The sophistication of engine health monitoring systems is catching up with the complexity of engine maintenance management. The instrumentation to monitor an engine's gas path has increased, and this allows monitoring systems to alert managers of pending problems.

Systems for Engine health monitoring

The old adage that prevention is better than cure holds true for aircraft maintenance, and even more so for engines. Systems have evolved to assist airlines, leasing companies and engine shops to better manage both the on- and off-wing life of engines.

Pro-active engine management

Like engine management, engine assembly is enormously complex, but the computerisation of some of the monitoring systems is becoming ever more sophisticated and the instrumentation of the gas path is more precise and wide-ranging. A range of engine condition monitoring (ECM) systems to assist operators track engine performance has been analysed *(see Using ECM to reduce engine maintenance costs, Aircraft Commerce, August/September 2005, pages 36-41)*. These ECM systems provide a set of indicators alerting airline managers to impending problems. Some of these system features are analysed in more detail here. A second issue involves what happens when the engine is removed and sent for overhaul. This half of the engine management process is equally important and we look at how these specialised engine tracking systems can complement or integrate with the larger maintenance repair and overhaul (MRO) software suites.

Towards predictive maintenance

ECM or engine health monitoring (EHM) has been practised for years. In its simplest form, these systems and services trend two basic groups of engine parameters for abnormalities: mechanical vibration, and oil temperature and pressure; and performance measurements along the engine gas path. The speeds and temperatures of the turbomachinery are examined at a given power setting to look, for example, for degradation in blade/casing clearance. Such systems have been around for decades and traditionally used pilot-recorded data on paper, after a flight, to input to ground-based systems. Nowadays, many more parameters are linked to the ground, usually via an aircraft communication addressing and reporting system (ACARS), to provide more accurate and timely trend data.

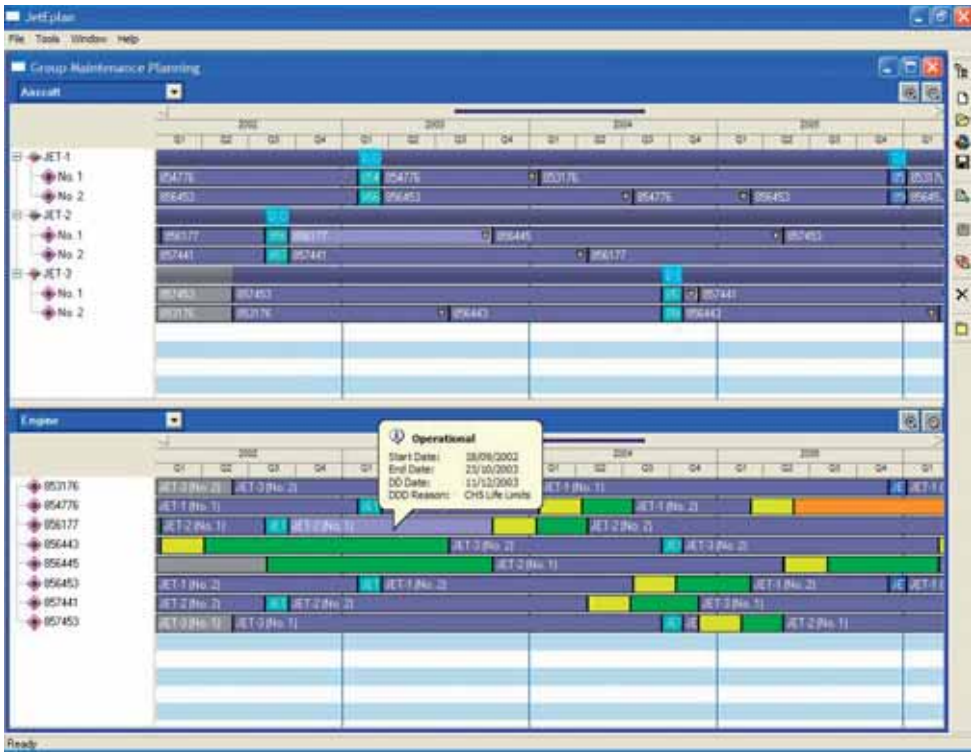
All the original equipment manufacturers (OEMs) have ECM/EHM systems. Pratt & Whitney Engine Services' ADEM and GE's SAGE have already been featured *(see Using ECM to reduce engine maintenance costs, Aircraft Commerce, August/September 2005, pages 36-41)*. Here the Rolls-Royce (RR) offering is examined to show how the market is moving very firmly to a wider mixture of integrated software products to provide a more in-depth predictive maintenance service and total lifetime care solution for airlines.

The RR TotalCare® service has evolved from several software products and concepts into one comprehensive service. Its portfolio covers all aspects of engine support facilities, comprising off-wing management of the engine, information and engine programme health monitoring, in-service support and inventory management. A key feature of the TotalCare concept is that it transfers the technical and financial risks associated with engine aftercare from the operator to the OEM. Clearly the OEM will build an insurance 'buffer' into the financials, but theoretically the OEM is best placed to look after the engine maintenance and management since they have the necessary experience and staff knowledge. The RR offering comprises many layers of applications and support. An important software layer of the service is the web-based Aeromanager data portal. This provides the operator with an on-line, real-time view of both on-wing metrics for each engine, and off-wing repair status and engineering data. It also provides access to resources such as technical documentation, airworthiness directive (AD) lists, and repair scheme advice. This is provided in one integrated view to facilitate more rapid decision-making by management. From Aeromanager, users can link to another layer of detail in the enginedatacenter sub-portal, which provides a wealth of detailed information about traditional ECM trending and alerts. This sub-portal also has a service to keep electronic track of engine logbook technical records, and acts as the front end to the CoreControl suite of software tools offered by Data Systems & Solutions (DS&S).

DS&S is a 50:50 joint venture between RR and SAIC, a US-based software and consulting company. The final part of the enginedatacenter is advanced oil analysis using the JetSCAN debris analysis system.

Advanced oil debris analysis

JetSCAN is an interesting high-tech development that has crossed over from the military jet engine. Again marketed and provided by DS&S, this fully integrated system combines Scanning Electron Microscope (SEM) and X-ray analysis technology with the engine manufacturer's unique product knowledge in specially designed diagnostic software. It aims to augment or indeed replace the traditional job of airline engineering personnel in carrying out engine oil analysis for signs of early bearing failures. Results from analysing regular debris samples from magnetic chip detectors (MCDs), oil filters or filtered oil samples are stored in JetSCAN's integral database. These stored data then enable the user to judge the



The graphical planning board for engine maintenance from AEROinformatics' JetEplan product provides a very easy-to-use interface to aid what is a very complex task.

increasing risk to mechanical integrity by trends of single or combined debris characteristics in each of the monitored machinery regions. Trendable individual particle characteristics include material classification, particle numbers, particle sizes and morphological classifications. JetSCAN is portable and only takes an hour to set up and become live. Data can be fed back remotely to the enginedatacenter for operators to review, with recommendations for corrective action being added by the RR operations centre's expert staff. JetSCAN can also be adapted to review hydraulic fluid and fuel contamination. It was jointly developed with LEO Electron Microscopy Limited of Cambridge, UK, a leader in software-controlled analytical SEM systems.

At present JetSCAN is only offered on the Trent family, but this will be expanded in future. DS&S claims that the benefits are significant, pointing to the proven in-service military track record. In its first application as a custom design to support the Turbounion RB199 powering the Panavia Tornado, JetSCAN delivered an annual reduction in logistics costs of over $10 million. This was achieved by eliminating unnecessary engine removals, previously needed to inspect bearings susceptible to wear, and preventing expensive on-wing engine failures.

The bigger picture

The enginedatacenter is the window to a comprehensive world of advanced data management for airlines. Behind this sits the CoreControl suite of tools. The major module for ECM/EHM within this suite is CoreAlert. This on-line, web-based system takes parametric data, linked off the aircraft, and uses them to predict failures. "The system currently monitors over 200 separate fleets, and 6,100 engines on over 3,000 aircraft worldwide," comments Nick Godwin, marketing director civil aviation at DS&S. "We aim to help airlines to pro-actively manage tomorrow's problems before they occur rather than reacting to, and fixing, yesterday's. Our added value is to crystallise value in the raw data using advanced software and experienced personnel. Our service delivers improved efficiency of engineering and maintenance functions in the airline and leads to lower operating costs and better schedule reliability. Expensive aircraft are therefore in the air for longer, generating revenue. Finally individual airlines benefit from fleetwide 'learning' gained from all the operators' combined fleetwide experience. This is especially important for very small operators who tend not to see all the engineering issues that are coming up. We need to put CoreAlert into context with our long-standing ECM/EHM products. Traditionally, COMPASS and COMPASS Navigator have been, and still are used, by individual airlines. CoreAlert is the full service provided by DS&S, using COMPASS as the basic tool for data processing. Some airlines are still using COMPASS standalone under licence. The CoreAlert service also uses the remote data analysis tool (RDAT) to manually check the raw data over and above the automated functions in COMPASS."

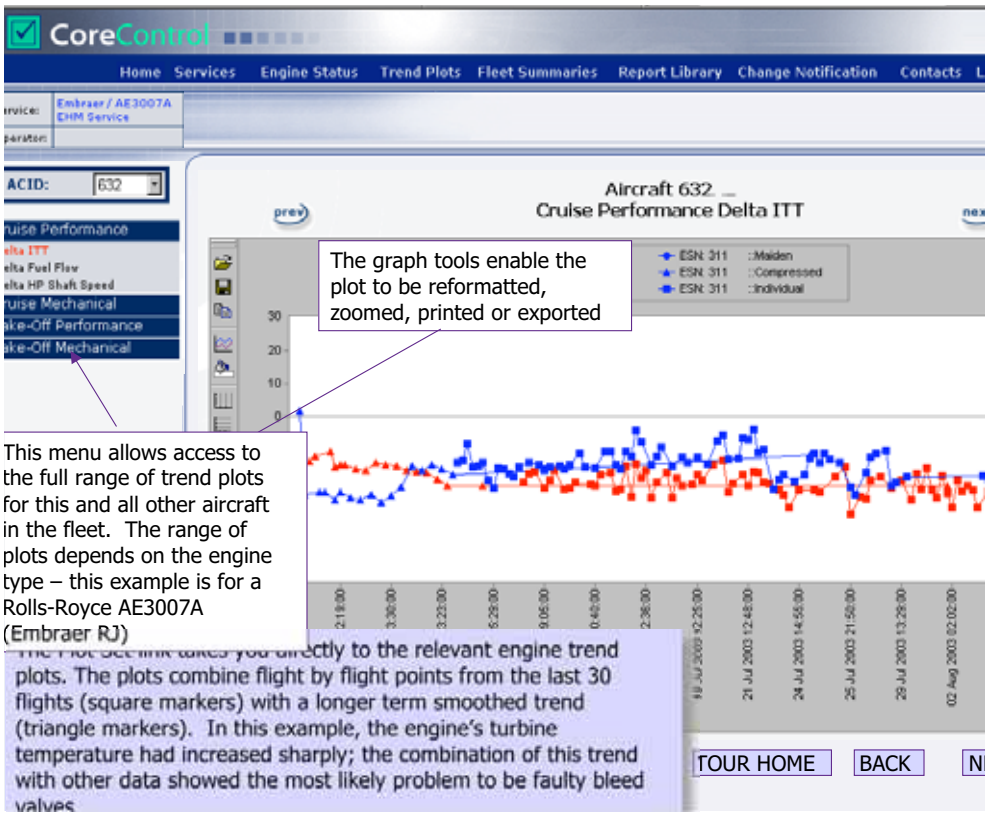
The CoreAlert service process is straightforward. The aircraft data acquisition systems are programmed to collect engine data from different phases of flight, usually take-off and cruise, and climb data points on latest generation aircraft. Sometimes these data files are provided via other ground-based systems, or through manual transcription, and are sent directly to DS&S via ACARS (SITA or ARINC), or are downloaded from the aircraft and sent by e-mail or file transfer protocol (FTP). Data are processed by DS&S's suite of advanced analytical tools. Customised alerts and summary report demands are posted to the CoreControl website. Alerts can be sent by e-mail or text message.

DS&S's team of experienced EHM engineers continually monitor engine behaviour to ensure that the knowledge base is always up to date. Results are posted on the web within a few minutes of data receipt for complete 24/7 service. Interestingly, DS&S claims it can develop new models for additional engine types within a few days of receiving typical performance data samples, even for non-RR engines. "Models can be more accurate than OEMs' performance look-up models," claims Godwin. "We offer three levels of service for CoreAlert, all as a hosted application service provider (ASP) solution. This means there is little or no upfront investment and customers simply pay as they use. Level 1 is a basic EHM service, which includes a working day alert service and trend plots. There is also a monthly updated dynamically sortable table showing engine serial number, fuel flow, turbine gas temperature (TGT), deterioration figures for fuel flow and TGT, and a listing of current margin limiting parameters. Level 2 is a full EHM service, comprising the Level 1 service plus a daily exceedance report, a list of all alerts for the month, an engine usage summary and various performance curves. Level 3 is a 24/7 EHM Service, including all the features of Level 2 plus a close-to-real-time data posting service round the clock."

Return on investment

Godwin continues to make the financial case for his predictive maintenance toolset. "Overall, our experience shows that the return on investment is enormous, around 300% or 3:1. Big savings come from quicker and more accurate high-pressure turbine (HPT) system deterioration monitoring.

The near real-time tracking of engine performance by DS&S's CoreAlert (example shows cruise performance trend) can pick up technical problems, for example due to a deterioration in the high pressure (HP) turbine system. Early diagnosis of these problems can save millions of dollars of fuel and costly in-flight shutdowns.



This includes spotting early HPT blade track loss, HP static vane cracking and distress and pre-swirl chamber damage ahead of the HPT section. Savings also come from monitoring for compressor damage, for example blade rubbing on the casing. Another benefit is early detection of fuel nozzle damage and coking. We have even detected the incorrect installation of a full authority digital engine control (FADEC) software version. Bleed valve faults are also commonly picked up. Variable inlet guide vanes are quite sensitive and can have a big effect on performance, and CoreAlert can pick up on poor scheduling and system damage. The final big money-saving area is early alerts of bearing distress. A bearing failure can be extremely expensive. In CoreAlert, potential problems are designated as 'Alert' or 'On Watch' depending on the immediacy of the issue. The table *(see picture, page 57)* shows the date the alert was first activated. The likely cause of each alert as determined by CoreAlert's intelligent diagnostic system is shown along with recommended actions.

"A link is provided to the relevant trend charts," continues Godwin. If we can prevent an unscheduled event in service, we can avoid having an aircraft out of service for 24 or 48 hours, with a consequent loss of revenue, high levels of compensation to passengers, and disruption costs like hotels and extra food. The cost of finding a spare engine at short notice and potentially shipping it half-way around the world can be significant. By using our predictive services, the airline can manage the issue before it turns serious."

Off-wing management

But this only partly addresses the role of software in lowering engine maintenance costs. The RR Aeromanager data portal goes much further than the on-wing CoreAlert module. Off-wing management of the engine is also covered. Aeromanager is effectively a one-stop, on-line repair and overhaul information system that can be accessed on the internet. The service allows customers to request a repair slot and agree the workscope on line. Once the engine or module is inducted, customers can view progress against key milestones and check the status and forecast delivery date. They can also view associated documentation and even digital images of scrap parts if required. Finally, they can receive the commercial documentation and a summary of RR service performance on-line against a set of pre-determined metrics.

Aeromanager integrates with the SAP system that RR uses for its enterprise resource planning (ERP) in the overhaul centres. The home page is the heart of Aeromanager, where RR displays information, customised for each airline, to help them plan and manage their engine operation. There are four main options on the home page area: 'current messages'; 'to do'; 'past messages'; and 'update my profile'.

The messages and 'to do' functions hyperlink into the applications behind the main portal and allow busy engineers to quickly drill down into a particular engine issue. Aeromanager also provides access to other important engine resources, for example dedicated engine leasing solutions. This allows the user to search for available engines for lease, view technical data through enginedatacenter and request a leasable engine. Emergency aircraft-on-ground (AOG) support is also provided. This allows the user to request and locate emergency lease engines. The engines can normally be made available within 24 hours for a maximum term of 90 days. The RR Lease Engine Guide is also accessible here. Aeromanager offers access to the latest Facilities Tooling technical data such as line maintenance, test, module change and information on assembly/disassembly. It even allows warranty claims to be processed on line. A new software solution from RR, Sourcerer, is also integrated into Aeromanager. Looking after low-value, but still critical overhaul materials (OMat) products, this process releases valuable time for the airline to concentrate on core activities.

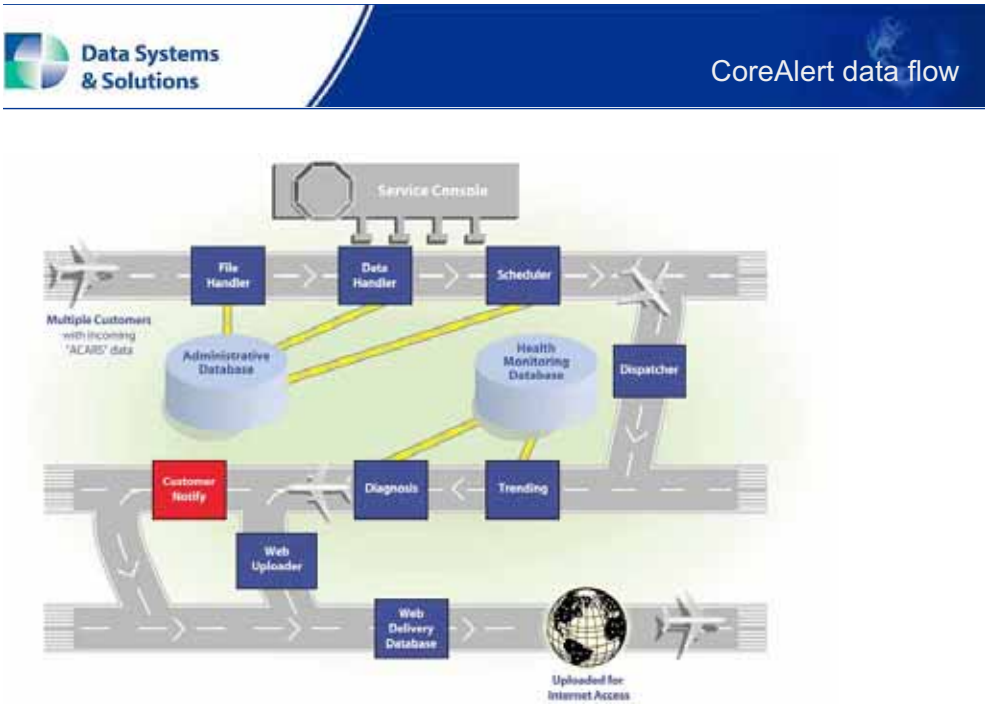
Independent software

At least one OEM is therefore taking a very comprehensive view of the total engine management task. Off-wing management offered by specialist software vendors claims even bigger savings, however. JetEplan is a software tool that addresses the engine off-wing management task *(see Using ECM to reduce engine maintenance costs, Aircraft Commerce, August/September 2005, pages 36-41)*. Daniel McLoughlin, JetEplan product director of AEROinfomatics, expands on the magnitude of the potential savings. "Engine maintenance makes up about 40% of the total maintenance cost of an aircraft. While ERP and MRO software packages have evolved very well to deal with line and base maintenance, the engine remains a large but expensive 'black box'. The fact is that jet engines are extremely complex pieces of equipment, and understanding them fully and completely requires a significant investment in time and expertise. Of 100 engineers in a large airline 10 will be engine specialists, each of them specialising in only one or two engine

types. That is all they do. The problem is that the pool of specialist knowledge is dwindling. Our JetEplan software is aimed at supporting the complex business of full engine management." The cost savings of properly managing the subtleties of engine maintenance are significant. A typical D check on a widebody aircraft costs around $3 million and occurs about every seven years. A shop visit for an engine powering a widebody can cost upwards of $1.6 million and happens about every four years. This means the maintenance cost for one engine is about equal to the cost of a D check, and yet engines are given little real attention. "We see airlines still trying to manage engine shop visits and workscopes on Excel spreadsheets," says McLoughlin. "That is because the engines are so specialised and the ERP/MRO software is not capable of handling the complexity. We see that airlines have difficulty challenging the engine build report from the engine shop, and cannot adequately challenge the invoice for work completed. An airline would not dream of letting the aircraft go to the hangar for a D check without sending an on-site rep to scrutinise and sign off almost every non-routine item, even with a value of only $50. The engine can go in for a $1 million overhaul, however, and no-one is on site to scrutinise the work. That is why there is now a growth in people like TES to offer this as a third-party service. It is effective. JetEplan can enable the airline to fully take control of the maintenance process for the first time, however. We can deal with subtleties like engine power ratings on maintenance requirements, and EHM data trends on workscope definitions. Engine leasing companies also want to have a more detailed scrutiny of the management of their prize assets."

McLoughlin claims that JetEplan is an expert ERP system for engines. It auto-compiles engine workscopes, including parts and pricing, and has advanced planning capabilities to assist the maintenance department to balance work load. A key feature is the handling of unscheduled events. JetEplan will provide an instant impact analysis of an engine failure, either catastrophic or partial, on the fleet, or of the impact of a delay in engine turn-time in the shop on the airline's overall operational plan. The third key strength, according to McLoughlin, is the electronic scrutiny of the financial side of the engine visit. This compares the estimated costs of the overhaul to the actual processed invoice data and looks for mis-matches or anomalies. Interestingly, McLoughlin is convinced that his product provides an edge in the planning department over anything available from OEMs or other software vendors, even services like Aeromanager and CoreAlert. "The OEM service providers like GE and DS&S do not provide real engine planning like JetEplan. We provide real in-depth predictive maintenance capability to see into the future for the engine and plan for it. In comparison, airframe maintenance planning is easy. The aircraft can come out of service for a set period of time and go into the hangar for work. An engine can be removed, replaced with another, and the aircraft can continue to fly. The removed engine is worked on and three months later may be flying on a different aircraft. Thus the interfacing of the engine work with the flying programme is more intricate." JetEplan is now used by a number of customers, although McLoughlin declined to give details. One key question is how it sits alongside the main ERP/MRO system for the airline, including the master parts database and purchasing system, and the configuration management system contained in most modern MRO software systems. Interfaces are never straightforward, in particular configuration data interfaces. It may be better to split the engine and airframe management systems and run

DS&S's Core Alert system integrates ACARS message data with other data inputs and provides timely, pro-active alerting to airline engineering and flight operations departments.



them as separate standalone applications, if JetEplan's cost benefits are big enough.

Outsourced engine health

With a growing shortage of engine specialists within airlines, there is a trend towards third-party outsourcing of the engine management task. One US-based company, Aviation Management, has been rapidly expanding its business base in the US and Europe since 2002, and now has a team of over 10 people. "Our customers are mainly engine leasing companies, but we also have a number of smaller airlines like Gemini Air Cargo," says Pred Milenkovich partner/manager of technical services at Aviation Management. "We offer a service to take customer data and track and advise on the health of individual engines. We have just introduced EZ-ECM, an engine health software program that tracks engine parameters and can produce alerts when things start to deviate from the normal engine 'signature'. Unlike some software systems, we track four main engine parameters, as opposed to the normal three, which provides a clearer picture of what is going on. Customers receive weekly interim updates and a full health report once a month from EZ-ECM. Along with the software, we also offer a service to manage an engine shop visit off-wing, and to ensure that the workscope and any unscheduled work are optimised from a cost perspective."

There are a number of other companies that offer services and products like EZ-ECM. Based in the UK, Total Engine Services (TES) has gone down the same path as Aviation Management and grown a very successful engine management business, including physical management and, increasingly, procurement of powerplants to offer leasing of spare engines. TES has developed a more sophisticated software product called EFPAC, written by a company called Imagitech. The EFPAC product enables tracking of engine health data using the normal key raw engine parametric data. This is run against a standard engine model and deviations from the norm are highlighted. Exhaust turbine gas temperature margin, which is one key parameter that will force the engine off-wing, is monitored and trended to look ahead at engine removal dates. Another feature of the product is the engine removal planner. It combines forecasts of 'soft' removals due to deterioration in performance or margins, and combines this with hard-time expiry of engine parts such as shafts or disks. It will also enable planners to look at lease return dates and conditions. All of this is displayed graphically on a planning board and enables the engine planner or analyst at TES to then graphically drag and drop these dates to smooth out bunching in engine removals and distribute the workload evenly over time. It also facilitates the 'staggering' of engines and spare engine fitment, to balance the accumulation of life, ensuring that one engine is not overworked, while another is left with very low utilisation counts.

The future

What comes next? The most likely steps forward will be in better interpretation of the engine data, more accurate data capture and more integration between on-wing and off-wing systems. Fusing data from a variety of EHM sources is also a prospect, providing fuzzy-logic analysis of the results. As an example, an ECM company called Scientific Monitoring (SMI) sees the credibility of advanced, expert systems as a key issue. Based in Phoenix, Arizona, SMI offers EHM capabilities as part of its IntelliMaint product suite, and also through a web-enabled system called intelligent condition-based equipment management service (ICEMS). While ICEMS features advanced prognostic, predictive maintenance capabilities, a reduced version of the product, which focuses on trending, diagnostics and alerts only, has also been made available. "SMI has found that most of our customers are not ready to use more advanced technologies like prognostics and life extension," says Dr Link Jaw, president and chief executive officer at the company, which was founded in 1993. "They are mostly interested in trend monitoring." Nonetheless, SMI continues to refine its decision assurance tools and capabilities. "Condition-based maintenance and aircraft condition-monitoring systems need to be held accountable for the alert and maintenance decisions they recommend," asserts Jaw. "SMI is working to mature this technology, through our involvement in the US Army's future combat systems, alongside Boeing and Honeywell." Naturally, any innovative decision assurance solutions it develops for the military would subsequently be applied in the commercial sphere. "Improved data integration and decision assurance are key commercial imperatives for the future," says Jaw. AC