The JT8D-200 requires simple maintenance management. Many operators do not plan removals or shop visit workscopes. The engine has good exhaust gas temperature margin retention and removal causes have been dealt with, gradually extending on-wing times. The engine is capable of having costs per flight hour similar to the CFM-56.

JT8D-200 maintenance costs stand up against CFM56-3/-5

Compared to many other engine types, the Pratt & Whitney (P & W) JT8D-200 series requires simple maintenance management. On-wing times and shop visit patterns and costs are consistent and predictable. There are about 2,200 JT8D-200s in operation. An analysis of how airlines manage their JT8D-200 removals and shop visits and what the resulting maintenance costs per engine flight hour (EFH) are, is undertaken here.

JT8D-200 description

The -200 series powers about 1,100 MD-80s and a small number of Super 27s. The MD-80 is concentrated in just 11 large fleets of original operators. Small fleets are now growing as a few airlines acquire used aircraft.

The JT8D-200 is a derivative of the baby JT8D series. "The -200's hot section is basically the same as the baby series'," says Tom McCoy, vice-president engineering at Pacific Gas Turbine Center. "The fuel nozzles are bigger and combustion chambers slightly different. The biggest change is that the -200 has a single fan stage and higher bypass ratio".

The -200 also has a redesigned low-pressure turbine (LPT) module. Both the -200 and the baby families have a single-stage high-pressure turbine (HPT) and the same low-pressure compressor (LPC) booster. "The bypass duct on the -200 has acoustical liners and a jet mixer with a longer exhaust tube, which helps it get Stage 3 performance," explains McCoy.

There are four variants of the -200: the -209, -217A, -217C and -219. The initial model was the -209, which powered the first MD-81s. This is rated at 18,500lbs.

"Most -209s have been upgraded to higher thrust variants of the -217 and -219," explains Heikki Kurikka, manager P & W engine group at Finnair.

The -217A and -217C are rated at 20,000lbs. The -219 is rated at 21,000lbs.

There are minor physical differences between the -217A and -217C. The -217C and -219 are physically the same, but have different thrust ratings. The -219 powers the highest gross weight MD-83, while the -217 powers the lower gross weight MD-82.

"The -200 has the advantage of being more modular than the baby series, making the -200 more accessible for maintenance," says McCoy.

In-service performance

The majority of MD-80s are operated on intra-European and domestic US routes, with flight cycle (FC) times in the region of 1.0–2.0 flight hours (FH). The extremes are the Danish domestic routes of about 30 minutes operated by SAS and some longer sectors of up to 3.0FH by American, Delta and Continental. The fleet average is an 80 minute cycle, or 1.33EFH.

Annual MD-80 utilisations are 2,500–3,000FH and 2,135–2,565FC.

Operators either plan their engine removals or manage their JT8D-200 maintenance on an on-condition basis, where removals are unplanned.

The global fleet has an unplanned shop visit rate (SVR) of 0.127 per 1,000EFH; equal to 7,900EFH between removals. The total SVR is 0.161, equal to an average shop visit interval of 6,200EFH and 4,660 engine flight cycle (EFC). The unplanned SVR indicates that more than 50% of shop visits are unplanned. Such visits include removals due to foreign object damage and technical problems.

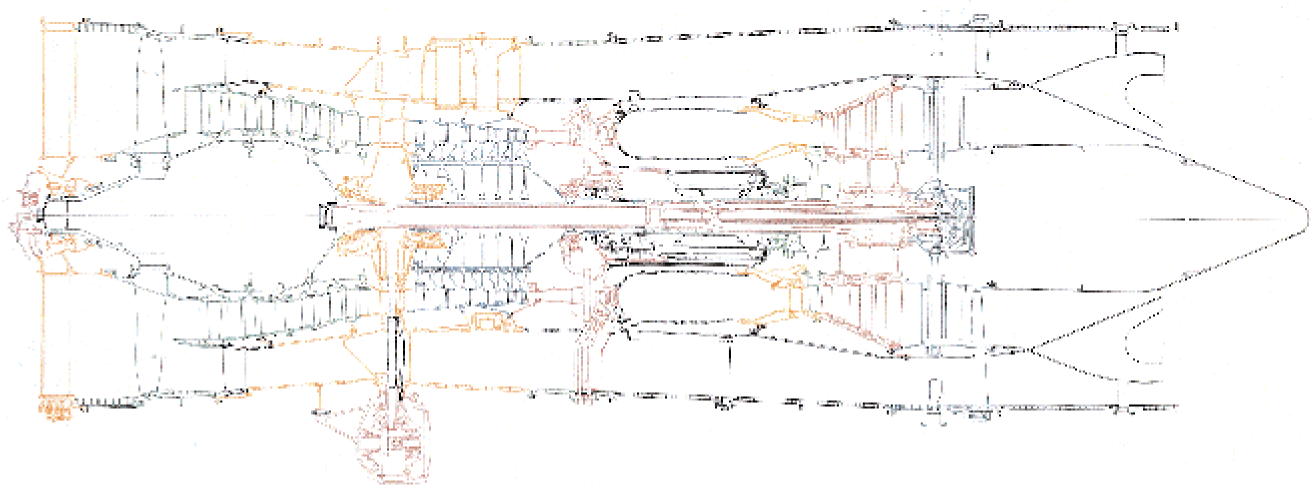
Operators that have a planned removal and shop visit pattern have generally conformed to either an alternating pattern of hot-section inspections (HSIs) or overhauls, or constant heavy shop visits. HSIs, or shop visits with a similar workscope, are often referred to as an engine shop visit 1 (ESV1), and overhauls or heavy workscopes, as ESV2s.

The JT8D-200 is generally regarded as being capable of achieving 8,000–10,000EFH on-wing between scheduled removals. An average cycle time of 80 minutes (1.33EFH) makes this equal to 6,000–7,520EFC.

"As a rough guide, we could, in theory, get an interval of 9,000EFH from ESV2 to ESV1. About the same is possible again to the next shop visit; an ESV2," says Kurikka. Finnair has an average FC of 1.6FH, and this type of removal and shop visit pattern would result in a shop visit on average once every 5,625EFC.

"This would result in a total of 18,000EFH/11,250EFC for an overhaul cycle of one ESV1 and one ESV2. This is rarely achieved because of unscheduled

JT8D-200 SERIES ENGINE



removals," explains Kurikka.

"Because of additional unscheduled removals our average interval between all shop visits is similar to the global fleet; 6,200EFH. In our case, this is 3,800EFC," says Kurikka.

Like Finnair, operators with planned shop visits will have a scheduled pattern of alternating ESV1 and ESV2 workscopes, with interruptions by unscheduled visits.

The ratio of unscheduled to scheduled removals will depend on quality of maintenance, but also on problems with the engine's durability. Longer on-wing times achieved between scheduled removals will directly increase average removal intervals, as well as reducing the ratio of unscheduled removals.

Other airlines that operate a planned removal and shop visit pattern are Continental and SAS. They have their engines maintained by Volvo Aero Engine Services (VAES). "Actual on-wing time depends on how our customers manage their powerplants," says Jerker Nylund, engineering at VAES. "Engines in lease-back transactions or that are being phased out will reduce the average shop visit interval because their operators find it economic in the short-term to have small workscope shop visits.

"We build engines during a shop visit that achieve on-wing times as long as 8,000–10,000EFC," says Nylund. "This long interval is because we operate a constant ESV2 shop visit pattern. Because about 10–15% of removals are unplanned the actual average we get is about 6,500EFC between each shop visit. Although engines can be built for 10,000EFCs, some will not last this long because of problems with 4th stage turbine blade tips and the 8th compressor stage stator.

"In the case of Continental, which operates 2.0FH cycles, this 6,500EFC interval is about 13,000EFH. We have been maintaining Continental's engines for about one and a half years and expect the same engines to come back to the shop about once every four years."

Other operators manage their engines with less emphasis on scheduled removals and a specific shop visit workscope pattern. "Many airlines maintain their engines on an unscheduled removal basis," says Mark Brown, senior director sales and customer service at Avteam. "This is seen with airlines that have acquired small fleets of used MD-80s. Many operators do removals and maintenance on an on-condition basis, rather than a fixed pattern or alternating ESV1/ESV2 shop visits. This is in contrast to large fleets operated by original operators."

Other JT8D-200 maintenance shops see that a traditional shop visit pattern of alternating ESV1/ESV2 workscopes is being replaced by on-condition removals and customised workscopes. "Small operators do not want to 'gold-plate' their engines, which is different to the way large fleets manage their powerplants," says McCoy.

Operators using unplanned removals and an average FC time of 1.33FH will achieve intervals of about 6,500EFH and 4,900EFC. Because of an on-condition maintenance philosophy, shop visits do not conform to any particular workscope pattern.

Removal causes

Removals of the JT8D-200 are generally not forced by exhaust gas temperature (EGT) margin erosion. While the JT8D-200 will lose some EGT margin, rate of erosion is low and removals are triggered by other causes.

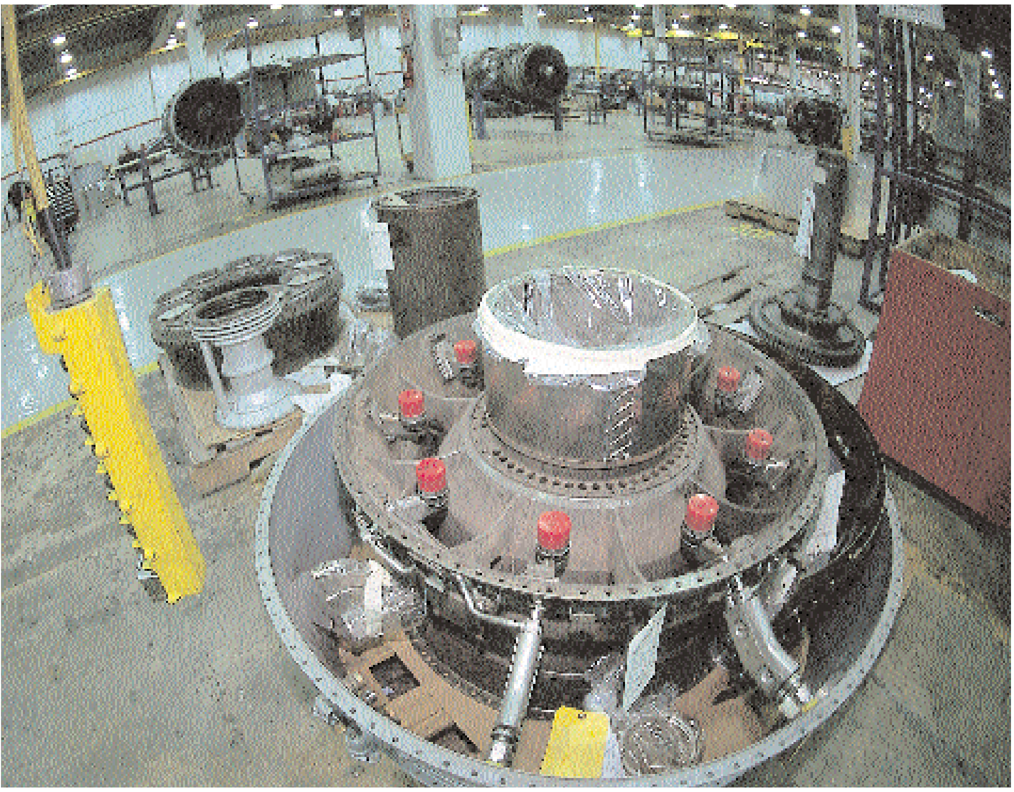
"We have not removed any JT8D-200s for EGT margin erosion," says Kurikka. "This has to be considered against our cool operating environment and 80% de-rate of take-off thrust, which preserves EGT margin.

"A new or freshly overhauled engine will have an EGT margin of 25–30 degrees centigrade, which is small compared with the CFM56. Modern engines have hi-tech turbine blade tip clearance control, and consequently higher EGT margins.

"A JT8D-200 with a 25 degree margin after an overhaul will probably lose 5 degrees of margin after the first 1,000–2,000EFH on-wing. The rate of EGT margin erosion then declines. An engine can stay on-wing for 10,000EFH, or even as long as 20,000EFH and EGT margin will have hardly declined.

"If an ESV1 is done at 10,000EFH, by which time the EGT margin will have reduced to about 10 degrees centigrade, only about 5 degrees will be regained. An overhaul will restore the margin to the 25 degree level," says Kurikka.

The EGT margin is higher for lower thrust rated JT8D-217s; at about 35-45 degrees centigrade. EGT margin erosion is low for the -200 series because EGT margin is based on an outside temperature of 40 degrees centigrade, which is rarely reached. The actual EGT margin is therefore higher in most operations. "EGT margin erodes at a rate of 1.5–2.0 degrees C per 1,000EFC," explains Nylund. A 6,000EFH on-wing time will therefore see a small erosion and plenty of margin left when the engine



Despite low EGT margin compared to modern engines, the JT8D-200 rate of EGT margin is low and removals are caused by factors relating to wear and tear.

is removed because of other reasons".

The JT8D-200 tends to be removed for shop visits for a variety of factors relating to mechanical wear and tear. One common problem is 4th turbine stage blade tip wear. These tips are provided by a shroud which join to form a ring. "There is a service bulletin (SB) issued to deal with this wear problem," says Nylund.

There has also been a problem with the 8th stage HPC stator cracking, which again has been taken care of by a SB and a high-quality repair.

"Other causes are hot-section distress and vibration," says Kevin Hill, director technical operations at Aeroturbine. Common removal causes also include foreign object damage (FOD), fuel nozzle support assembly and time expiry of disks and shafts.

"Time on-wing used to be in the region of 3,000EFH for the majority of -200s," says Brown. "This performance has now been improved because of the SBs and airworthiness directives (ADs) issued to take care of technical problems".

FOD has not been helped by airlines using reverse thrust to push the aircraft back from the gate. "The problem of FOD is made less difficult by the -200's modular design," explains McCoy. "Another well-known difficulty has been high oil temperatures and uncontained fan blade failure due to tie-rod failures".

Removal management

As indicated, the JT8D-200 is capable of on-wing times of 8,000–10,000EFH between scheduled removals, when engines are operated on an alternating ESV1/ESV2 programme. On-wing times have improved from lower levels since various SBs and ADs were issued to deal with the most common removal causes.

The average on-wing time is reduced by unscheduled removals, again caused by common removal causes, to about 6,200EFH/4,660EFC.

The actual shop visit pattern and EFHs and EFCs achieved every overhaul cycle is affected by the lives of disk and shaft life limited parts (LLPs). The JT8D-200 is simplified by most of its LLPs having just EFC life limits, which are set at 20,000EFC. There are a few LLPs that have lives of more than 20,000EFC.

Ideal shop visit scheduling will occur when the 20,000EFC lives of LLPs coincide with an overhaul or ESV2. A heavy shop visit or overhaul is required when LLPs have to be replaced. If LLPs expire when an ESV1 or light shop visit otherwise occurs, then costs will be higher because workscopes will have to be increased.

LLPs also often expire between scheduled shop visits, when only a small number of EFCs have accumulated since the previous shop visit. It is more economic to replace LLPs, for example, during a shop visit if their remaining lives are say 2,000EFC less than the predicted 4,000EFC interval to the next shop visit, rather than keeping them and having another shop visit after just 2,000EFC.

Maintenance and removal pattern is also simplified if all LLPs have the same lives, and replaced at the same time.

Maintenance is complicated by a few LLPs that have shorter lives than the rest. One such part in the JT8D-200 is the low pressure (LP) shaft. "The LP shaft is affected by SB 5019 which requires oil holes to be reworked," says Andres Cedeno, vice-president engineering at Avteam. "The LP shaft has a full life limit of 25,000EFC, but this can only be reached if the shaft is removed at 12,000EFC. This means engine disassembly to remove the shaft is required at the 12,000EFC interval. This then affects the workscope and makes it hard to manage and schedule shop visits. This re-work of the LP shaft then effectively forces a heavy workscope and dictates shop visit scheduling".

The need to re-work the LP shaft after 12,000EFC means only two average shop visit intervals of 4,660EFC, a total of 9,320EFC, can be performed. The probability of an unscheduled removal at some point means that three shop visits within the 12,000EFC limit will actually have to be accomplished. One of these will be a repair workscope. The third shop visit will have to be an ESV2 for LP shaft re-work.

This will leave 8,000EFC until another ESV2 is required to replace all LLPs after a life of 20,000EFC. This 8,000EFC interval will probably include two shop visits: one ESV1 and one ESV2.

Five shop visits are likely to be required over two average overhaul cycles; limited at 20,000EFC of the LLP life limit. On average one will be a repair, two will be ESV1s and two ESV2s.

The number of shop visits and type of each workscope performed is influenced by average FC time and scheduled removal interval.

Finnair's FC time of 1.6FH and average interval of 6,200EFH/3,800EFC, means that 11,400EFC and three removals can be accomplished by the time of the LP shaft re-work limit of 12,000EFC. Another two shop visits can be performed in the remaining 8,600EFC until LLP replacement is required. This way Finnair can expect to use about 19,000EFCs of the 20,000EFCs of the LLP lives over the course of five shop visits. "These five will be two ESV2s and either one ESV1 and two repairs, or two ESV1s and a

SUMMARY OF JT8D-200 MAINTENANCE COSTS

Style of shop visit management	Alternating ESV1/ESV2	Constant ESV2
FH:FC ratio	1.6	2.0
Average shop visit interval	6,200EFH/ 3,800EFC	13,000EFH/ 6,500EFC
1st overhaul cycle		
Number of shop visits	3	2
Shop visit types	Repair, ESV1, ESV2	ESV2
Interval between shop visits	6,200EFH/ 3,800EFC	12,000EFH/ 6,000EFC
Total interval	18,600EFH/ 11,400EFC	24,000EFH/ 12,000EFC
2nd overhaul cycle		
Number of shop visits	2	1
Shop visit types	ESV1, ESV2	ESV2
Interval between shop visits	6,200EFH/ 3,800EFC	13,000EFH/ 6,500EFC
Total interval	12,400EFH/ 7,600EFC	13,000EFH/ 6,500EFC
Total interval	31,000EFH/ 19,000EFC	37,000EFH/ 18,500EFC
Workscope costs		
Repair $	250,000	250,000
ESV1		
Man hours	2,000	
Materials $	200,000	
Sub-contract repairs $	80,000	
Total cost	380,000	
ESV2		
Man hours	4,500	4,750
Materials $	350,000	400,000
Sub-contract repairs $	250,000	350,000
Total cost $	825,000	987,500
Total shop visit costs $	**2,300,000–2,700,000**	**2,700,000**
LLP amortisation		
Life utilisation	19,000EFC	18,500EFC
LLP replacement $	**855,000**	**855,000**
Total maintenance budget		
Shop visit costs	$90/EFH	$73/EFH
LLP replacement	$29/EFH	$23/EFH
Total	$119/EFH	$96/EFH

repair," explains Kurikka. This 19,000EFC interval is equal to 31,000EFH *(see table, page 26)*.

VAES' system of a constant ESV2 shop visit pattern and average 6,500EFC removal interval allows LP shaft re-work on the second shop visit and full LLP replacement at the third. The second shop visit must be done before 12,000EFC. A third visit will be done after 6,500EFC, when full LLP replacement takes place. This way, about 18,500EFC out of the 20,000EFC LLP lives will be used over the three shop visits.

With a 2.0FH cycle time, an overhaul cycle will be about 37,000EFH, which will be accumulated for every LLP replacement cycle *(see table, page 26)*. Shorter cycle times will reduce the EFH for a similar number of cycles.

These two scenarios of engine removal and shop visit management influence maintenance and LLP replacement costs per EFH/EFC. Shorter FC cycle times and short average EFH intervals incur more shop visits, some of them light workscopes, in the 20,000EFC LLP life limit. Longer average EFH/EFC intervals means fewer but heavier shop visits over the same EFC interval.

Shop visit workscopes

The three broad categories of workscope are unscheduled repair, ESV1 and ESV2. As already described, operators use either an unscheduled and on-condition maintenance system, or a scheduled pattern of ESV1 and and ESV2 shop visits. "Small US operators tend to do less shop visit planning and operate on-condition programmes than European carriers," explains Kurikka.

Many scheduled workscope patterns alternate ESV1 and ESV2 shop visits. ESV1s are generally intended to restore performance and some EGT margin. "There is a P & W maintenance planning guide and engine management plan," says Kurikka "but this does not give precise definitions of a workscope. The purpose of the ESV1, in our case, is not so much EGT margin restoration but to restore turbine mechanical durability".

This is relevant to many operators considering the 4th turbine blade shroud wear problem. ESV1s involve work on the hot section of the engine, but rarely the fan or compressor. EGT margin is restored by 5–10 degrees centigrade".

The ESV2 is heavier and involves work on all modules. EGT margin will be restored by about 25 degrees centigrade for lower thrust variants. Besides full disassembly, inspection and parts repair or replacement, the ESV2 also provides an opportunity for LLP replacement and LP shaft re-work.

In the case of VAES, which operates a constant ESV2 pattern for Continental's and SAS's engines, the workscope will be heavier than one in which an alternating ESV1/ESV2 pattern is used.

Unscheduled repairs will vary widely in workscope. The JT8D-200 has several interesting problems that force small unscheduled removals and repairs. "Examples are the oil system, LPT 4th blade wear problem and internal sulphidation on cluster vanes," says Cedeno. "The highest thrust-rated -217C and -219 experience a high rate of wear in their LPT blades. The oil system has a problem of oil mixing with air heating up and then breaking down, and so no longer lubricates".

Larger unscheduled repairs will be used by airlines operating on-condition maintenance. "These workscopes will be customised," explains McCoy.

Workscope inputs

The three workscope inputs are labour, materials and vendor repairs.

Man hours (MH) required for an ESV1 and ESV2 are fairly predictable. "These are about 1,800–2,200 for an ESV1" says Hill. The ESV1 has less parts repair and mainly involves disassembly and inspection than an ESV2. Low parts repair also reduces material cost and vendor repairs.

The spread between MH, materials and vendor repairs is determined by the in-house repair capability that a shop has. "We can repair some parts, but we outsource turbine repairs because they have expensive coatings," says Kurikka. "Material accounts for about 50% of the total shop visit cost; 30% is for labour and 20% is sub-contract or vendor repairs. If more repairs are done in-house then labour and material costs will be higher, but sub-contract repairs less". Kurikka estimates about 2,200MH are used for an ESV1.

Total cost for an average ESV1 across the industry is in the region of $300,000–$400,000. Labour of 1,800–2,200MH charged at a unit rate of $50 will total $90,000–$110,000. Finnair, which has a high level of parts repair, estimates about $200,000 will be required for materials. Another $80,000 will be used for vendor repairs, taking the total cost for an ESV1, excluding LLPs, to $370,000–$390,000 *(see table, page 26)*.

Hill of Aeroturbine estimates a similar total in the region of $360,000. The cost of an ESV1 will be higher if the workscope is increased by the need to replace LLPs.

An ESV2 will consume about 4,000–4,500MH, which includes special processes for sophisticated repairs. "We cap MH at 2,850 for an ESV2, but this does not include special processes and repairs," explains Brown at Avteam. "European shops build labour for this into their MH portion, while European shops tend to bill them separately as sub-contract repairs".

A labour portion of 4,000–4,500MH will cost $200,000–$225,000. This will be accompanied by a material cost in the region of $350,000 and sub-contact repairs in the region of $150,000–$300,000. This will take total cost, excluding any LLPs, to $700,000–$850,000.

A heavier EVS2, such as that used in a constant ESV2 workscope pattern, will incur a higher cost approaching $1 million.

The cost of customised workscopes for operators using an on-condition maintenance programme will vary between the costs of an ESV1 and ESV2; $360,000–$850,000.

Smaller unscheduled repairs in a scheduled programme will vary between $150,000–$400,000, averaging $250,000.

Shop visit scheduling is complicated by the need to re-work the LP shaft at 12,000EFC. This forces the heavy shop visit. Shop visit planning has to consider this interval in relation to scheduled time that is possible between removals and unscheduled removal intervals.

LLPs are the other main element. A full set has a list price of $855,000. Although a few parts have lives of more than 20,000EFC, it will be economic to replace them all at the same time to avoid 'stub' lives of LLPs. If engines get unmatched LLP lives then maintenance costs escalate. Stub lives can often occur when LLPs in the turbine are changed to speed up the throughput time. It is also difficult for many shops to return original material to the same engine. This is caused by logistical problems of third-party repairs".

Maintenance costs

In the case of an airline conforming to a pattern such as that operated by Finnair, five shop visits, with an average interval of 3,800EFC, can be made in the 20,000EFC LLP life overhaul cycle timeframe.

This will involve two ESV2s, and either one repair and two ESV1s or two repairs and an ESV1 *(see table, page 26)*. The total cost of these five shop visits will be in the region of $2.5–$2.7 million. This will be incurred over an overhaul cycle of 18,500–19,000EFCs, or 31,000EFH. The cost will therefore be $135–142 per EFC. A cycle of 1.6FH will make this equal to $85–90 per EFH *(see table, page 26)*.

A full set of LLPs removed at this 18,500–19,000EFC limit will produce a cost of about $46 per EFC. This will take total costs to $119 per EFH *(see table, page 26)*.

A constant ESV2 programme, with an average interval of 6,500EFC, will achieve three shop visits in an overhaul cycle of about 18,500EFC. These three ESV2 will have a cost of about $1 million each. Unscheduled repairs will, however, be cheaper and reduce the average shop visit cost. If unscheduled removals account for 15% of all removals and have an average cost of $250,000 then average shop visit cost in the overhaul cycle will be about $900,000 *(see table, page 26)*. The three shop visits will have a total cost of $2.7 million. This will result in a cost of $146 per EFC, or $73 per EFH for a 2.0FH cycle time. A shorter FC time of 1.5FH will increase this to about $100 per EFH.

LLP amortisation will be similar to the alternative schedule of about $45 per EFC, or $23 per EFH. Total costs will be $96 per EFH.

Nylund explains that a constant ESV2 workscope pattern is best in terms of LLP life utilisation, but low costs per EFH are only likely to be obtained with this system if an average FC of 2.0FH or more is operated.

A constant ESV2 pattern results in similar costs per EFH and EFC as a pattern of more frequent and lighter workscopes. It will mean, however, fewer shop visits in the same EFC interval with consequential benefits in fewer spare engines.

This analysis indicates that similar costs per EFH can be achieved with different systems of shop visit patter and removal scheduling. It also shows how a managed system of scheduled removals will also allow an airline to realise costs per EFH that are comparable with the CFM56-3 and -5A/B series. This is an important ingredient which will help the MD-80 maintain an economic operation compared to replacement candidates. AC