The amortisation of life limited parts accounts for a high portion of maintenance costs for engines operated on short-haul missions. Careful management can bring heavy engine shop visits to coincide with life limited part expiry, producing savings for airlines.

LLP management for short-haul engines

The management of disk and shaft life limited parts (LLPs) in engines used on short- and medium-haul operations is an essential in minimising maintenance costs. Airlines need to be aware of the main issues that influence LLP management.

Main principles

The main engines operated on short-haul missions are the: Rolls-Royce (RR) Tay 620/650 powering the Fokker 70 and 100; RR BR715 powering the 717; Pratt & Whitney (PW) PW6000 powering the A318; PW JT8D-200 powering the MD-80 series; CFM56-3B/C series powering the 737 Classics; CFM56-7B series powering the 737NG; CFM56-5A/B and V2500 both powering the A320 family; and RR RB211-535E4 and PW2000 both powering the 757-200.

The manufacturer's list price for a full set of LLPs in most of these engine types usually usually equals or exceeds the cost of a shop visit. A full set of LLPs for a V2500 or CFM56-7B has a list price of $1.7 million.

The lives of LLPs are specified in engine flight cycles (EFC), and in most cases are 15,000-30,000EFC. Most short-haul engine shop visit intervals are in the region of 6,000-12,000EFCs *(see Maintenance cost analysis: JT8D-200, CFM56-5B/-7 & V2500, Aircraft Commerce, December 2002/January 2003, page 18)*. LLPs are therefore replaced at frequent intervals compared to engines operated on long-haul missions, which have shop visit intervals in the region of 1,500-3,000EFC.

LLPs account for a large percentage of overall engine maintenance costs per engine flight hour (EFH). Reductions in engine maintenance costs can be made with improved LLP management.

LLP lives cannot be exceeded, so some engine removal intervals can be compromised to replace one or several LLPs. Engine maintenance costs are reduced if the interval between shop visits is extended. Shop visit costs will become excessive, however, if the interval is extended too much. The optimum on-wing interval for the lowest cost per EFH in respect of shop visit input may occur at a time when LLPs still have a few thousand EFCs remaining. LLP replacement at this stage will be necessary if remaining lives are not to limit the subsequent removal interval. The several thousand EFCs of remaining LLP life, or 'stub life', will not be used and the parts will be scrapped. If scrapped with excessive stub life the amortised cost per EFC and EFH is increased.

Shop visit workscopes also vary, with heavier ones requiring more extensive disassembly and re-assembly. One that requires a high level of disassembly is preferable for LLP replacement, since man-hours (MH) for disassembly account for a large percentage of shop visit costs.

The lowest cost per EFH is achieved when a heavy shop visit coincides with full LLP utilisation.

Engine configuration

Engine construction and maintenance revolve around modules. All engines analysed here have two shafts, except the RB211-535E4 which has three. Most engines have the four main modules of the fan and low pressure compressor (LPC) or booster, high pressure compressor (HPC), high pressure turbine (HPT) and low pressure turbine (LPT) that contain engine turbomachinery. The RB211-535E4 in addition has an intermediate pressure compressor (IPC) and intermediate pressure turbine (IPT). All these engines have other modules, but these do not have engine turbomachinery and LLPs.

Tay 620/650

The Rolls-Royce (RR) Tay 620 and 650 are thrust rated at 13,850lbs and 15,100lbs. The Tay has a fan section, three LPC stages, 12 HPC stages, two HPT stages and a three-stage LPT.

The Tay 620 has LLP lives that relate to two types of operation. "The first of these is a normal operation, for which all LLPs in the four modules have lives of 22,000EFC *(see table, page 37)*," explains Michael Goeing, chief engineer of the BR715 and Tay at Rolls-Royce. "There is also the hot and high operation, for which LLPs are lifed at 20,000EFC. The same two types of operation are used for the Tay 650. In the case of normal operation all LLPs have lives of 22,000EFC. For hot and high operation most LLPs have lives of 20,000EFC, although the first stage HPT has a life of 14,200EFC and the first stage LPT has a life of 19,250EFC."

BR715

The BR715 has two thrust ratings of 18,500lbs and 21,000lbs. The engine has a fan, two-stage LPC, 10-stage HPC, two-stage HPT and a three-stage LPT.

Like the Tay 620/650, LLP lives vary depending on style of operation. "In a moderate climate at a thrust rating of 18,500lbs, the BR715's LLPs have lives of 20,000EFC, although the target is for this to be extended to 25,000EFC," explains Goeing. "The engine is still young, but this target should be achieved by the end of 2005. When operated in an island hopping mode the engine's LLPs are rated at 25,000EFC, although LLPs in the LPT are already at 43,800EFC and LLPs in the booster at 68,000EFC."

There are three styles of operation for the BR715 rated at 21,000lbs. The first is in a moderate climate; all LLPs have lives of 15,000EFC *(see table, page 37)*,

LLP LIVES OF ENGINE TYPES OPERATED ON SHORT-HAUL MISSIONS

Engine variant	Thrust rating lbs	Fan & LPC LLP EFC	HPC LLPs EFC	HPT LLPs EFC	LPT LLPs EFC
Tay 620 - normal operation	13,850	22,000	22,000	22,000	22,000
Tay 620 - hot & high operation	13,850	20,000	20,000	20,000	20,000
Tay 650 - normal operation	15,100	22,000	22,000	22,000	22,000
Tay 650 - hot & high operation	15,100	20,000	20,000	14,200-20,000	19,250-20,000 * Corrosion inspection
BR715 - moderate climate	18,500/21,000	15,000	15,000	15,000	15,000
BR715 - tropical climate, derate	18,500/21,000	15,000	15,000	12,000-15,000	15,000
BR715 - tropical climate	18,500/21,000	15,000	15,000	5,000-15,000	15,000
PW6000	22,100/23,800	25,000	25,000	25,000	25,000
JT8D-200/-217A/-217C/-219	18,500/20,000/21,000	20,000	20,000	15,000/20,000	12,000/20,000
V2500-A1	25,000	20,000	12,000-17,000	15,000	20,000
V2500-A5	23,000/24,500/26,600/30,400/33,000	20,000	20,000	20,000	20,000
CFM56-3B1	18,500/20,000	30,000	20,000	20,000	25,000-30,000
CFM56-3B2	20,000/22,000	30,000	18,000-20,000	15,800-25,000	25,000
CFM56-3C1	22,000/23,500	30,000	15,000-20,000	15,100-17,000	25,000
CFM56-5A1/A4/A5/A3	22,000/23,500/25,000/26,500	30,000	20,000	16,700-20,000	24,000/25,000
CFM56-5B	22,000/23,500/27,000/30,000/31,000/33,000	19,000-30,000	13,900-20,000	14,300-20,000	20,600-25,000
CFM56-5B/P	22,000/23,500/27,000/30,000/31,000/33,000	20,000-30,000	17,200-20,000	14,300-20,000	20,600/25,000
CFM56-7B	19,500/20,600/22,700/24,200/26,300/27,300	23,600-30,000	13,000-20,000	14,700-20,000	19,500-25,000
PW2000	37,250/41,700	20,000	20,000	20,000 AD 72-220 inspection	20,000/30,000
RB211-535E4	40,100/43,100	LLPs vary between 14,000EFC and 27,000EFC throughout the engine.			

although a higher target of 17,000EFC has been set. In a tropical climate all LLPs have lives set at 15,000EFC, although the first stage HPT is currently limited to 12,000EFC. In a tropical climate without de-rate all lives are set at 15,000EFC, although the first stage HPT is currently limited to 5,000EFC.

PW6000

The PW6000 is due to enter service on the A318 in 2005, and has been designed with a single-stage fan, four LPC stages, six HPC stages, one HPT stage and three LPT stages. Dennis Enos, vice president commercial development programmes at Pratt & Whitney explains that the PW6000 has deliberately been designed with a small number of stages to minimise maintenance costs. "All LLPs in the engine have design lives of 25,000EFC *(see table, this page)*."

JT8D-200

There are four JT8D-200 variants. These are the -209 rated at 18,500lbs, the -217A and -217C rated at 20,000lbs and the -219 rated at 21,000lbs. The engine has the five main modules of the fan, booster, HPC, HPT and LPT.

The engine has a single-stage fan, five-stage LPC, seven-stage HPC, single-stage HPT and three-stage LPT.

LLP lives are mainly uniform, with a life of 20,000EFC *(see table, this page)*. Only the -217A has an HPC disk with a life of 15,000EFC and LPT shaft with a life of 12,000EFC.

V2500-A1/A5

The V2500 series has fan, LPC, HPC, HPT and LPT modules. The V2500-A1 series has a single fan, three booster stages, 10 HPC stages, two HPT stages and a five LPT stages. The -A5/-D5 series have a similar configuration except for a four-stage LPC.

There is a single variant of the V2500-A1, and this is rated at 25,000lbs thrust. LLPs in the V2500-A1's fan, LPC and LPT modules have lives of 20,000EFC. Those in the HPC and HPT have lives varying between 12,000EFC and 17,000EFC *(see table, this page)*.

There are five variants of the V2500-A5: the V2522-A5 rated at 23,000lbs; the V2524-A5 rated at 24,500lbs; the V2527-A5 rated at 26,600lbs; the

There are five variants of the V2500-A5, rated between 23,000lbs and 33,000lbs thrust. All models have uniform LLP lives of 20,000EFC.

V2530-A5 rated at 30,400lbs; and the V2533-A5 rated at 33,000lbs.

The -A5 series has a total of 25 LLPs. All current LLPs have lives of 20,000EFC for all thrust ratings *(see table, page 37)*, with one exception. Earlier part numbers of the stage 3-8 HPC drum had lives limited to 10,000-16,000EFC. A new part number 6A7705 has recently been introduced with a life of 20,000EFC.

The uniform life of 20,000EFC simplifies engine maintenance and LLP management.

CFM56 family

CFMI's policy for LLPs in the CFM56 is to have target lives of 30,000EFC in the fan/booster module, 20,000EFC in the HPC and HPT modules and 25,000EFC in the LPT module.

There have been several part numbers issued for each LLP in all CFM56 variants. Some of these have been superseded by later part numbers with longer lives, which were installed on the production line. Many of the latest part numbers equal target lives. Earlier built engines will have had to replace older parts with later part numbers.

Some parts have shorter initial lives at engine certification, but these are extended in increments with operational experience. CFMI tries to extend lives of LLPs ahead of EFC accumulated by fleet leader engines so that engines' on-wing intervals are not limited by individual LLPs. Lives quoted are for the latest part number of each LLP *(see table page 37)*.

CFM56-3 series

The CFM56-3 has the five main modules for fan, booster, HPC, HPT and LPT. The LPC has three stages, the HPC nine stages, HPT one stage and LPT four stages. There are three variants of the -3 series, and these are the -3B1 rated at 18,500lbs or 20,000lbs (Category A), the -3B2 rated at 22,000lbs (Category B) and the -3C1 rated at 23,500lbs (Category C). -3B2 engines can also be operated at Category A and -3C1 engines can be operated at Category A or Category B thrust ratings.

LLP lives vary with operated thrust rating; some parts in the higher-rated engines have shorter lives than in lower-rated variants.

A large number of part numbers for the -3 series have been issued since the engine's introduction in 1984. These have had varying lives, which have complicated engine management, but the most recent part numbers have more uniform lives.

For the lower rated -3B1, the three fan and LPC section LLPs all have lives of 30,000EFC, all five LLPs in the HPC section have lives of 20,000EFC, all four parts in the HPT have lives of 20,000, and all seven parts in the LPT have lives of 25,000EFC *(see table, page 37)*.

Lives of LLPs in the intermediate rated -3B2 vary. Two of the three LLPs in the fan and booster had initial lives of 30,000EFC, but have since had service bulletins (SBs) issued. Fan disk part number 335-014-511-0 had its original life of 24,900EFC extended by re-work to 30,000EFC, becoming part number 335-014-557-0.

Most parts in the HPC have a life of 20,000EFC, except the CDP seal which has a life of 18,000EFC. Parts in the HPT section have the highest degree of variation, with the front air seal at 15,800EFC and the HPT rear shaft at 20,000EFC. All parts in the LPT have lives of 25,000EFC *(see table, page 37)*.

The highest rated -3C1 also has a degree of part life variation. The fan and booster LLPs have lives of 30,000EFC, with the fan disk having been re-worked. Lives of HPC parts vary from 15,000EFC to 20,000EFC. LLPs in the HPT vary from 15,100EFC to 17,000EFC. Parts in the LPT have lives of 25,000EFC *(see table, page 37)*.

CFM56-5A series

The CFM56-5A/B has 18 LLPs.

The -5A has a three-stage LPC, a nine-stage HPC, a single-stage HPT and four-stage LPT. The engine has four different variants and thrust ratings: the -5A1 at 25,000lbs; the -5A3 at 26,500lbs; the -5A4 at 22,000lbs; and the -5A5 at 23,500lbs.

Most LLPs now have standardised lives for each thrust rating. All parts in the fan and booster have lives of 30,000EFC, and all parts in the HPC have lives of 20,000EFC. LLPs in the LPT module all have lives of 25,000EFC, with the exception of the Stage 1 disk in the -5A4 and -5A5 which has a life of 24,000EFC *(see table, page 37)*.

Parts in the HPT have varying lives. The HPT front shaft has a life of 20,000EFC in all four variants. The HPT disk has a life of 19,500EFC in all four variants, the HPT front rotating air seal has a life of 17,800EFC in the -5A1 and -5A3, and a life of 16,700EFC in the -5A4 and -5A5.

CFM56-5B series

There are two main sub-families of the CFM56-5B. These are the -5B series and -5B/P series. The P designation in the latter denotes a performance improvement, and LLPs in these engines have more uniform LLP lives. The -5B/P has been in production since 1996, and accounts for the majority of -5Bs that have been built. Moreover, some -5Bs that were built earlier have had their hardware updated to -5B/P standard during shop visits.

The CFM56-5B series has the same configuration as the -5A series, except for an additional LPC stage. There are nine variants, with thrust ratings between 21,600lbs and 33,000lbs. The -5B3 is rated at 33,000lbs and powers the A321, as do the lower rated -5B1 and -5B2. The -5B4, rated at 27,000lbs powers the A320, while the -5B5, -5B6 and -5B7 rated between 22,000lbs and 27,000lbs power the A319. Two others power the A318.

The CFM56-5B has 18 LLPs. The LLPs do not have uniform lives in all four modules. Some have reached their target lives, while others have shorter lives but are due to be extended. There are also several part numbers for each LLP in the -5B engine.

The fan disk has a life of 20,000EFC in all nine variants. The other two LLPs in the module have lives of 30,000EFC. All LLPs in the LPT have lives of 25,000EFC in all nine variants, except the Stage 3 disk in the -5B3 which has a life of 20,600EFC *(see table, page 37)*.

Lives vary in the HPC and HPT in all nine variants. Three HPC LLPs have lives of 20,000EFC. All other HPC and HPT parts have lives between 13,900 and 19,000EFC and are in the process of being extended.

The lives of LLPs in the fan/booster and LPT modules of the -5B/P series are the same as those in the -5B *(see table, page 37)*. All parts in the HPT module have a life of 20,000EFC, except the HPT front shaft which has a life of 14,300EFC. As with the -5B, three LLPs in the HPC have lives of 20,000EFC, while two have lives of 17,200EFC and 18,200EFC in all variants.

CFM56-7B series

The CFM56-7B has six variants, rated between 19,500lbs and 27,300lbs. The engine has 18 LLPs, and while not all have reached their target lives, the lives are of each part are uniform across all six variants. The fleet leader has currently accumulated about 15,000EFC.

In the fan and booster module the fan shaft has a life of 30,000EFC, while the booster spool has a life of 23,600EFC and the fan disk 27,600EFC. These two parts are due to have their lives extended to 30,000EFC.

All LPT parts have lives of 25,000EFC, except the LPT shaft which is at 19,500EFC *(see table, page 37)*.

Four of the HPC LLPs have lives of 20,000EFC, and one has 18,600EFC. Two HPT parts have lives of 20,000EFC, and the remaining two lives of 15,900EFC and 17,300EFC.

PW2000

The PW2000 has five main modules: the engine a fan stage, four-stage LPC; 12-stage HPC; two-stage HPT; and five-stage LPT. The engine has two thrust ratings of 37,250lbs and 41,700lbs.

"All LLPs have lives of 20,000EFC, except the LPC shaft and rear turbine hub which have lives of 30,000EFC," explains Jon Beatty, vice president of operational commercial engines at Pratt & Whitney. "A full set has a list price of $2.5 million. It is better to have uniform LLP lives, since this has a long-term cost advantage."

RB211-535E4

The RB211-535E$ is unique in this class of engines in that it has six main turbomachinery modules. These are the fan, IPC, HPT, HPT, intermediate pressure turbine and LPT. LLP lives vary between 14,000EFC and 27,000EFC throughout the engine.

Airworthiness Directives

Airworthiness Directives (ADs) have been issued that have affected the lives of LLPs in some engines. Lives that are reduced or inspections caused by ADs result in an uneven 'stack' of LLP lives in engine modules and cause early removals for their replacement. This raises maintenance costs, and results in an uneven 'stack' of LLP lives in modules,

CFMI's target is for fan & booster LLPs to have lives of 30,000EFC, HPC & HPT LLPs to have lives of 20,000EFC and LPT LLPs to have lives of 25,000EFC. Lives are uniform in each module in the -3B1, but there is some variation in the HPT & HPC modules in the -3B2 and -3C1 variants. Only a few parts in the -3B2 & -3C1 require small extensions to reach life targets.

because new LLPs are combined with time-continued ones. Engine manufacturers then introduce new part numbers which have lives equal to the originally intended life of the earlier part.

The Tay 620 has not had any ADs that have affected LLP lives, but the Tay 650 has one that could influence the lives of some parts. "The first concerns corrosion on LPT disks in extreme operating conditions, and could reduce life of LPT LLPs," explains Goeing. "This requires an inspection to check for corrosion."

The BR715 had an AD that affected the life of an LLP in the turbine of early build standard engines, but currently only affects a single leased engine.

There are no ADs affecting the PW6000 since the engine has not yet entered service.

The current PW2000 has no ADs concerning LLP lives, but there were some in the past. "AD number 72-220 affected the first turbine air seal," says Beatty "but this required an inspection and did not limit part life."

The V2500-A5 series has AD number 99-04-03 that reduces the life of the stage 9-12 HPC drum from 20,000EFC to 12,000EFC. This concerns part number 6A4156. Part number 6A7546 has since been introduced, which has a life limit of 20,000EFC, equal to the lives of all other LLPs in the engine.

The CFM56-3 has had several ADs relating to LLPs. The first, AD 97-08-01, affected a limited number of engines, but is now complete. AD 96-18-16 resulted in a reduction of the life of LPT stub shafts to part numbers 301-330-618-0, -619-0, -623-0 and -624-0 and LPT conical support to part numbers 305-056-106-0, -109-0, -110-0 and -111-0.

The CFM56-5A1's LPT rotor conical support was reduced to a life of 11,300EFC by AD 96-18-16. This concerned part number 336-000-305-0. Hinnerk Behn, propulsion systems engineer for the CFM56-5A/-5B and RB211 at Lufthansa Technik explains that a new part number has been introduced which has a life of 25,000EFCs for all variants of the -5A1.

The CFM56-A1 has also been affected by AD 99-06-16, which caused a reduction in the life of the engine's HPT front rotating air seal. "The affected part numbers were 1319M11P05/06/07/08/09, and their lives were reduced to 11,000EFC in case of the CFM56-A1 rating, if accumulated time had not reached 4,000EFC at the issue date of the AD. If more than 4,000EFC had already been accumulated then only another 7,000EFC could be accumulated," explains Behn. "This airseal thus caused early removals in a lot of engines. A new part number became available in 2002, which has a life of 16,700EFC or 17,800EFC, depending on thrust rating. This LLP is linked to the HPT disk, however. A new HPT disk, part number 1319M13P08, also has to be installed for the new rotating air seal's full life to be used. This AD caused a first engine removal at 9,100EFC for engines installed on our A319s. This is a much shorter interval than the engine's performance would have allowed. New HPT air seals were installed, but these were still limited to 9,100EFC because it was not economical for the second run to fit new HPT disks at the time. This means the second engine removal, during the first performance restoration shop visits, will be performed at a total time of about 18,000EFC."

The CFM56-5A and -5B were both affected by AD 97-06-01, which affected the HPC 1-2 spool in less than 50 engines. This AD required re-work for the LLP to achieve its original life limit, so caused no actual reductions.

There are no ADs affecting the CFM56-7B series.

The RB211-535E4 has no ADs affecting LLPs.

Removal intervals

Removal intervals are mainly related to EFC on-wing, rather than EFH, and are governed by several factors. The main removal driver in many engines is EGT margin erosion. Most engines also have several technical problems that account for a smaller percentage of removals.

Technical problems account for a higher percentage of removals in engines that have a high EGT margin. Engines with high EGT margin may also have removals due to LLP expiry.

First removal intervals are longer than subsequent and mature interval: LLP expiry in most engine types will come due at the second or third removal. The first shop visit is a performance restoration in most cases, involving the engine core. A second removal requires a heavier workscope, and usually a higher level of disassembly. Later removals will result in work on the fan/booster module. This can lead to a mismatch of shop visit intervals and full LLP life utilisation. Optimising LLP replacement and shop visit timing can be made easier by uniform LLP lives throughout the engine, although careful planning can achieve the same result.

As with all other CFM56 models, target LLP lives in the CFM56-5A/B series are 30,000EFC in the fan/booster, 25,000EFC in the LPT and 20,000EFC in the HPC and HPT modules. Most LLPs in the fan/booster and LPT in most variants have reached their target lives, while several parts in the HPC and HPT require life extension to meet target lives.

Tay 620/650

The Tay 620/650 are mature engines and have average removal intervals of 9,000-11,000EFC. Every second removal conveniently coincides with LLP life expiry. "This provides operators with simple engine management, and allows the majority of LLP lives to be utilised, since most engines are operated in 'normal' conditions, and so have LLP lives of 22,000EFC," says Goeing. An average interval of 10,000EFC would allow LLPs to be replaced at a stub life of 2,000EFC.

BR 715

The BR715 is a young engine, and the fleet leader has so far accumulated 9,000EFC. "The target average first run interval is 13,000EFC for engines rated at 18,500lbs, while it is 9,000EFC for engines rated at 21,000lbs," explains Goeing.

This implies that low rated engines would have LLPs with stub lives of 7,000EFC at the first shop visit. These could remain for the second interval, which would be limited to 7,000EFC. The second shop visit would then be a full overhaul with replacement of LLPs that had been fully utilised.

Higher rated engines would have a stub life of 6,000EFC after the first shop visit. The operator would then have two options: either limiting the second interval to 6,000EFC, at which point LLPs would be replaced after full life utilisation; or replacing LLPs at the first shop visit, scrapping parts with a stub life of 6,000EFC and performing a heavy shop visit to achieve a second interval of 9,000-10,000EFC.

PW6000

The PW6000 has not entered service yet, but Enos explains that the target on-wing life between removals is 12,500EFC. "It is anticipated that the engine will go through an alternating pattern of performance restoration or light shop visit and overhaul or heavy shop visit, with an average interval of 12,500EFC. The heavy shop visit will thus coincide with LLP life expiry, at which point they will be replaced, having used their full life. Unscheduled visits will disrupt this sequence of shop visits in some engines. The first removal interval of 10,000-12,000EFC should be possible with an expected EFH:EFC ratio of 1.4:1 and an installed EGT margin of about 120 degrees centigrade. Re-installed EGT margin will be about 90 degrees and 20-30 degrees will still be left after the second on-wing run, and so we expect a mature interval of 10,000-12,000EFC. The PW6000 has two ratings of 24,000lbs and 22,000lbs, and re-rating to 22,000lbs should gain an extra 2,000-3,000EFC."

JT8D-200

The JT8D-200 is operated by most airlines at an EFH:EFC ratio of 1.2-1.5:1. On-wing intervals vary according to the standard of shop visit workscope between 4,500EFC and 10,000EFC. A high standard workscope with a high level of parts replacement can typically achieve intervals of 8,000-10,000EFC and average EFH:EFC ratios, while a lower standard workscope, with a high level of parts repair will have intervals of 4,000-6,000EFC.

Most operators manage the engine with an alternating pattern of performance restoration and overhaul shop visit workscopes, often referred to as SV1 and SV2. "The ideal situation is where operators can get the heavy shop visit to coincide with near full LLP utilisation, so that excessive stub lives do not occur at LLP removal," says Charlie Cranshaw, manager of JT8D/JT9D customer technical services at Pratt & Whitney. "If an average interval of 8,000-10,000EFC can be achieved then the SV2s will be at 16,000-20,000EFC, which matches well with LLP replacement." Intermediate shop visit intervals of 6,000-7000EFC result in cheaper workscopes, but then LLPs come due for replacement at the second SV1 in the sequence after about 18,000-20,000EFC, and a higher level of engine disassembly and re-assembly is required.

A short interval of 4,000-5,000EFC results in LLP replacement coming due at about 16,000-20,000EFC at the second SV2, or fourth shop visit in the sequence. The lowest overall cost per EFH is likely to be achieved when maximum intervals of 8,000-10,000EFC are reached.

V2500-A1/-A5

The V2500-A1 and -A5 both have standard LLP lives of 20,000EFC, making it easier to manage the engine so that a heavy shop visit coincides with LLP expiry.

The -A1 is expected to have an on-wing interval of 7,000-10,000EFC to the first removal, and about a further 6,000-8,000EFC for the second interval, taking total time at the second interval to 13,000-18,000EFC. The first shop visit

The PW2000 has the advantage of uniform lives of 20,000EFC for all its LLPs, except for two which have lives of 30,000EFC. These lives of 20,000EFC simplify engine management.

will be a performance restoration, while the second will be an overhaul. The highest possible intervals will therefore result in a total time at the second shop visit of 17,000-18,000EFC, which will minimise the stub life of removed LLPs and achieve the lowest possible cost per EFC for LLP amortisation. Short intervals will lead to a total time at the second shop visit of 13,000-15,000EFC. This gives the operator a dilemma of replacing LLPs early, or waiting until the third shop visit at a total time close to 20,000EFC, at which point a high level workscope will be required for disassembly and re-assembly, resulting in a higher total maintenance cost per EFH. Improvements in engine hardware and reliability and good engine management should allow the -A1 to achieve the higher intervals of 8,000-10,000EFC.

The three lowest rated of the five main variants of the -A5 have high enough EGT margins for intervals to the second shop visit to total 16,500-18,000EFC *(see .2500 demonstrates simple maintenance management, Aircraft Commerce, October/November 2003, page 25).*

The two higher rated variants, the V2530 and V2533, typically have a first interval of 6,000-7,000EFC and a second one of 5,500EFC, taking total time at the second removal to 11,500-12,500EFC. This leaves enough stub life for the LLPs to be replaced at the third shop visit.

CFM56-3 series

The CFM56-3's three thrust ratings have different on-wing intervals and shop visit patterns. The replacement of LLPs is complicated by the variation in LLP lives.

Engines rated at 18,500lbs and 20,000lbs have first intervals as long as 18,500EFC *(see CFM56-3 series maintenance cost analysis, Aircraft Commerce, February/March 2004, page 27)*, which is close to the lives of HPC and HPT LLPs. These are then replaced at this stage. The second interval can be as long as 11,500EFC, but this would take total time to 30,000EFC, which exceeds the 25,000EFC life of LPT LLPs. LPT LLPs would thus also need to be replaced at the first shop visit, with stub lives of about 6,500EFC. Fan and LPC LLPs would be replaced at the second visit.

Mature intervals thereafter are 10,000-11,000EFC, and all HPC, HPT and LPT LLPs, with lives of 20,000-25,000EFC, would have to be replaced every second shop visit. This could leave some LPT parts with stub lives of 5,000EFC, which could possibly be sold on the aftermarket. Fan and LPC LLPs, with lives of 30,000EFC, would be replaced every third shop visit at almost full life utilisation.

Engines rated at 22,000lbs have a first interval of about 11,000EFC *(see CFM56-3 series maintenance cost analysis, Aircraft Commerce, February/March 2004, page 27)*, and a second interval of about 9,000EFC. This would take total time to about 20,000EFC, although several LLPs in the HPC and HPT have lives of 15,800-18,000EFC. Although these are expected to be increased to 20,000EFC, like the remaining LLPs in these sections, their current lives would limit total time to the second removal to 15,800EFC, unless they were replaced at the first shop visit. All LLPs in the HPC, HPT and LPT would be replaced at this first shop visit, with the LPT parts having a stub life of about 5,000EFC.

A mature interval of 8,500EFC is typical and would take total time at the third shop visit to about 28,500EFC, at which point a workscope on the fan and LPC would be due, and be convenient for their LLP replacement.

This mature interval would mean replacement of all LLPs in the HPC and HPT every second visit after about 17,000EFC. LLPs in the LPT, with lives of 25,000EFC, could possibly be replaced every third interval after about 25,000EFC on-wing, which might also be the most economic interval for fan and LPC LLP replacement.

CFM56-3s rated at about 23,500lbs have a first interval of about 8,500EFC and mature intervals of about 6,500EFC thereafter *(see CFM56-3 series maintenance cost analysis, Aircraft Commerce, February/March 2004, page 27)*. LLPs in the HPC and HPT could thus be replaced at the third shop visit. The total time at this stage would influence whether LPT LLPs would be replaced or left until the fourth shop visit, when the three parts in the fan/booster section would be replaced.

CFM56-5A

The four CFM56-5A variants have varying EGT margins and on-wing intervals. The accumulated time to the second shop visit will only have been 15,000-19,000EFC, depending on variant, because of the effects of AD 99-06-16. All LLPs in the HPC and HPT would have been replaced at this stage. Mature on-wing interval for the -5A series is expected to be about 7,500EFC, and the third removal would be forced by LLP expiry in the LPT at a total time of 25,000EFC. The expected interval of 7,500EFC means HPC and HPT LLPs would require replacing again at the fifth

The JT8D-200 has uniform LLP lives of 20,000EFC. If managed well, full LLP utilisation can coincide with every second shop visit which will be a full engine overhaul. This is only possible if removal intervals are at least 8,500EFC, which the engine is capable of.

shop visit. Fan and booster LLPs would therefore probably be replaced at the third shop visit with a stub life of 5,000EFC. Replacement thereafter would be every fourth shop visit, almost fully utilising LLP lives.

CFM56-5B

On-wing times for the different variants of the -5B vary. The highest rated engines may only accumulate 12,000EFC at the second removal, but the lower rated variants could accumulate as many as would be as many as 15,000-16,000EFC. The first run would be limited by the short life of the HPT front shaft in the -5B6 and -5B7. Total time to second removal would also be limited by the life of the HPT disk. LLPs in the HPC and HPT would be replaced at this stage.

Mature intervals of about 7,500EFC would be expected, and so parts in the HPC and HPT would be replaced about every third visit, fully utilising their lives of 20,000EFC. LPT LLPs would be replaced at the third shop visit and then about every third visit thereafter, while fan and booster parts would be replaced at the fourth shop visit and every fourth shop visit thereafter.

CFM56-7B

The high EGT margin of low-rated -7Bs means their first interval to shop visit could be as long as 17,000-20,000EFC. This would only be possible if LLPs with restricted lives had been extended. These engines would be capable of a second run of 11,000-13,000EFC, and so LPT parts with lives of 25,000EFC would also have to be replaced at the first shop visit to avoid limiting the second run. Total time at the second shop visit would be 28,000-30,000EFC, when the fan and booster LLPs would be replaced.

Third on-wing interval is expected to be 8,000-11,000EFC, and so HPC, HPT and LPT parts installed at the first shop visit would be replaced at this visit.

Shorter first runs of 14,000-16,000EFC would force replacement of HPC and HPT parts at the first shop visit, while LPT parts could remain until the second shop visit.

The high rated -7Bs, -7B26 and -7B27, are expected to have first runs of 10,000-15,000EFC. Second runs would be 8,000-12,000EFC, taking total time to 18,000-25,000EFC. LPT parts could thus be left in the engine until the second shop visit, but an operator would have to consider HPC and HPT LLP replacement at the first shop visit to prevent limiting the second on-wing run.

A probable third run interval is 9,000EFC, but this would only be possible if time to the second visit was 21,000EFC, because of fan and booster LLP lives of 30,000EFC. These parts would be replaced at this stage. If total time at the second shop visit was more than about 24,000EFC, fan and booster LLPs would have to be replaced at this stage to prevent limiting the third run.

PW2000

Most PW2000s in operation are now mature and have typical on-wing intervals of 5,000-7,500EFC. Most airlines operated with an EFH:EFC ratio of 2:1. The first interval is longer, up to about 10,000EFC, and is usually followed by a performance restoration involving work on the HPC, HPT and combustor sections. Intervals thereafter take total time to the second removal from 15,000EFC to a maximum of 20,000EFC, since all LLPs have lives of 20,000EFC. The second shop visit workscope would therefore be a full overhaul, involving workscopes on all modules and replacement of all LLPs.

Mature on-wing intervals of 5,000-7,500EFC means LLPs are then replaced every second or third shop visit. Beatty explains that this would ideally be at the second visit, since the engine follows an alternating shop visit pattern of performance restoration and overhaul. This would, however, mean LLPs being replaced at a maximum of 15,000EFC, with a stub life of 5,000EFC at removal.

RB211-535E4

The RB211-535E4 has an average interval to first shop visit of 8,000EFC. Second run intervals are about 6,500-7,000EFC. LLPs are typically only replaced at second and third removals, where refurbishments are performed. Rolls-Royce manages the maintenance of most RB211-535E4s, and remaining life of removed LLPs usually varies between 0 and 5,000EFC. Parts with long stub lives may be reused on shop visits where anticipated subsequent interval is expected to be short.

LLP stub lives

Engine types with staggered LLPs are more likely to see LLPs being removed early, with stub lives of several thousand EFC. Parts may be removed early to prevent limiting subsequent intervals. These parts may be useful to another operator managing similar engines with a stack of LLPs with varying lives. The stub life may then even out this stack of LLP lives.

Market values of LLPs with stub lives are typically 60-80% of pro-rated remaining lives. Sale of parts with stub lives of several thousand EFC can reduce the amortisation of LLPs by several dollars per EFC. LLPs with stub lives of just a few thousand EFC remaining are unlikely to be sold, however. AC