There is limited IT capability for managing engines with respect to optimising removal intervals, minimising spare engine requirements, managing engines for lease returns and optimising maintenance costs over an extended period. The available systems are reviewed.

IT systems to manage & optimise engine maintenance

Maintenance information technology (IT) systems are so highly developed that maintenance events can be planned and analysed in detail, taking into account all resources, while cost data for labour, materials and sub-contracted work can be recorded accurately for all elements of maintenance. Airlines are increasingly demanding IT systems that can analyse all their maintenance costs. While there is a high level of functionality to monitor and analyse airframe- and component-related maintenance costs, there is little capability to provide the same level of analysis for engine-related maintenance costs.

Engine maintenance

Airlines have several choices for managing engine maintenance.

The traditional in-house method has declined in use, particularly over the past 30 years. Many airlines still have engine shops to carry out in-house maintenance, and perform third-party work for other carriers. In-house maintenance still sub-contracts some work to specialist shops, particularly for component repairs.

It is mainly larger flag carriers and the US majors that still use in-house maintenance, managing several hundred, or even thousands of, engines.

Airlines' engineering departments are responsible for managing engines and their maintenance, as well as performing it. This involves monitoring the health of engines during operation, predicting, planning and budgeting their removals for maintenance, planning shop-visit workscopes, planning the provisioning of spare engines, managing leased engines, and optimising engine maintenance costs.

The growth in sub-contracted engine maintenance during the 1980s and 1990s was due mainly to independent engine shops, but some sub-contracted engine maintenance still has to be performed by specialist shops. Independent shops tend to charge on a time-and-material basis.

Airlines still retain and perform the engine management functions when sub-contracting engine maintenance to independent shops.

Since the mid-1990s, manufacturers have gained a large share of the overall engine maintenance market. Original equipment manufacturers (OEMs) tend to provide airlines with fixed-rate-per-engine-flight-hour (EFH) programmes or contracts to eliminate the unpredictability of maintenance performed in-house, or charged for on a time-and-material basis.

Using fixed-rate-per-hour maintenance contracts involves engine management with respect to planning engine removals and shop visit workscopes, and optimising engine maintenance costs. These protect the airline from unexpected budget overruns and remove the overhead of forecasting engine shop visits.

Airline requirements

The IT functionality for managing engines therefore needs to be more detailed for in-house, and time-and-material maintenance, than it is for engines managed under a contract with a fixed rate per EFH or engine flight cycle (EFC). Many airlines using fixed-rate-per EFH/EFC contracts are still interested in implementing a removal and staggered plan that is beneficial to their operation and engine lease obligations, which may conflict with the plan proposed by the maintenance provider.

Airlines have comprehensive needs for managing the maintenance of their engine fleets, which can often number several hundred units. First, engine health monitoring (EHM) data must be recorded and analysed to predict when each engine's performance parameters, such as exhaust gas temperature (EGT) margin, will force a removal for a shop visit.

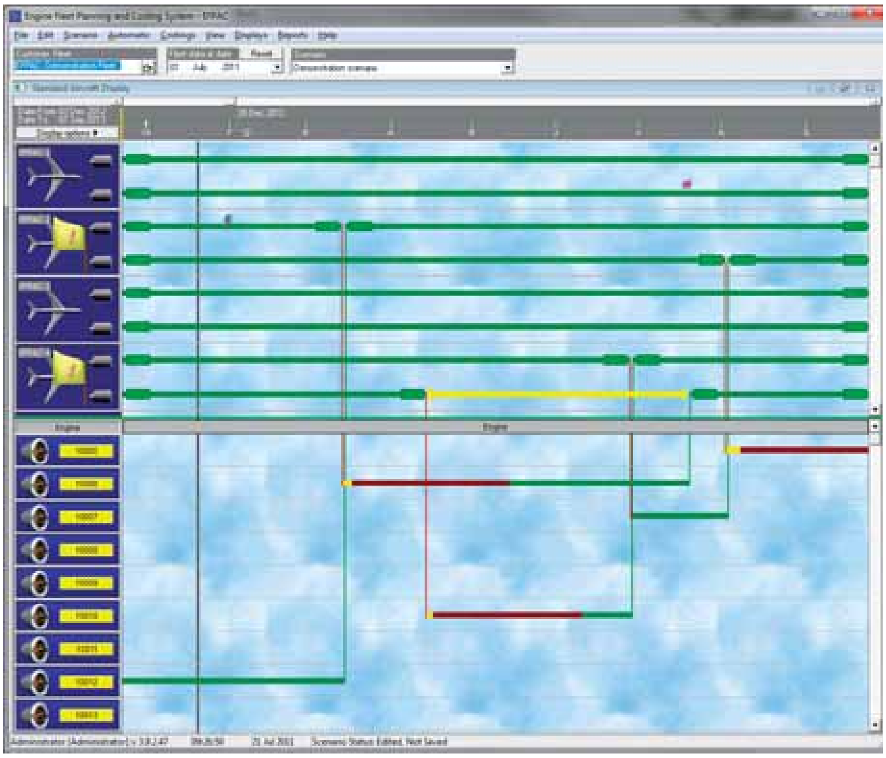
Other parameters that cause engine removals include: the remaining life, in EFC, of life-limited parts (LLPs); airworthiness directives (ADs) and service bulletins (SBs); and other practical constraints such as engine shop capacity and spare engine availability.

Engine removals must be optimised in terms of engine performance and maintenance criteria, and compromise with other constraints. The objective is to achieve the lowest possible engine maintenance cost during the ownership period by: managing lease re-delivery requirements; maximising on-wing life and the use of LLP life limits; reducing the number of removals and having a manageable and even spread of engine shop-visit activity; and minimising the number of spare engines needed to support the fleet.

Airline engineering departments need to accurately predict engine maintenance costs by defining workscopes, parts requirements, maintenance reserve accruals and lease re-delivery requirements and compensations. The maintenance status of engines has to be monitored continuously, and planned removal timings and workscopes must be updated and regularly reassessed.

Shop-visit workscopes and engine maintenance status also affect subsequent removal intervals. The removal intervals and workscopes of several successive shop visits are the main elements of optimising engine maintenance costs per EFH or per EFC over a prolonged period.

The data required are kept in different systems and managed by separate departments, which makes an integrated analysis difficult. While it is possible to manually carry out these management tasks for one or a few engines with simple tools such as an Excel spreadsheet, bigger fleets need a more sophisticated tool.



One of EFPAC's engine management functions is to coordinate the removal of engines, shop visits, and engine installations as part of the process of optimising engine removal intervals.

Variables

Airlines therefore need IT systems that can use all the data for variables that affect engine maintenance and the related costs. These variables can be divided into those that relate to engine maintenance condition and operational performance, and those that relate to operational and practical constraints.

Operational performance variables include engine operating parameters. The key parameter that receives the most attention is EGT and EGT margin. EGT gradually climbs as engine hardware deteriorates during operation. These data have to be collected and plotted to predict the time at which the EGT will reach its limit, and so force an engine removal. EGT climbs in relation to accumulated EFH and EFC, so EGT data have to be taken or sent from the aircraft during or after each flight, and a plan of future aircraft usage has to be prepared.

Other engine performance parameters include engine vibration, fuel flow and oil consumption. This information has to be collected or sent from the aircraft on a regular basis, and plotted and analysed. Not only does the rate at which the raw data change indicate probable timing of engine removals, but also the ratio of certain parameters affects the rate of performance deterioration.

Other engine operating performance and maintenance condition parameters include: the engine's total accumulated EFH and EFC since new; the EFH and EFC accumulated since the last shop visit; LLP life limits and accumulated time; and the airworthiness directives (ADs) and service bulletins (SBs) that apply to each particular engine.

Specific data on maintenance status is also provided, including the EFH and EFC since new, or repair of all main turbomachinery components, such as the high pressure turbine (HPT) blades. Algorithms predict the rate at which new or repaired blades and vanes will deteriorate in relation to accumulated EFH and EFC, and other parameters such as EFH:EFC ratio.

Practical considerations include the date and length of airframe maintenance events, since the aircraft must be on the ground long enough to remove an engine. Although it is desirable to remove engines for shop visits when the maximum possible removal interval has been achieved, this may be prevented by the need to stagger engine removals at a steady rate. There is also the issue of the availability of spare engines. Many engines are now leased, and lease return conditions specify the engine is returned in a particular maintenance condition. Return conditions relating to a particular maintenance status often mean removing the engine at a specific time to achieve a certain maintenance status, or to perform maintenance to meet return conditions.

All these factors affect the timing of engine removals. The number of variables means that optimising engine management and maintenance costs is impossible without some kind of IT system. Moreover, accurately predicting the timing of engine shop visits and their workscopes means that fewer shop visits will be prolonged by a lack of parts due to poor planning. This will lead to savings through lower spare engine requirements.

IT systems

Much of the engine management process starts with collecting EHM and engine performance data from the aircraft and engine.

The time-consuming system of recording EHM data and physically entering it into a database for manual analysis has been replaced with automated systems. EHM systems and services are now virtually all provided by OEMs, coupled with fixed-rate-per-hour maintenance contracts. EHM is also a necessary element for the OEMs to provide airlines with technical support assistance, since EHM data is used to diagnose problems with engines.

With automated EHM systems, data can also be transmitted in real time to ground stations provided the aircraft is equipped with aircraft crew and reporting system (ACARS) equipment. These EHM data can then automatically be populated into the airline's maintenance and engineering (M&E) IT system. Aircraft not equipped can still store data, which are downloaded by a mechanic after each flight, and then uploaded manually. The data can be trended and analysed using algorithms as part of the engine management and removal planning process, which is also an EHM service provided by the OEMs.

General Electric (GE), for example, offers its myEngines product, which is a suite of eight main applications that include an EHM service. The applications are: Overhaul, Health, Config, Ops, Materials, Fleet, Fuel and TrueEngine.

The Overhaul application manages engines in the shop-visit process.

The Fuel application helps airlines save fuel by monitoring fuel burn.

The Health application is the EHM software. GE says it currently monitors 83% of the GE and CFMI engines in operation today. Airlines using GE's EHM service send data to GE's aircraft operations centre (AOC) in Cincinnati. These data are monitored in real time during three particular phases of the flight: take-off, cruise and landing.

The Health application records and trends the data, and has alerts built-in to notify airlines when a shift in certain parameters occurs. "A customer notification report is then issued," says Huntley Myrie, service solutions manager at GE Aviation. "This is used with the algorithms in the software to analyse the shift in engine performance, so that airlines can be alerted to impending problems with individual engines, and be ready to exchange an engine at short notice. The algorithms indicate what is wrong with an engine. We can advise customers on what to do following particular events."

Smaller shifts in performance parameters may not trigger alerts. "These still need to be analysed, to see if the engine is performing normally," says Myrie. "A small blip in a particular parameter may indicate that a particular type of deterioration is occurring. Analysing these small blips can prevent an unscheduled removal.

"Overall, trending and analysing all the engine's parameters helps predict the timing of engine removals," continues Myrie. "The software also automatically records EFH and EFC data as part of this predictive process."

Rolls-Royce (RR) wholly-owned subsidiary Optimised Systems and Solutions (OSyS) has operations centres to receive, monitor and analyse EHM data. RR engines have transducers that analyse the engine's performance, while sensors monitor temperatures, pressures, shaft rotational speeds, vibration levels, and other parameters. The data give several snapshot reports at specific flight conditions such as take-off, climb, cruise and engine shutdown. Exceedence reports are also made.

The EHM data are transmitted via ACARS to OSyS's network of ground stations. The data can then be analysed, or fed into an M&E system.

M&E systems have been designed to keep track of aircraft configuration, maintenance programmes, aircraft flight hours and cycles, and an itinerary of airframe maintenance events that are coming due, plan airframe checks, and record shop visit inputs. This is the same functionality required to manage engines and optimise maintenance costs. Most M&E core systems do not offer this, partly because many engines are managed and maintained at a fixed rate per EFH. A lot of the engine fleet is still maintained in-house or sub-contracted on a time-and-material basis. Engines being managed this way require some dedicated system functionality, which is provided by point solutions for this specialist function.

EFPAC

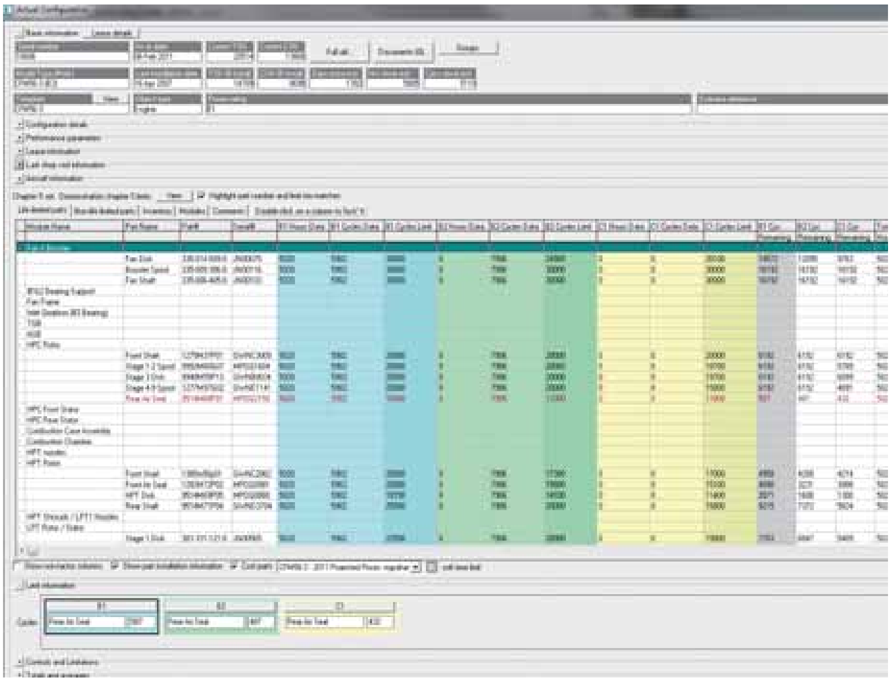
Point solution EFPAC was originally developed by Total Engine Support (TES), but has since been acquired by AerData. It is the only available point solution for engine planning and financial management, and uses all the types of data that affect engine maintenance costs as described. AerData's products are now used extensively, with more than 60 customers under contract.

In order to become efficient in use without the worries of continuously updating the information, engine cost management systems need to interface with the user's existing core maintenance system. "At AerData we do not want the airline to have to manually update information that is already available somewhere in their operation," says Jaap van Dijk, director of sales and marketing at AerData. "The easy interfacing of EFPAC with other applications, and bringing across data from other sources was part of the design concept from the beginning. EFPAC also helps in the communication between the financial departments and engineering in terms of optimising the best removal plan and maintenance budgets on a daily basis."

EFPAC can automatically capture data from an airline's operations IT system, the M&E systems and the EHM systems.

EFPAC's main feature is that, taking into account the several dozen variables that affect engine removal timing and maintenance cost inputs, it analyses a large number of scenarios with respect to the removal timing of each engine in the fleet. These scenarios are determined using all operational, maintenance, technical and financial data described.

These provide the user with a large number of engine management options, and the costs of each are calculated. EFPAC achieves this by analysing a large number of options for removal timings for each engine and presenting these as different flags on intuitive graphical displays. The system calculates the workscope an engine requires after a particular removal interval, by taking



The process of optimising engine management and maintenance costs requires a lot of data feeds from various sources. One important element is the tracking of engine LLPs. EFPAC can provide a summary sheet of LLPs for each engine at any time, indicating the remaining life for each part.

into consideration the total time since new and maintenance status. The cost of the shop visit can also be determined. EFPAC can reassess the workscope an engine requires when the user manually changes the removal interval. This is the basis for optimising maintenance costs.

Engine management

Engine management can be represented graphically in several ways to the user. EFPAC has a horizontal timeline for each engine, and specific events are superimposed as icons on the timeline. These flags can be colour-coded. Different colours are used for EGT margin and LLP expiry, planned engine removals, shop visits and lease returns. Airframe maintenance events can also be superimposed on the timeline for each engine, so that engine removals can be planned appropriately. The positioning of these events is adjusted as changes take place to planned aircraft utilisation or other operational factors.

Ramco Systems' Series 5.0 M&E core system provides a similar functionality for engine management. Jon Stone, director product market management at Ramco, explains that the system considers accumulated EFH and EFC, future EFH and EFC based on flight schedules, and remaining LLP lives to predict removal dates for each engine. Each engine is displayed on a horizontal time line. The user can drill down into details of removal factors. Like EFPAC, Ramco Series 5.0 provides a macro view of the engines for each aircraft type in the user's fleet. It displays all maintenance events coming due.

Another system, SAP from HCL-Axon, predicts the timing of maintenance events coming due by tracking LLPs, ADs and other items with fixed lives. The system does not, however, automatically tell the user when to remove an engine by predicting when certain performance parameters will get close to or beyond their limits. Instead it requires an engineer to manually monitor on-condition parameters, and manually raise a notification that an engine needs removing. The system can, however, be programmed to automatically send the user notifications that certain parameters are getting close to particular limits. This means that performance data have to be manually monitored.

EFPAC also provides data on engine number and particular airframe, variant and thrust rating, and accumulated EFH and EFC. EFPAC puts these data into an engine location report, which summarises the engine fleet in terms of: each engine's location; the shortest EFC remaining on the LLPs installed in the engine; parts tracking; AD and SB tracking; lease details; EHM data; and a history of the engines' shop visits.

EFPAC has multiple display options, while a popular display for larger fleets is the Shop Visit display, where each spare engine shows which engine it is replacing at planned shop visits. EFPAC also records every engine's operational and maintenance history: dates; total FH and FC since new; removals; installations; shop visits; lease returns; and workscope details, including the parts repaired, replaced and installed in each module so that the parts are fully traceable. It also calculates the required workscope and its associated cost when the removal interval or another parameter is changed. EFPAC can analyse the LLPs in the engine and the accumulated and remaining FH and FC at each event, and at any date.

EFPAC's planning function not only includes a timeline chart and symbols for engine and airframe events, but also manages the installation of engines on the next aircraft by determining the length of each shop visit, and tracking which aircraft is having an engine removed at the time the engine is due to finish its shop visit, and is therefore available to accept the engine. The user can therefore manually change the engine removal, for example, by bringing it forward to an earlier date, so that when it finishes the shop visit at the expected time it is available for an aircraft that needs it because one of its engines has had to be removed at a similar time. The removal plan therefore takes into account the needs of the whole fleet as a first step to optimising the amount of spare engine inventory the user requires. Although this results in the removal intervals of some engines being compromised, it is overall financially beneficial because it reduces the cost of having a larger number of spare engines to support the fleet. EFPAC is able to calculate the workscopes and shop visit costs for a large number of different engine fleet removal plans.

Each removal plan is presented graphically by EFPAC. Each engine shop visit is represented by a rectangle. The details of each engine are displayed in each box. Successive shop visits are therefore displayed by several rectangles placed end-to-end in a timeline. EFPAC displays coloured flags on the rectangle to indicate the cause of removal, for example, loss of EGT margin, LLP expiry and lease return. The user then drills down to get the maintenance status of the engine, and compare it to lease return conditions.

Airlines usually require that no more than a certain number of engines are removed for maintenance at any one time. A limit of five engines in maintenance at the same time will be represented by five timelines. Additional timelines of rectangles will indicate that a cluster of engine removals is expected during a particular period. Engine shop-visit dates can therefore be manually adjusted, and usually brought forward, to reduce the peaks in engine shop-visit activity. An important issue is which engines should be brought forward. The system calculates the different cost implications for moving the removal date. EFPAC, however, includes optimisation functions that take away the labour part of manually planning engines by calculating the cheapest solution for the airline for bringing engine removals forward, and to meet constraints such as a given number of spares.

The removal data and information for each engine can also be shown in a table, with a removal reason, a brief workscope description, and estimated cost.

Another aspect of engine management is tracking LLPs. This requires the serial number of each installed LLP to be entered into the system, the exact time of installation of each part, the EFC accumulated at installation, and the autopopulation of EFC data into EFPAC from the flight operations department following aircraft operations. Most of these data have to be fed from the core M&E system. EFPAC then recalculates the EFC remaining following each flight. The LLPs with the shortest lives are represented on the graphical timeline for each engine. The replacement cost of each LLP can also be fed into EFPAC, which will be used in workscope cost estimates. LLP data are further used to forecast or determine at which shop visits they will need to be replaced. This will be reassessed each time the engine removal pattern is modified or changed, for example, because of changes in planned utilisation or EFH:EFC ratio.

LLP lives can be affected by ADs and SBs, since they can force engine removals earlier than expected, for example. The engineering module of the core M&E system will have this information, which is then fed into EFPAC.

EFPAC also generates a list of engine removals, and several main aspects of management information, including removal date, EFH and EFC, workscope, and estimated cost. The information can provide a cashflow forecast to be compared with the engine removal plan.

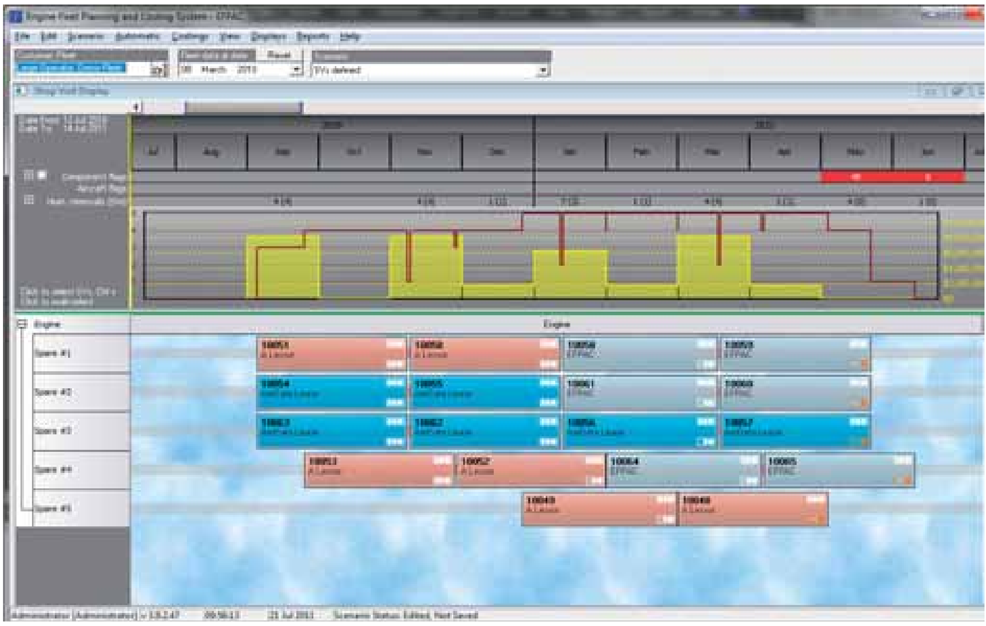
Another useful engine management function is an aircraft and engine status overview, particularly for lessors that like to be regularly informed of their engines' maintenance status. The summary data for each engine include: EFH and EFC since new and last shop visit; lease reserves that have been accumulated; lease return date; predictions with respect to timing of removals, LLP expiry and EGT margin expiry; and forecast shop-visit workscope and associated cost. Details of reserves and shop-visit costs are split between the shop visit and LLPs allowing analysis of a possible shortfall in the cost of the shop visit. The system also compares lease return conditions with forecast maintenance status and condition, so that engines can be removed early to avoid penalties or additional maintenance expenditure.

Engine optimisation

Planning the timing of engine removals is the first stage of optimising engine management and maintenance costs. This includes the costs associated with spare engine provisioning and leasing. The EHM data, future aircraft utilisation and LLP data fed into EFPAC will indicate possible engine removal timings. The user then considers the number of engines it can have in maintenance at the same time, and the coordination of engine removals with serviceable engines coming out of the shop to generate an engine removal plan.

EFPAC computes and stores a large number of engine removal plan scenarios, calculates the workscopes for each engine, and computes the associated cost. An issue with this is that the workscope at the engine's first removal will be determined by the removal interval, EFH:EFC ratio, engine de-rate and other operational factors. Workscopes tend to increase as removal intervals lengthen, because the percentage of parts that is repaired reduces and the percentage that is replaced increases with longer removal intervals. The workscope cost can increase in proportion with the removal interval to a point, and then rise at increasingly higher rates thereafter, because the percentage of parts that has to be replaced increases exponentially as the engine's physical condition starts to deteriorate at increasingly faster rates.

The resulting shop-visit cost amortised over the removal interval therefore generally declines as the removal interval increases, although the cost per EFH can rise again as the shop-visit workscope rises sharply for the longest removal intervals. The trend of maintenance costs per EFH against removal interval therefore follows a U-curve relationship. While it may initially appear desirable to remove engines at the interval that corresponds to the lowest point of the U-curve, van Dijk says there are several reasons why it is not. The first is that the need to manage all engines in a fleet inevitably results in engine removals being brought forward and intervals shortened, with the result that costs per EFH increase up the left side the U-curve. Van Dijk comments that engine managers require insight in all cost contributing aspects on order to arrive at a removal plan acceptable for the airline's operation and at the lowest overall cost.



One process automatically performed by EFPAC is the creation and management of an even flow of engine removals. Should a cluster of engine removals arise, then EFPAC can provide the user with several options for a revised removal plan, and compute the costs of each one.

Another problem is that the first shop-visit workscope will affect the second removal interval and workscope. The higher the percentage of parts that is replaced, as a result of a long first removal interval, the longer will be the second removal interval. This will affect cost per EFH, as will the workscope of the second shop visit. When a workscope or removal date is changed, the system will indicate how long an engine can remain on-wing for the subsequent interval. The effects of removal intervals and shop visit workscopes over three or four intervals have to be considered to optimise costs per EFH over the long term.

The second element of maintenance costs is how LLPs' life limits fit in with the need to optimise several successive engine removal intervals and shop-visit workscopes.

For engines operating at short EFH:EFC ratios, for example, shortening removal intervals is likely to result in many LLPs not using their full lives, and being removed early, which increases LLP reserves per EFC. In addition, extending the first interval to its maximum possible and incurring a high shop-visit cost may not be desirable, since the second removal interval, and total of first and second intervals, could be fixed by LLP lives.

Optimising maintenance costs per EFH or per EFC for each individual engine is highly complex, and laborious when managed manually. EFPAC's ability to automatically recalculate shop visit workscopes when removal intervals are manually changed means the user can experiment with different intervals for subsequent removals.

"EFPAC optimises removal intervals and maintenance costs for the whole engine fleet, and provides transparency in multi-year and multi-removal interval plans and related budgets that result in reduced cost per EFH or EFC," explains Van Dijk. "EFPAC automatically generates a master plan for the fleet over several subsequent removal intervals. This can be over a period lasting more than 10 years. It achieves optimisation by automatically determining removal intervals and shop visit workscopes for each engine in terms of all parameters. EFPAC keeps the engine management team in the loop, while removing the complexity of calculating multiple variables in a dynamic airline operation."

EFPAC produces a master plan for first, second, third and fourth removals for the entire fleet. This plan is updated, usually once every month, and reassessed as time progresses and events occur.

EFPAC calculates the cost and number of shop visits for each year of the plan, and summarises the number of shop visits and their costs in a table or graphically. This can result in an uneven flow of costs over several years, so the system optimises the total budget for an engine fleet over a specified period.

In the case of a cluster of 10 removals and shop visits, and where the user only wanted five engines in maintenance, the system will calculate which five engines to bring forward that have the smallest cost impact.

EFPAC computes and compares thousands of options for engine management, and all their associated costs, taking into account all relevant constraints, such as engine installation planning, LLP lives, lease return conditions, and engine maintenance status.

User experience

An EFPAC user is UK low-cost airline easyJet, which has a fleet of 198 A319 and A320s, most of which are powered by the CFM56-5B5. About 40 aircraft are operated with -5B4s. "The maintenance of all of our engines is contracted with GE Engine Services," says Gary Smith, head of powerplant and fleet transition at easyJet. "The contract provides us with fixed prices for a wide range and number of shop-visit workscopes. We manage the engines in terms of removal and decide the shop-visit workscopes.

"We use AMOS from Swiss Aviation Software as our core M&E system, but we use EFPAC as a point solution so that we can focus on shop-visit planning, since the large number of engines we have makes it too risky and hard to do in Excel," continues Smith. "Life is made relatively simple for us in some respects, since our oldest aircraft are about seven years old. We therefore only got into planning the first workscopes in late 2010. Moreover, the fleet plan is to only keep the aircraft until they are seven to 10 years old, so the engines will only go through a single shop visit.

"Shop-visit timing is complicated, however, by about 50 different variables and constraints. EFPAC defines the maximum number of engines we can have in the shop at any time, and also inputs all the other variables," continues Smith. "EFPAC also manages the fine details, and is completely automated.

"We use it to optimise the removal plan for the whole engine fleet. EFPAC's presentation graphics make it more user-friendly," adds Smith. "A huge amount of data and experience are required to find the optimal interval to get the lowest cost per EFH or EFC. We can programme in the cost for each defined shop-visit workscope, but it is hard to automate the process of getting the lowest cost per EFH/EFC. Putting the engines through just one shop visit simplifies the process of managing them, and we simply aim to get the longest removal interval possible, and therefore the lowest cost per EFH."

Smith adds that EFPAC gets the best spread of removals and removal intervals possible, by minimising the total spend on maintenance over a given period. "EFPAC is even able to take into account the effect of extended removal intervals on fuel burn, and the cost of removing and installing engines to get the most optimised removal plan," he says. AC