Engine condition monitoring systems and softwares have grown in sophistication. Softwares now provide alerts and possible causes of an engine's poor health or weakening performance. The derived data can be used to predict removal timings, and avoid expensive unscheduled removals.

Using ECM to reduce engine maintenance costs

Good quality engine condition monitoring (ECM) can contribute to long-term lower engine maintenance costs. ECM has evolved from the simple manual recording, storage and analysis of a few basic engine performance parameters into a high-technology process. ECM data are now more comprehensive: they can be monitored and interpreted in real-time; be used to derive behavioural models of engines; and provide data and information that can be used to determine the most economic times to remove engines and put them through shop visits. There is also the benefit that unscheduled failures become easier to predict, and so avoided.

ECM evolution

ECM developed as a result of aviation authorities requiring flightcrew to monitor engine performance in flight from engine instruments on the flightdeck. The recorded information was used by each airline's engineering department to derive a maintenance programme for the engine.

Performance parameters measured fall into two basic categories. The first comprises engine vibrations and oil temperature and pressure, parameters that are not significantly influenced by flight conditions and engine thrust setting during a particular flight phase.

The second group of parameters includes those that are influenced by flight conditions and thrust setting. These are the gas path parameters that include exhaust gas temperature (EGT), fuel flow (FF), low pressure rotor speed (N1), and high pressure rotor speed (N2). These parameters are monitored and compared against a model of expected engine performance readings.

The minimum parameters that were required for engines which used N1 as the power setting were N1, N2, EGT and FF. The minimum parameters for engines which used engine pressure ratio (EPR) for power setting were EPR, N1, N2, EGT and FF. EPR not only indicated engine power for take-off and cruise settings, but also the efficiency of the engine's performance.

In addition to these engine parameters, altitude, Mach number and total air temperature were also measured to provide an indication of flight conditions.

"The parameters measured in current generation aircraft depend on the avionics and engine instruments on the aircraft," says Ivo Krastev, system engineer at MTU Maintenance. The parameters measured on first or older generation engines, such as the JT9D and CF6-50, were only those which had cockpit instruments. The flight engineer or pilots in a two-man aircraft recorded these manually, which created room for

ECM data was traditionally recorded manually by flightcrews, and only during take-off and once in the cruise. ECM data is recorded automatically on modern aircraft. It can even be recorded and transmitted to ground stations in real-time.

errors.

"The information was of poor quality and it took a long time for data to be recorded before it could be analysed or interpreted," continues Krastev. "Moreover, flightcrew were only required to take readings of each parameter for each engine during take-off and cruise, which merely provided a snapshot of the engine's performance."

"Modern engines have more sensors for measuring more parameters such as inter-stage pressures and temperatures," says Steve O'Flarity, programme manager of advanced diagnostics and engine management at Pratt & Whitney Engine Services.

Young generation aircraft, with digital flightdecks, are capable of recording a larger number of engine performance parameters automatically. These can then be downloaded from the aircraft after each flight or several flights, or transmitted to ground stations during flight via an aircraft communication and reporting system (ACARS). Airlines choose which to use, but although the cost of using ACARS is higher it has the advantage of automatically transmitting the data immediately it has been recorded.

"Modern aircraft and engines allow data to be recorded automatically, and ECM data is recorded locally to an airline's engineering department," explains Manfred Paul, manager system engineering powerplant at Lufthansa Technik. "Once data is collected it is interpreted by the analysis software.

"We automatically capture data every four hours during the cruise, as well as during take-off at the point of peak EGT. Data are therefore captured several times during a long-haul flight. The interval between automatic recordings of data can be set, however, in the DMU in the avionics rack on the aircraft. The DMU picks the point at which EGT reaches its peak," continues Paul. "Older aircraft recorded the data manually at 300 feet above ground level. It is now actually possible to record the data for an entire flight in real time, since they can be transmitted by ACARS, but this would provide large volumes of data. We manage 1,200 engines and record about 1,500 sets of data each day, and each report has many parameters. The resulting volume of raw data that has to be stored and analysed for any airline is considerable."

Analysing data

The prime objective of ECM is to plot the performance data of each engine so that its performance can be monitored. Each plot of data can then be compared to a model of how the engine is expected to behave in the experienced flight conditions. Adverse deviations or shifts in performance indicate deterioration in the engine's hardware, or that there are operational problems. The objective is therefore to provide engine management engineers with indications that an engine's performance is deteriorating. The information may further be used to interpret which part of the engine is causing the problems. A larger number of parameters is intended to provide engineers with more information that allows a clearer diagnosis of the engine's health.

ECM data will be analysed once raw ECM data has been recorded and stored. The majority of airlines use ECM software provided by the original equipment manufacturers (OEMs), although there are also a few specialist providers. General Electric (GE) provided GEM for its older generation engines and offers SAGE for the current generation GE and CFM56 engines. Pratt & Whitney (PW) provides EHM, and Rolls-Royce (RR) provides COMPASS. Older systems, such as ADEPT, processed manually recorded data. PW's most advanced system is advanced diagnostics and engine management (ADEM).

SAGE, for example, is programmed to generate an alert when a significant shift in one or more parameters is identified. Combinations of specific parameter changes are known to be symptoms of specific anomalies in the engine or deterioration of specific engine hardware. SAGE also establishes major performance trends to indicate how an engine should behave in service. The EGT trend is the one most commonly used for forecasting engine removals.

Monitoring the engine's performance also allows engineers to decide when an engine should be removed for a shop visit. Removals are not required when an engine is operating satisfactorily, but should not be delayed for too long when EGT, for example, is rising fast to its maximum limit.

SmartSignal is one of the few independent software providers, and offers its Epi*Center software. "This is analytical software which is designed to improve the performance of engine equipment by delivering early warnings of emerging problems with engine hardware," explains David Bell, vice president of application engineering at SmartSignal. "Epi*Center takes raw ECM data and analyses it in a similar way to the OEMs' software. Epi*Center is indifferent to which engine is being analysed."

Services

Most airlines have traditionally had their own engineering departments to record, store and analyse data, and make decisions about when to remove engines for a shop visit. Many smaller carriers now avoid having their own engine management departments, so there are opportunities for specialists to offer engine trend monitoring and engine management services.

"We started remote diagnostics services in 1997 and have since developed what we offer," says Rick Donaldson, manager of information and diagnostics technology at GE Aircraft Engines. "We offer two levels of service that use the same technology. Data are sent to us via ACARS to our computer. The raw ECM data are corrected to standard flight conditions so that they can be compared with the model of what the data should be. Examples of corrections are take-offs at airports with different ambient temperatures and elevations. The corrected data are then trended automatically, and our software detects significant shifts with alerts being given to large shifts. The alerts are prioritised and GE gives recommendations for maintenance actions to customer airlines. These can be small shop repairs that do not require a full engine disassembly, and which can keep an engine on-wing for several thousand hours. The onus is on the customer airline to respond to recommendations via the GE website.

"Operators can also plot ECM data and run a root cause analysis tool that indicates probable causes of the problem," continues Donaldson. "Spikes in EGT or FF, for example, are compared to standard data and the problem is identified using statistical analysis. GE has a large database of data from the 7,700 engines we monitor for 110 operators, which is about 40% of the CFM56 and GE engines that are operational. The amount of data we have means it is possible to have an accurate analysis."

In addition to diagnosing ECM data, GE also offers engine management services that include removal forecasting and decisions in managing engine spares.

Snecma Services also uses SAGE for analysing CFM56 ECM data, and uses conversion tools to transfer raw data into its own system. Engineers from the CFM product support engineering team are used in addition to the automatic processing of data. Snecma Services will use a web-based monitoring system by the end of 2005 for remote diagnostics of CFM56 engines, using root cause analysis models and anomaly detection algorithms to improve the efficiency of the diagnostics.

Like GE, Snecma Services can monitor engine performance in real time and so provide its customers with periodic reports and alerts. It can then also recommend maintenance actions, such as minor repairs and water washing, to extend the on-wing life of engines. Snecma Services also provides an engine removal forecasting service. These forecasts can in turn be used to optimise engine maintenance costs, as well as reduce spare engine requirements.

ECM is the first step to predicting the timing of engine removals. With engine management software, this information can thus be used on a fleet-wide basis to plan shop visits at even intervals, with the objective of minimising spare engine requirements.

Optimal engine workscopes can then be suggested.

Pratt & Whitney offers three levels of service. The first of these is a power-by-the-hour fleet management programme, which includes monitoring, managing and maintaining engines on 5- to 20-year agreements. PW uses ADEM to manage engines on these programmes. PW also offers an engine management programme that provides an engine monitoring service only, which can involve PW engineers. Customers have access to ADEM software.

SmartSignal not only offers its own monitoring software, but also provides a hosted service to collect and analyse data for customers using its Epi*Center software. Results are distributed over the web to customers, but SmartSignal does not analyse or interpret the data. "We do provide a watch list of potential problems, such as abnormal temperature or an unexpected parameter change," says Bell.

Airline and independent maintenance providers also offer ECM and engine management services. "We provide ECM to 40 customers with fleets ranging in size from very small to large," says Paul at Lufthansa Technik. "This starts with the ECM data collection process, and continues with data analysis, alerts to changes in performance parameters, and engine maintenance management and customer engineering. Engine maintenance management is done manually, rather than with a software programme. Our overall philosophy is to extend removal intervals to achieve the lowest cost per engine flight hour (EFH). We believe that engine maintenance costs will continue to decline with longer removal intervals, and that costs per EFH do not increase beyond an optimum interval because of increasing shop visit costs.

Over the past two years, MTU has been working on different ECM solutions for its customers. "We will start offering an engine monitoring and management service from the first half of 2006," says Krastev.

Further developments

There are attempts to increase the sophistication of ECM by analysing the relative difference between parameters to indicate which parts of the engine are deteriorating or causing problems with performance.

"It is possible to build a mathematical model of an engine's expected performance and compare this with the actual trend data. ECM works by making this comparison, and raising an alert when a parameter differs significantly from what it should be. More sophisticated ECM systems can analyse symptoms and indicate what the problem might be," says Bell.

OEMs and other ECM software providers are in the process of trying to develop artificial intelligence. "Artificial intelligence is a system's ability to pinpoint the area and problem with the engine by analysing the ECM data. This is still in the embryonic stage," says Paul. "Artificial intelligence requires a lot more parameters and data to be followed than are currently recorded, and more intelligent ECM capability. Measuring directly an engine's LRU, for example, will save a lot of costs related to line maintenance of engines on-wing because 60% of the cost is for isolating faults on the engine. Future ECM systems could reduce this cost by up to 50%."

Economic benefits

Engine maintenance and shop visits can generally be divided into planned or scheduled events and unscheduled events.

ECM is used to predict both these events. Planned engine removals are mainly done on the basis of predicting when EGT margin will be eroded to the point that removals for a performance restoration or an overhaul are forced. "ECM helps to manage the timing of these removals. By predicting removals accurately it is possible to reduce the EGT margin threshold for removal, and so extend the removal interval," says Donaldson. "In some cases it possible to extend the interval by up to 1,000EFC, which can be as long as one year's operation. In hand with close monitoring of EGT margin, it is also possible to re-rate engines that are used across two aircraft types, which also leads to removal interval extensions. Scheduled or planned engine removal intervals can be extended by as much as 20%, thereby leading to big savings for airlines."

Other benefits of close monitoring are related to the prevention of excessive deterioration in engine hardware, which will then result in a high level of parts replacement and so high shop visit costs. An example is the wear of high pressure turbine (HPT) blade shrouds which can cause HPT blade damage, and even further damage. HPT shroud deterioration also affects other engine performance parameters, such as EGT, FF and N2 rotor speed. If these changes are detected early enough severe secondary damage to the engine can be avoided. Savings on HPT blades alone can be as much as $200,000.

ECM also contributes to improving planned removals and scheduled maintenance by providing alerts that allow engines to be fixed on the flight line. O'Flarity gives the fixing of a bleed valve as an example which can give the same symptoms as a turbine problem. Repairing bleed valves can be done on the line, thus avoiding the need for a shop visit, which would be required in the case of a turbine problem.

Unscheduled engine failures and shop

One advantage of high quality ECM analysis softwares it that they can make alerts to poor performance and provide indications of the possible causes of an engine's problems. This information can be used to perform small repairs that avoid full removals and shop visits.

visits can result in high costs due to aircraft often being stranded at outstations and requiring technical fixes and spare engines. Passengers also have to be accommodated in hotels and placed on flights with other airlines. ECM can minimise these events by detecting deterioration early, and alerting engineers to give them time to remove and replace troublesome engines.

"Engine failures can be detected between seven and 35 flights before they occur," says Donaldson. "These advance warnings, which are particularly effective in real-time ECM, can save the cost of unscheduled events that can amount to several hundred thousand dollars. More subtle signatures are possible with advanced ECM and fuzzy logic."

There are also other direct and indirect benefits. Paul explains one of these is that because an airline can be notified about the condition of a particular engine with low EGT margin it can be limited to airports that allow easier operations and at a higher level of derate.

PW and GE both estimate that better quality ECM allows a saving of $5-10 per EFH, due mainly to avoiding unscheduled engine failures.

Additional ECM use

Traditionally engine maintenance management, like the ECM process, was done manually by airlines. It is becoming increasingly possible to replace these manual processes with engine management systems. Further to ECM systems that use fuzzy logic and artificial intelligence to more accurately pinpoint the problems engines are suffering, systems have also been developed to manage engine maintenance with the objective of realising the lowest possible maintenance costs per EFH. In addition to this, the systems are also an engine management tool that can predict spares requirements, plan shop visit workscopes, and monitor and track the maintenance status and part number build-up of engines. These systems first require information that is derived from ECM.

Jet E-Plan is an example of engine management software used to manage engines and allow airlines to optimise and realise the lowest possible engine maintenance costs. "Jet E-Plan is based on a time series, and so requires calendar and aircraft utilisation information from an airline's operation, as well as ECM data," says Daniel McLoughlin, product director at Jet E-Plan. "The system shows shop visits, as well as spare, operational and off-lease engines in different colour codes. The last and next workscope can be viewed for each engine by clicking on it. The system also provides details of all parts installed in each module, as well as the part numbers of the disks and shafts. Jet E-Plan also shows the remaining life on LLPs, as well as the engine's status at entry and exit of a shop visit. Knowing the predicted shop visit workscope, the system predicts the cost based on the man-hours, consumables and materials used, and the cost of third-party repairs.

"The cost of new parts can also be listed, and the remaining life and value of stub life LLPs can also be analysed with changing shop visit intervals," continues McLoughlin. "The stub life and value of all LLPs are then calculated and the write-off value given, as well as being adjusted with changes in the removal timing."

Jet E-Plan goes on further to accumulate the engine's reserves at the time of the shop visit, which are split into workscope reserves and LLP reserves. The system therefore allows engine management engineers to estimate reserves accurately, and shows how they change with altered removal times. With each engine analysed by the system, Jet E-Plan then generates a cashflow forecast for the engine fleet, as well as the write-offs for LLPs each month.

Besides the plan for engine removals and overall management, the system is also flexible in analysing the effects of unscheduled maintenance on maintenance costs and spares requirements. The timetable of planned events of all other engines in the fleet then has to be modified.

Total Engine Support (TES) offers its EFPAC system. "We take data from ECM systems and feed them into EFPAC as a starting point," explains Wayne Pedranti, programme manager of powerplant engineering at TES. "These data form the basis for predicting EGT margin deterioration, timing of engine removals, and shop visit workscopes. The system therefore also requires utilisation data of EFH and EFC to be input. The utilisation and EGT margin data are plotted against a time series. We use EFPAC as an aid in managing engines for customers without an engine management department.

"EFPAC can then be further used to adjust the timing of removals if required, and analyse the consequences of this. Removal timings can be shifted because of changes in engine performance, or because there is expected to be a cluster of removals that need to be spread more evenly," continues Pedranti. "The timing of removals can also be changed to optimise maintenance cost per EFH, since EFPAC also calculates shop visit workscopes for different removal intervals, and also the cost of inputs for a changed removal interval. The timescale and tracked engine utilisation also allow maintenance costs per EFH or EFC to be optimised because EFPAC can also predict subsequent engine removal intervals and shop visit workscopes.

"Besides ECM data, EFPAC also requires an interface with other systems in the maintenance and flight operations process. Not only are aircraft and engine utilisation data required, but pilot reports and data from previous shop visits also have to be input," explains Pedranti. AC