The cost of accessing spare engines is high and made unpredictable by unscheduled events. Modern engine condition monitoring systems follow a high number of parameters and alert to problems that can be treated, making removals more predictable and easier to manage.

Minimising engine inventory costs

Airlines can access spare engines in several ways. Engine inventory falls into long-term spare engine coverage for engine shop visits, and short-term coverage for unexpected removals and technical problems.

Inventory requirements

Spare engine coverage is required to allow continual fleet operation while engines are removed for scheduled and unscheduled maintenance. Several factors determine the number of engines for airlines' long-term requirements.

The first factor is fleet size, or number of installed engines. The theoretical spare engine requirement and scheduled engine removals are easy to determine when other factors are known.

If a fleet of 10 narrowbodies has an annual utilisation of 3,000 flight hours (FH) per year, then each engine will accumulate 3,000 engine flight hours (EFH) per annum, and the engine fleet will therefore accumulate 60,000EFH each year. If the interval between scheduled removals were exactly 10,000EFH, then an average of six removals per year would be expected.

A spare engine would be required for the period between the removal of each one and its reinstallation. This turnaround time (TAT) varies widely, but may, for example, be 90 days.

If the six removals occurred neatly in succession, the airline would have engines in the shop for 540 days each year. This is referred to as 540 'days in progress'. One spare engine would cover four of the six annual removals if they occurred in succession, since they would generate 360 days in progress. A second engine would therefore be required for the other two events for only 180 days of the year.

This scenario implies that only two spare engines would be required (540 days divided by 365). Two engines, however, are only likely provide sufficient coverage for 50% of the time, because engine removals do not occur neatly in succession, but at random. There may be periods when there are no engines in the shop, and others when three or four engines are in the shop.

Also, the periods when each engine is in the shop may overlap. The number of spare engines required is not constant, although the variation in spares will be smaller with larger fleets.

Removals are likely to be clustered, especially in young fleets where aircraft were delivered in batches around the same time. Engines on the same aircraft will also come due for removal at similar times, causing peaks in removals. Airlines try to stagger removals to counter these effects, and so have to compromise between optimum removal intervals and the number of spare engines they hold.

The negative effects of the variation in removals can be minimised by using a Poisson distribution to determine the number of spare engines that will provide a higher probability of coverage on a high percentage of occasions. For the hypothetical fleet discussed above, three engines will supply sufficient coverage on 96% of the time. This increases the cost of owning spare engines by as much as 100%, even though only one spare engine will be utilised all the time.

Engine ownership

There are several ways to calculate the cost of owning spare engines. Some include cost elements for both depreciation and interest, which varies between airlines. The engine may instead be financed with debt, or leased.

A CFM56-7B or V.2500-A5, for example, has a new cost of about $6 million and market value in the region of $4.5 million. Airlines may secure purchase discounts, so financing costs for spare engines vary widely.

Owned engines may be depreciated over 15-20 years with differing assumptions for residual value and interest rate. Engines acquired for between $4.5 million and $6 million and financed to zero over 15 or 20 years at 6% interest will have annual charges between $387,000 and $607,000.

This compares to long-term lease rates of 0.9-1.1% per month of market value, which could be $40,500-$55,000, or $486,000-660,000 per year.

An airline with a fleet of 10 A320s or 737NGs could therefore expect an annual cost of $450,000-650,000 for one spare engine. A second or third additional spare engine would therefore be a cost that an airline would seek to minimise.

Airlines can use short-term leases to cater for peaks in demand, but short-term lease rates are high. A typical daily lease rate for a CFM56-7 is about $4,500, and so coverage for a second engine for 100-145 days would equal the cost of owning a second engine, which would be available all the time.

An airline may therefore need to own two engines, and lease a third on a short-term basis, to cover for a few removals.

Maintenance reserves will also have to be paid, in cash for engines on a short-term lease, but for an owned spare engine only when it is due a shop visit.

The operator could therefore expect a minimum cost of $900,000 to access spare engines, but this is more likely to exceed $1 million. Amortised over the

Modern systems that provide better quality conditioning monitoring of engines allow problems that might cause unscheduled removals to be detected at an early stage to be treated with on-wing maintenance. This also has the added benefit of extending scheduled removal intervals which also become more predictable and easier to manage.

fleet utilisation each year, this will be equal to at least $33 per FH.

Reducing costs

The obvious factors airlines have targeted to reduce inventory-related costs are minimising TAT and increasing removal intervals, the effect of which is to reduce the number of days in progress. Increasing removal interval to 12,000EFH and reducing TAT to 80 days will bring days in progress down to 400. Just one full time spare engine can more easily provide complete coverage, with short-term leases covering peak demands.

It has not been uncommon for some airlines to have TATs as long as 120-150 days. In this case, the same fleet with a removal interval of 10,000EFH would have 720-900 days in progress, thereby raising the number of spare engines required.

With the original TAT of 90 days, a fleet of 20 aircraft would have 800 days in progress, which could be supported by two owned, fully utilised engines, and a smaller requirement for short-term leased engines.

The unpredictable requirement for spare engines caused by unscheduled removals, however, incurs additional cost.

Reducing engine inventory costs focuses on three or four main factors.

The first is a more accurate prediction of removal interval and timing, which leads to the second: a more even flow of engine removals, and so a better estimate of the number of spare engines required. The third is a reduction in shop visit TAT, and the fourth is an effective increase in fleet size to achieve economies of scale, thereby reducing the spare engine requirement per aircraft.

Predicting removals

Predicting scheduled removals has traditionally been done using manual interpretation and removal decisions based on analogue data from condition monitoring systems. "Ideally an airline does not want to have any unexpected events or removals," says Russ Shelton, general manager of maintenance marketing at GE Engine Services. "Better removal planning will be the result of better quality monitoring."

Traditional condition monitoring systems have been used to indicate when the condition of engines is approaching the specific removal criteria specified by the Federal Aviation Administration (FAA) and Joint Airworthiness Regulations (JAR). The number of parameters monitored, however, was limited and accurate interpretation difficult. These systems have also been unable to limit the number of unscheduled engine removals. Shelton estimates that up to 30% of General Electric and CFM International engine material is tied up in support inventory, with the remaining 70% on installed engines.

"The percentage of support inventory will be as low as 10% for the most efficient airlines, but the higher the percentage of material in support inventory generally the higher the proportion of unscheduled removals," explains Shelton.

Accurate monitoring systems, including remote diagnostics, are used to provide a more exact picture of more engine performance parameters. Remote diagnostics flag early divergence from a performance trend that may indicate problems arising, thereby providing better criteria for deciding the timing of engine removals. This is also used to diagnose problems as they arise so that they may be treated on-wing, thus preventing an unscheduled or early scheduled removal.

"Limiting the number of unscheduled removals starts with training pilots to derate engines to a higher degree whenever possible, and also to start and rev up engines more gently," explains Pierre Gires, general manager commercial overhaul operations at Snecma Services. "It also helps if the engine is cleaned and washed correctly.

"Staggering removals to achieve an even flow of shop visits also helps, and this can be done by proper engine removal planning, which we do with one of our major customers, Northwest Airlines. This is achieved by using the data from remote diagnostics to predict and plan removals," continues Gires. "Accurate fleet management and removal allow a more accurate prediction of spare engine requirements, but also help postpone removals. On-wing support and repairs in conjunction with remote diagnostics also leads to a reduction in unscheduled removals."

Removal interval

The benefits of higher quality condition monitoring translate into fewer unscheduled removals, and also an increased removal interval.

Remote diagnostics are supplied by engine maintenance providers, including GEES and Snecma Services, in isolation or as part of a larger overall engine management package for airlines. Other elements can include engine maintenance and on-wing support. The decision to perform these is based on findings and data from remote diagnostics.

As Gires already comments, lower take-off derate, gentler handling and better cleaning also contribute to lower removal rates, and also improve removal intervals.

Remote diagnostics also allow a more even flow of removals, and so can prevent overlapping of several removals at the same time. This reduces the number of engines required for a high certainty of spare engine coverage, such as 96%, down to the same number that would provide 50% coverage in normal circumstances. Two engines would therefore provide coverage for removals for 96% of the time rather than three for the fleet of 10 A320s or 737s with an average removal interval of 10,000EFH.

Turnaround time

Shop visit total turnaround time plays an important role in reducing engine inventory requirements. TATs can be as long as 150 days, because significant delays can be experienced when engines are removed and shipped to engine shops. Engines can also be split into modules, which can then be shipped to different engine shops. Further delays are incurred when the repair of some components takes longer than the remainder of the engine in the shop visit.

TAT is extended if all original components and repaired modules are reassembled to the same engine. TAT can therefore be reduced by swapping modules or components between different engines in various stages of maintenance. TATs of 45 days, for example, are not possible for an overhaul if all original modules are reassembled, since the repair of some takes longer than this.

TATs are therefore easily reduced with strict control over time spent shipping, disassembling, reassembling, testing and reinstalling engines. Some airlines allow modules to be swapped, in which case TATs have been known to be as short as 45-50 days.

The disadvantage of swapping modules and parts is that the amount of inventory material increases, so airlines have to find an economic balance between TAT and amount of inventory required to support its operation.

"TATs can be reduced if engine shops have long-term contracts with customers, since modules will be swapped but kept within the same fleet if there are a high number of engines in progress," explains Gires.

"Tight control over TATs requires the supply of parts and repairs to be coordinated. Long TATs caused by shop inefficiencies can be compressed. A normal TAT is 70 days, and a good level is 55-60 days if modules are not swapped," says Roger Welaratne, managing director at Shannon Engine Support.

An engine shop visit therefore requires a high degree of coordination, and weak links in the chain can upset the process. "The whole process or co-ordination can be managed well with a computer system, and if done properly can make TAT predictable," says Shelton. "Predictability of TAT is important so that planning can be made and long delays avoided. Delays in returning engines from the shop are expensive in terms of engine inventory costs, because they have to be covered by short-term leases, which are relatively expensive.

Spare engine pooling

Spare engine pooling was devised to give a group of airlines economies of

Reducing shop visit turnaround time is a crucial element in reducing engine inventory costs. This can be achieved in many cases by using computers to monitor and coordinate all the processes and repairs to prevent delays.

scale in fleet size and a higher degree of asset utilisation, thereby lowering the spare engine requirement per aircraft. "Pooling only works if the pool members are physically close together," comments Shelton. "The requirement for closeness of location is reduced if removals can be more accurately predicted, thus giving the pool more time to ship spare engines to the airline that requires them."

"Pooling is now less fashionable," adds Welaratne "because airlines are now deliberately undersupplying themselves in an effort to cut costs to the bone. It still makes sense for large engines like the GE90, since not all airlines can afford to have spare units located at remote stations. Some airlines, such as British Airways and Qantas, pool certain types of engines at London and Sydney. Pooling is complicated in most cases, however, because of the ownership structure of a pool and the different tax breaks on the engines each airline has in its country of domicile. It is actually simpler for airlines to own an engine and lease it, if possible, on short-term contracts."

Pooling is still popular in regions where airline fleets are relatively small and the same aircraft types are operated. Willis Lease Finance Corporation (WLFC), for example, has recently set up a CFM56-3/-7 pool with about 15 engines for five major Chinese airlines, including Air China. The pool is run by WLFC, which apportions the spare engines between the five airlines. WLFC only charges a usage fee when engines are used, and does not charge a pool membership fee.

Sale & leasebacks

The sale and leaseback of spare engines is usually done by airlines that are phasing out a fleet, when they require cash or want to pay off outstanding debt.

"Sale and leasebacks do not actually direct reduce the costs of engine inventory," explains Welaratne "but the cost of leasing can be cheaper than owning the engine if the lease term matches the airline's fleet plan. That is, lease rentals over a longer term will exceed the cost owning the engine. The economics of sale and leaseback depend on the point in the value cycle at which the engine was bought, the value at which it can be sold, and the outstanding debt. Sometimes a profit on residual value can be made, and the profit can also exceed the lease rentals that will have to be paid for the remaining time the engine is in the fleet. Lease rentals may also be less than the remaining debt payments that would have to be made if the engine was not sold.

Shelton explains that airlines can also reduce their spare engines needs, GEES can buy spare engines and lease them back to the pool at the appropriate rates of utilisation, while also guaranteeing spare engine availability. This way an engine that is surplus for a fraction of the time can be used to support another customer.

Older engine types

While current and young generation engines have been considered, many airlines operate fleets of out of production engines like the JT8D. The practice of airlines swapping timed-out engines with time-continued engines acquired on the aftermarket is well established. The supply of some older generation engines can be so high that the cost of buying time-continued engines on the aftermarket is considerably lower than putting engines through a shop visit. Airlines can thus reduce engine maintenance costs and avoid holding inventories of spare engines. This is currently possible with types such as the JT8D, JT9D and CF6-50.

"Although this policy may result in short-term savings, it is risky and probably results in a false economy," says Shelton. "There is one 737-200 operator that still overhauls its JT8Ds instead of buying time continued engines on the aftermarket. This way it gets a long removal interval compared to the time continued engines. Although time continued engines are cheap, cutting corners can be risky."

Costs can be raised in the long run, since the supply of time continued engines often dries up when this policy is followed by a lot of airlines. All engines left then have to be overhauled, meaning it may be cheaper for an airline in the long term to have a policy of achieving sustained cost reductions. Using time continued engines also results in more frequent engine removals.

Airlines may, however, take advantage of a high supply of engines at low value on the market and acquire an inventory of spare engines for a low capital investment, thereby reducing their long-term inventory costs. AC