the number of systems it interfaces with to capture all primary airline systems.

Similarly, Lufthansa Technik has developed its Aviatar system to provide BD and Predictives services to airline customers. Aviatar's self-learning system algorithm has to be regularly fed with data from its customers, including every change in an airline's flight schedule, modifications made to components, and other related data to optimise rotable stocks.

System disadvantages

While BD and Predictives are clearly intended to increase the portion of planned component removals, the practice of removing components before they have failed does create some new problems. "A main issue is that 70% of all P/Ns will have three or fewer removals per aircraft per year," says Michael Armstrong, chief executive officer at ARMAC Systems. "When this is taken into account together with the number installed on each aircraft and the size of each fleet, this means there is not a particularly large sample size for each component from which to produce a detailed level of data.

"Ideally, what is required is a control group of components to get removal intervals and failure rates for when they actually fail," continues Armstrong. "That is, a control group of components would provide some data and indication of what each P/N's actual mean time between failure (MTBF) is. This is different to the mean time between removal (MTBR). The MTBR for components managed with Predictives will include mainly components that have been removed before they have failed. Without a control group, it will not be clear how big the difference is between MTBF and MTBR. If it was predicted that a component was going to fail, how can it be validated that it was really going to fail?

"Another way of expressing this is that Predictives mean that a soft removal interval has been created, and these cannot be validated as being too short or about right unless there is a control group of P/Ns providing real MTBF information," adds Armstrong. "It is of course difficult to create a group of control P/Ns to provide this information. The main problem with aircraft components is that there is a large number of different P/Ns, because of the complexity of aircraft and their systems, and these have a relatively small number of removals. This can mean that you do not have a large number of failures if you have correctly identified the failure in the part. The identification of the failure has to be matched with the repair report.

"The irony is that there may not be enough data to provide a predictive maintenance system," adds Armstrong. "Many airlines only have one or two spare units per P/N, and there is a strong possibility that one of these spare units will be used for a predicted failure and planned removal. This exposes the airline to having a real failure and an AOG situation at a later time. An airline can be too eager to replace a part because the predictives system recommends it, which can drive up the number of component removals.

"We eventually want to integrate our rotable management software with predictives models, and we want to create predictive demand. The supply chain part of the system could be enhanced later by using data to feed back into the predictive maintenance process to facilitate the scheduling of the replacement," continues Armstrong. "It would therefore be possible to holistically optimise the support model. The main issue against predictives is that modern aircraft types have a smaller number of highly reliable parts. This is especially the case with loadable software aircraft parts (LSAPs). Many of the hydromechanical components on aircraft have been replaced with electronic units."

Bespoke services

Malecha makes the point that integration with the airline by the support provider is also required to enhance a service. "This is because the service provider needs to understand an airline's operation at a day-to-day level. An airline's requirements cannot be completely understood by analysing data alone, or managing the support programme through an IT platform," says Malecha. "Kellstrom provides on-site support to an airline. We manage the balance of inventory between its operational and maintenance bases. We need to have a good understanding of an airline's operations, and why a part has been removed. There are usually several reasons that could lead to a high rate of NFF, for example, and we need to examine all possibilities. This is easier if we are on site." AC