The CFM56-7B is destined to become the world's most popular engine type. Its high EGT margin provides it with long removal intervals. While these will offset its expected higher shop visit costs, they also reduce the number of shop visits the engine will have in its period of operation.

CFM56-7B maintenance costs & reserves analysis

The CFM56-7B series is the most numerous of all CFM56 engines, and its only application is the 737NG, on which it has a monopoly. To date, more than 2,400 737NGs have been ordered, of which more than 1,600 are operational. This means that more than 3,200 installed CFM56-7Bs are in service. The 737NG is forecast to keep selling for at least another eight years, and the fleet is expected to reach about 3,700 units by 2013. The number of installed CFM56-7Bs would therefore have increased to about 7,400 by this stage, making it the most numerous engine in operation. The importance of the engine's maintenance costs is therefore clear.

CFM56-7B in operation

The majority of CFM56-7Bs power passenger variants of the 737NG, although there are about 80 business jet models of the type in service. These engines have life limited parts (LLPs) with different lives to those powering passenger-configured aircraft.

This means that about 1,570 of the 737NGs in service are passenger-configured aircraft. The majority of engines installed on these aircraft have a single annular combustor (SAC), while a few have a double annular combustor (DAC). The objective of the DAC is to reduce NOx emissions, and has been ordered by SAS and Austrian Airlines.

The SAC and DAC engines have six different thrust ratings, which power the four different variants of the 737NG.

The lowest of these is the -7B18, which is rated at 19,500lbs and used to power the smallest 737-600 model.

The second -7B variant is the -7B20, rated at 20,600lbs thrust. This also powers the 737-600, but is also the lowest rated engine powering the -700.

The third -7B model is the -7B22, rated at 22,700lbs thrust. This is the highest thrust rated model powering the -600 and the mid-range engine on the -700.

The -7B24 is rated at 24,200lbs thrust and is the highest rated engine for the 737-700. It is also used as the lowest rated engine for the larger and heavier 737-800 and -900 models.

The two largest CFM56-7B variants are the -7B26 and -7B27, and both power the 737-800 and -900. The -7B26 is rated at 26,300lbs thrust, while the -7B27 is rated at 27,300lbs thrust.

Only 110 737NGs in operation are -600s and -900s, and more than 1,460 are -700s and -800s. The majority of engines in operation are the mid-range thrust variants between the -7B22 and -7B26. There are no -B18s in service. Only 134 aircraft are equipped with the -7B20, and about 300 aircraft are each powered by the -7B22, -7B24 and -7B27. The most popular type is the -7B26, which powers more than 500 aircraft.

The 737NG has a longer range capability than earlier 737 models, so the NG series is used on longer average route lengths by airlines. While a few airlines use the 737NG on average flight cycle (FC) times of less than one flight hour (FH), the average FC time for the -700 and -800 fleets is 1.8FH and 2.1FH respectively. The -900 is also used on similar styles of operation, while the smallest -600 has a shorter average FC time of about 1.2-1.3FH.

The other extremes of operation are average cycle times of more than 3.0FH per FC in the case of charter operators.

Because of these relatively high average FC times, airlines also achieve relatively high levels of utilisation. "The -700, -800 and -900 fleets are all generating 8-9FH per day, equal to about 3,000FH and 1,600-1,700FC per year," explains Hans Klaiber, CFM56 program manager customer support engineering at SR Technics.

The first 737NG went into operation in January 1998 and is therefore about seven years old. At average rates of utilisation the oldest engines will have accumulated about 20,000 engine flight hours (EFH) and 11,000-12,000EFC when operated at average EFC times. This compares with the highest time engines. The lead-time engine powering the 737-700 has accumulated about 17,000EFC, the lead-time engine on the -800 about 13,000EFC and the lead-time engine on the -600 about 14,000EFC.

CFM56-7B architecture

The CFM56-7B has a similar core to the -5B series powering the A320 family. All variants have the same turbomachinery and components, with three low pressure compressor (LPC) booster stages, nine high pressure compressor (HPC) stages, a single high pressure turbine (HPT) stage and a four-stage low pressure turbine (LPT).

The fan is 61 inches in diameter. This allows the lowest rated -7B18 engine to achieve a bypass ratio of 5.5:1, while the highest thrust rated -7B27 has a bypass ratio of 5.1:1. Thrust rating is changed by an alteration on the data entry plug in the full authority digital engine control (FADEC). The common architecture, parts and components mean the lowest rated -7B18 has the highest exhaust gas temperature (EGT) margin and the highest thrust rated -7B27 has the lowest EGT margin.

The four main turbomachinery modules are the fan and booster section, HPC, HPT and combustor and LPT.

LIFE LIMITS IN EFCS FOR CFM56-7B SERIES LLPS

LLP	List	Life limits-EFC
		price $
Fan disk	90,230	17,900/25,200/27,600
Booster Spool	139,900	23,600/30,000
Fan shaft	74,570	30,000
Total	**304,700**	
HPC forward shaft	57,010	20,000
HPC stage 1-2 spool	81,440	13,000/20,000
HPC stage 3 disk	25,450	20,000
HPC stage 4-9 spool	183,200	20,000
HPC CDP air seal	34,480	18,600/19,700
HPT front shaft	65,600	17,300/20,000
HPT front air seal	137,100	19,300
HPT disk	152,300	20,000
HPT rear shaft	48,450	11,500/17,300/20,000
Total	**785,030**	
Stage 1 disk	55,830	25,000
Stage 2 disk	64,570	25,000
Stage 3 disk	63,460	25,000
Stage 4 disk	56,410	25,000
LPT shaft	111,180	19,500
LPT conical support	75,280	25,000
Total	**426,730**	

Life limited parts

An important consideration in engine maintenance management is LLPs. The amortisation of LLPs accounts for a high proportion of total maintenance costs in all engines used on short-haul operations. The CFM56-7B also has a high EGT margin and so is expected to achieve long on-wing intervals. Engines are expected to remain on-wing for their first removal until LLP expiry in many cases, and so LLP lives will influence shop visit workscopes and removal patterns.

Some CFM56-7B have 18 LLPs, and some still have 20 LLPs: three in the fan and booster module; five in the HPC; four in the HPT; and six in the LPT. There are LPT rear frames and LPT cases which are life limited by its parts number and model/rating.

There are several part numbers for each LLP in the engine. The lives of each part number are the same for each different thrust rating for all SAC engines, but in some cases they differ on DAC engines and engines used on Business Jet variants.

CFMI's philosophy with LLPs in all its engines is to set target lives, but it introduced engines into service with LLPs that have lives less than target lives. Lives are then extended in one or several stages to target lives following experience gained in service, with the objective that lives are extended before leading engines reach the original or restricted life limits.

Target lives for LLPs in the fan/booster module are 30,000EFC, and are 25,000EFC for the six parts in the LPT. Target lives for the nine parts in the HPC and HPT are 20,000EFC. These targets will influence engine management in respect of removal timing, shop visit workscopes and workscope patterns, and LLP replacement timing.

"The actual current life limits for LLPs throughout the engine are scattered," explains Klaiber. "First, different engines have different LLP part numbers installed, with the oldest and first produced naturally having the first part numbers and the latest and most recent manufactured engines having the latest part numbers. Most part numbers have already reached their projected life limits, while a few have lives a few thousand EFC less than the targets. The current life limits have to be considered in relation to the actual number of accumulated EFCs on the highest time engines. In July 2004 the highest time engine, which was an engine powering a -700, had accumulated about 16,000EFC. An approximate adjustment to date would take this engine up to about 17,000EFC. The highest time engine on the -600 fleet had accumulated about 14,000EFC, while the highest time engine on the -800 had accumulated about 13,000EFC. The remaining engines in the fleet will naturally have accumulated less cycles, which must be considered in relation to the timing for achieving these target life limits. It is expected that LLP lives will have been extended to their target limits before most engines reach the target number of EFCs."

The actual current limit depends on the part number installed and the model of engine in which the part operates. The fan shaft in the fan/LPC module has already reached the target limit of 30,000EFC for all part numbers and engine models. The booster spool part numbers have a current limit of between 22,900EFC and 23,600EFC, depending on which part number is installed. "The target date for reaching the booster spool's target life of 30,000EFC is 2005/06," explains Paul Smith, Engineer at Total Engine Support (TES).

The fan disk has a limit of either 17,900EFC or 19,900EFC, depending on part number. "There is a service bulletin (SB 72-0324) which allows a re-working of the fan disk to increase life up to a maximum of 27,600EFC," explains Smith. "The target date for extending the reworked disk's limit to 30,000EFC is 2006." Other non-reworked disks are targeted for 2007. This implies that all engines will have reached their target lives well before they have actually accumulated the same number of EFC in service.

The five parts in the HPC are: the forward shaft; compressor rear or CDP air seal; the stage 1-2 spool; the stage 3 disk; and stage 4-9 spool. "The forward shaft, stage 1-2 spool, stage 3 disk and stage 4-9 spool have reached their target limits of 20,000EFC, although the CDP air seal currently has limits of less than the 20,000EFC target," says Smith. "The CDP air seal has a current limit of 16,800-18,600EFC depending on the engine model, but is expected to be extended to 20,000EFC during 2005 for parts operating in most engine models."

Most part numbers in the HPT have either reached their target limit of 20,000EFC or are approaching their target. "The HPT front shaft and HPT rear shaft both have a current limit of 17,300EFC for most engine models, but in the case of the HPT rear shaft, this has already been extended to by a temporary revision to 20,000EFC," says Smith. "The HPT front air seal has a limit of 15,900EFC, but has a temporary revision available which increases the limit to 19,300EFC for some engine models. The HPT disk has a current limit of 16,700EFC across most engine models, although a new alternative part is available which increases the limit to 20,000EFC."

For most engines the most limiting part in the HP system is thus the HPT disk, currently limited at 16,700EFC.

The LPT LLPs comprise the stage one, two, three and four disks, the LPT shaft and the LPT rotor support or conical support. The four disks have all reached their limit of 25,000EFC, as has the LPT rotor support for the most common engine models. "The LPT shaft has a current limit of 19,500EFC for most engine models, but should be extended to 25,000EFC by 2005/06," says Smith. The limiting LLP in the LPT is thus the LPT shaft at 19,500EFC.

The list price for a full set of LLPs is $1.5 million. The list price for the LLPs in the fan/LPC module is $305,000, the LLPs in the LPT $426,000 and the LLPs in the HP system $785,000 *(see table, page 40)*.

EGT margin & deterioration

As described, the CFM56-7B has a high EGT margin, which allows long intervals between removals for shop visits. "This high EGT margin means that removals due to EGT margin erosion and loss of performance are not a major concern for most variants," explains Jean-Luc Ledder, CFM56-7 product director long-term contracts at Snecma Services. "The average EGT margin of the -7B18 is 131 degrees centigrade, while it is 136 degrees for the-7B20. EGT margin then reduces slightly with higher thrust rating. The -7B22 has an average margin of about 109 degrees, the -7B24 an average margin of 106 degrees, the -7B26 an average margin of 80 degrees, and the -7B27 an average of 59 degrees. These margins are all for new engines."

The number of -7B18s and -7B27s is small, and so most operators have engines with high margins that will allow long on-wing intervals for the first run.

"These initial margins are test cell, but the average installed margins for each variant can vary by plus or minus five degrees centigrade," explains Klaiber. "All fleets actually have a wide scatter of EGT margins. The 2 sigma standard deviation tends to be plus or minus 15 degrees about the average. The installed margin on many of the -7B27s could therefore be as low as 45 degrees centigrade, while the margin on some -B18 engines could be as high as 145 degrees. A mid-thrust -7B22 or -7B24 could have a margin as high as 120 degrees centigrade."

EGT margin and performance loss can be a major driver of engine removals for shop visits depending on model/rating and average de-rating used. EGT margins are high for most -7B variants, and so their on-wing intervals can be long. "EGT margin loss rates are similar to the CFM56-3," says Graeme Crawford, general manager at Pratt & Whitney Norway Engine Centre. "The engines lose about 10-15 degrees in the first 1,000EFC on-wing, which is known as the installation loss. This levels out to a steady rate of 3-5 degrees centigrade per 1,000EFC thereafter."

Actual rates of deterioration will vary with thrust rating and several other operational factors, such as de-rate and EFH:EFC ratio. "De-rate is probably about 10% for most operators," says Markus Kleinhans, propulsion systems engineering CFM56-3/-7B at Lufthansa Technik. "The initial rate of EGT margin loss is about 7.5 degrees per 1,000EFC for the first 2,000EFC on-wing for the -7B18/20/22, taking total loss to about 15 degrees. The EGT margin of these three engines is thus reduced to 95-120 degrees. Rate of loss is then about 3.5 degrees per 1,000EFC thereafter. The remaining margin after the first 2,000EFC means that engine removals for shop visits will not be forced by loss of EGT margin. The higher rated -7B24, -7B26 and -7B27 have an initial loss of about 23 degrees in the first 2,000EFC on-wing. This will take the average margin for the -7B24 down to about 79 degrees, for the -7B26 down to about 57 degrees, and for the -7B27 down to about 36 degrees. The rate of EGT margin loss then reduces to about 4.5 degrees centigrade per 1,000EFC. Theoretically this will allow the -7B24 to stay on-wing for about another 19,000EFC, the -7B26 to remain on-wing for about another 12,000EFC, and the -7B27 to stay on-wing for another 8,000EFC."

The implications of this are that the on-wing intervals to the first removal will not be driven by loss of performance for the -7B18/20/22/24, but will be for the -7B26 and -7B27 which have lower initial EGT margins.

One method of extending on-wing life or reducing rate of EGT margin loss is water washing. "Operators that water wash their engines every few months can gain 8-10 degrees centigrade of EGT margin per wash," says Klaiber. "Ultimately this process changes the EGT margin loss curve from a straight line to a saw-tooth curve and extends the time on-wing to the engine removal by 1,000-2,000EFH."

1st on-wing intervals

On-wing intervals are expected to be largely driven by accumulated EFC time rather than EFH time. Although the first -7B engines went into operation at the start of 1998 and the highest time units have accumulated about 17,000EFC on-wing, few engines have actually had their first scheduled removal.

Most engine shops handling the -7B series expect removal causes to be divided between lower thrust engines and higher thrust rated variants. "The -7B18/20/22/24 are expected to remain on-wing until they reach their first LLP life limit, which is currently the HPT front shaft at 17,300EFC," says Crawford. These engines will still have a lot of EGT margin remaining at this stage. For older engines this will be for the CDP air seal in the HP system, which is limited to 18,600EFC.

"The higher rated -7B26 and -7B27 engines are expected to be removed due to EGT margin and engine performance loss," continues Crawford.

"On-wing intervals will be mainly related to accumulated EFC time," says Klaiber. "The actual EFH achieved will be related to EFH:EFC ratio in operation. The -7B22 engine operated at an average EFC time of 2.0EFH and with no de-rate would have an interval of about 25,500EFH, equal to 13,000EFC. Factoring in a 10% derate would increase this to about 30,000EFH/15,000EFC. Similarly, a -7B26 would be expected to have an interval in the region of 24,000EFH/12,000EFC when operated with an average de-rating of 10%."

While on-wing intervals are more consistent in terms of EFC, actual times are also dependent on EFH:EFC ratio. Klaiber explains that a -7B24, for example, will achieve 2,000EFH less on-wing time for an engine operated at an average EFC ratio time 1.5EFH compared to one operated with an average EFC time of 2.0EFH. The same engine would have a 2,000EFH longer interval when operated at an average EFC time of 2.5EFH.

The high EGT margins of the -7B24 and variants with a lower thrust rating are expected to allow them to stay on-wing until LLP life limits are reached. "This is expected to be 17,300EFC for -B18/20/22/24 engines, which is the current limit for the HPT front shaft," says Crawford. This is equal to about 31,000EFH for engines operated at average EFC times. "The higher rated -7B26 is expected to have a first interval of about 13,000EFC/23,500EFH and the highest rated -7B27 an interval of about 10,000EFC/18,000EFH."

Ledder explains the current LLP limits of 17,300EFC will be extended to 20,000EFC for most engines, and so longer intervals will be possible for low thrust rated engines. Ledder says he expected some medium thrust rated engines to be removed for a combination of LLP life limits and performance deterioration. Kleinhans adds that the average for the -7B24 might be about 16,000EFC, while the -7B26 would reach 12,000-14,000EFC and the -7B27 10,000EFC. "These intervals are based on average EFH:EFC ratios," adds Kleinhans. "Engines operating with longer than average EFC times will get fewer EFC on-wing but more longer overall EFH intervals because some technical problems are EFH related and will therefore lead to engine removal."

LLP expiry and EGT margin erosion are expected to be the main drivers of scheduled removals. The CFM56-7B has, however, experienced some technical problems that have resulted in unscheduled removals prior to the anticipated scheduled removal time. "The first of these has been problems with the number three and four bearings, and another main issue has been looseness of the variable stator vane in the HPC due to the wear of bushings," explains Kleinhans. "The HPT blade has also experienced cracking on high-time engines which have accumulated 15,000-20,000EFH. This only affects two different HPT blade part numbers, and these can be replaced. Fan shroud cracking has also caused a few difficulties in terms of unscheduled removals. DAC engines have also had problems with the

The majority of CFM56-7Bs in operation power the 737-700 and -800 and are the mid-range thrust variants . The -7B22, -7B24 and -7B27 each power about 300 aircraft, while the -7B26 powers about 500 units. The number of installed CFM56-7Bs should exceed 7,000 by 2013.

stage 1 LPT."

Klaiber explains that while low-rated engines at an average EFC time of about 2.0EFH can remain on-wing until they reach a LLP life limit, higher rated engines can be removed due to deterioration of the burner can. "Few engines have had scheduled removals yet, but we expect pre-SB 72-0227 engines to come off at 18,000-26,000EFH because of disintegration of the combustion chamber outer cowl after this length of time on-wing," says Klaiber. "This problem requires a periodic borescope inspection to monitor, and there is a SB 72-0304 to cover this. An airline may therefore remove an engine at about 26,000EFH/10,000EFC due to burner can deterioration. A performance restoration will be required even though it will not have reached LLP expiry at this stage. A low rated -7B22 may achieve 22,000EFH/16,500EFC on-wing, and so will reach life limits of some LLPs when this coincides with burner can deterioration."

1st shop visit workscopes

All variants will require a performance restoration workscope at their first shop visit, which will involve work on the HP system. "The content of the first performance restoration shop visit will be similar to the CFM56-3's experience," says David Beale, project leader CFM56 at MTU Maintenance. "This includes: replacement of the HP system LLPs which have inadequate cycles remaining for a second run of about 10,000EFC; refurbishment of all seals and shrouds in the HPC, combustor and HPT; refurbishment of fan blades, HPC and HPT airfoils and combustor liners; and a bench check or overhaul of fuel nozzles and other major accessories. There will also be on-condition inspections of LPC, LPT and gearbox modules.

This will restore EGT margin. "The restored EGT margin is expected to be 70-80% of the original EGT margin,"says Ledder. "This is because only the core is restored at this stage, but the EGT margin recovery rate would be higher if the booster and LPT were also worked on."

Kleinhans makes the point that actual restored margins are difficult to estimate at this stage because few engines have been removed for a performance restoration. "Restored EGT margins are usually 10-20 degrees lower after the first shop visit than they were on new engines."

On the basis of a 25% loss of EGT margin, the -7B18 and -7B20 would have a restored EGT margin of 95-100 degrees after the first shop visit. The -7B22 and -7B24 will have EGT margins of 75-80 degrees after the first shop visit. The -7B26 will have an average restored margin in the region of 60 degrees and the -7B27 an average restored margin of about 45 degrees.

These restored margins then have to be considered in relation to likely second on-wing intervals to the second removal and its workscope, especially in relation to LLP replacement. "Not only do average restored EGT margins have to be considered, but so does the standard deviation about this average," says Klaiber. "There is a 1 sigma standard deviation of plus/minus six to eight degrees centigrade. Thus -7B27 engines with an average restored margin of about 45 degrees would have some with the lowest margins at about 37 degrees. Similarly, the lowest -7B22 engines would have a restored margin of about 78 degrees centigrade."

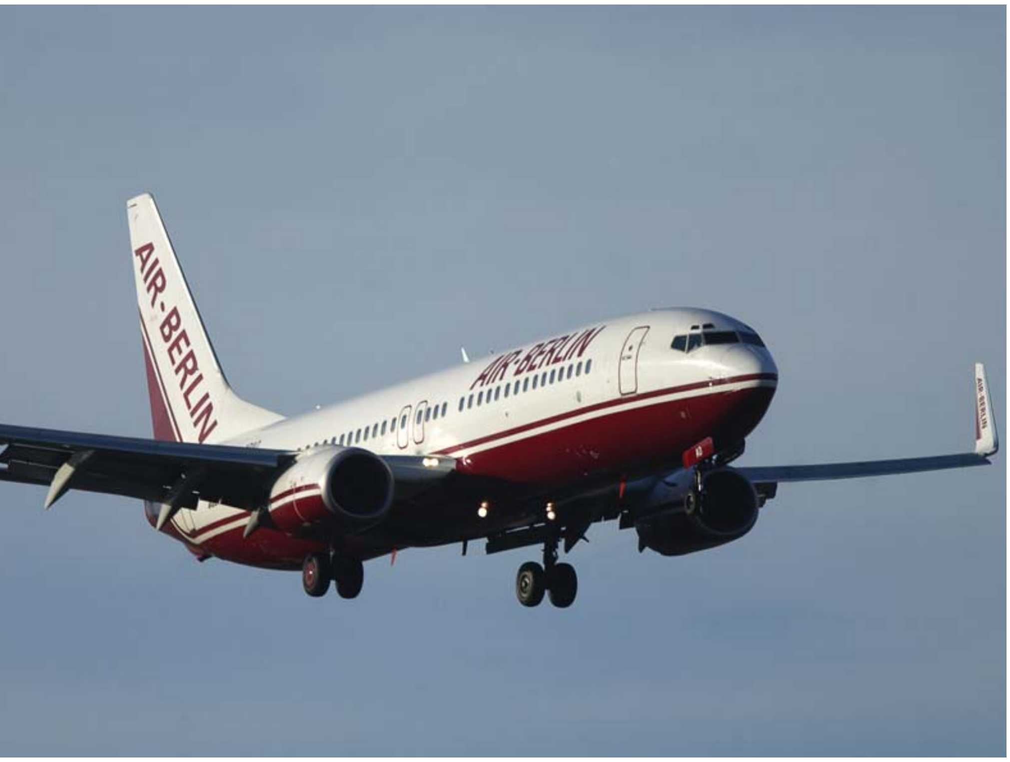
Similar rates of EGT margin loss would be experienced in the second on-wing interval. Low- and medium-rated engines could thus remain on-wing until reaching a LLP life limit. The higher thrust rated -7B26 could have an interval of up to 15,000EFC based on EGT margin and probable erosion rate, while the -7B27 could achieve an interval of about 10,000EFC on the same basis.

The implications of this are that engines will have to be managed carefully with respect to shop visit workscope content and LLP replacement timing. The combined first and second removal intervals will determine which LLPs should be replaced at the first shop visit and which can be left in the engine until the second shop visit.

Most low thrust rated engines are expected to have accumulated 17,000-20,000EFC on-wing by the first removal, which will have been forced by LLP expiry. Core LLPs in these engines will thus need replacing. This leaves the issue of LPT and fan/LPC LLPs with lives of 25,000EFC and 30,000EFC. Their remaining lives would limit the second interval. If LPT LLPs are left in the engine, the second removal would be limited to 5,000-8,000EFC. "One possibility is to work on just the LPT at the second removal, and leave work on the core again until the third shop visit," says Ledder.

Most engine shops recommend replacing LPT LLPs at the first shop visit along with core LLPs, which allows a second interval of 12,000-13,000EFC, and letting the second on-wing interval be limited by LLPs in the fan/LPC. This increases the scope of the first shop visit to full disassembly and overhaul on the LPT, as well as a core refurbishment.

Mid thrust rated -7B24 engines, which have achieved about 16,000EFC on-wing, would have HP LLPs in the core, with a remaining life of 4,000EFC, replaced at the first shop visit to prevent an early second removal. This would allow a second removal interval of 9,000EFC up to the life limits of LPT LLPs. The fan/LPC LLP life limits could allow a subsequent interval of up to



The majority of CFM56-7Bs are operated on average EFC times of 1.8-2.1EFH. This compares to an average EFC time of 1.4EFH for the CFM56-3. The -7B's longer average EFC time allows it to offset its expected higher shop visit costs, and so achieve a similar maintenance reserve per EFH to the -3.

14,000EFC. The engine would, however, have a restored EGT margin of 75 degrees and so could remain on-wing to fan/LPC LLP limits. This raises the issue of whether it is economic to replace LPT LLPs at this stage. "One possibility with some engine types is to remove LLPs with a stub life and sell them on the used market, or put them into other engines which only require a short on-wing interval, such as engines on lease from lessors," explains Crawford. "This is not possible with the -7B, since an aftermarket has not really been established yet. Airlines have to consider that it is relatively expensive to bring an engine into the shop after another 9,000EFC at the second removal to replace LPT LLPs and then in again after another 5,000EFC at the third removal to replace fan/LPC LLPs. Each removal requires a certain amount of routine work for disassembly, re-assembly and testing irrespective of the workscope. More frequent removals also increase spare engine inventory costs. It is therefore probably more efficient overall to replace LPT LLPs at the first shop visit, which means increasing the workscope for low rated engines to include a full disassembly of the LPT."

High rated -7B26 engines will have accumulated about 13,000EFC on-wing. This would leave LPT LLPs with a remaining life of 12,000EFC, which is close to the interval that would be allowed by the restored EGT margin. The LPT should thus be left at this shop visit, leaving the content to just work on the HP system. HP system LLPs should be replaced, however, despite having a remaining life of 7,000EFC.

The highest rated -7B27 would have HP system LLPs with remaining lives of about 10,000EFC at the first removal. This is close to the second removal interval that would be allowed by restored EGT margin. HP system LLPs should thus be left at the first shop visit for replacement at the second shop visit.

All variants and thrust ratings are unlikely to require work on the fan and booster sections, unless problems are detected by visual inspections. Despite planning the shop visit at which to do work on the LPT, Klaiber points out that there are technical problems with the LPT. "The first shop visit may be bigger than originally anticipated for many engines because of the need to replace the LPT case. There are rails on the inner wall of the LPT case which hold the wear strip for the LPT blade shroud; and these are deteriorating and require repair during the first shop visit," explains Klaiber. "There is also an airworthiness directive (AD) that affects the stage 2 and 3 LPT nozzles. This states that if the LPT is opened, which it will be to repair the rails, then a modification has to be performed on the nozzles. Moreover, if a core refurbishment is done then the LPT module has to be removed anyway, and so then requires a visual inspection. If something is found to be out of manual limits then corrective action has to be taken. Problems with the LPT rails have forced work on the LPT at the first shop visit for early engines."

2nd on-wing intervals

As previously described, the low rated -7B18/20/22 engines will have high enough restored EGT margin to allow them to remain on-wing up to expiry of fan and LPC LLPs. This will take the engine to a total time of about 30,000EFC at the second shop visit.

Assuming the first shop visit was performed at 17,000-18,000EFC and LPT LLPs were replaced, the second interval would be after another 12,000-13,000EFC. This assumes that all LLPs in the fan/booster module will have had their lives escalated to the target of 30,000EFC.

The medium-rated -7B24 would also have enough EGT margin to allow an interval up to fan and LPC LLP expiry, and so would have a second on-wing interval of about 14,000EFC.

"EGT margin has more of an influence on the second intervals on higher thrust engines," explains Kleinhans. The higher rated -7B26 would probably have LPT LLPs left in at the first shop visit, and so the second interval would be limited to expiry at a total of 25,000EFC. This would probably limit the interval to about 12,000EFC. This interval would coincide with probable EGT margin erosion. Some -7B26s would have had relatively short first on-wing intervals of 11,000-12,000EFC, and so may not have had HP LLPs removed at the first shop visit. The second run would thus be limited to 8,000-9,000EFC by HP system LLP expiry. This assumes all HP LLPs will have had their lives extended to the target life of 20,000EFC.

The highest rated -7B27 would also be limited by a combination of full EGT margin erosion after about 10,000EFC and HP system LLP expiry at a total time of 20,000EFC, which would occur at a similar time. This is on the basis that HP system LLPs will have all reached their target lives of 20,000EFC. This total time of 20,000EFC may not even be possible. "The restored EGT margin of about 45 degrees means it could be completely eroded after just 7,000EFC," says Ledder. This would take total time to just 17,000-18,000EFC.

2nd shop visit workscope

As described, this is dependent on the first on-wing interval achieved and which LLPs have been replaced. All variants will have had a performance restoration performed at the first shop visit, and most will have also had work done on the LPT. All engines will go through a heavier workscope at the second shop visit. This

POSSIBLE MANAGEMENT, SHOP VISIT PATTERN & LLP REPLACEMENT TIMING OF CFM56-7B SERIES ENGINES

Removal	Interval EFC	Accumulated EFC	Workscope content	Cost-$	$/EFC	LLP replacement	LLP cost $	LLP $/EFC	Total $/EFC	Total $/EFH
-7B27										
1st	10,000	10,000	Core	1,200,000	120	-		79	199	111
2nd	7,000-8,000	17,000-18,000	Core & LPT	1,500,000	200	Core & LPT	1,211,000	79	279	155
-7B26										
1st	13,000	13,000	Core	1,250,000	96	Core	785,000	91	190	106
2nd	12,000	25,000	fan/LPC & LPT	1,700,000	142	Fan/LPC & LPT	731,000	91	233	130
-7B24										
1st	16,000	16,000	Core & LPT	1,550,000	97	Core & LPT	1,211.000	87	184	102
2nd	14,000	30,000	Core & fan/LPC	1,700,000	121	Fan/LPC	305,000	71	192	107
-7B18/20/22										
1st	17,000-18,000	17,000-18,000	Core & LPT	1,600,000	92	Core & LPT	1,211,000	78	170	95
2nd	12,000-13,000	28,000-30,000	Core & fan/LPC	1,700,000	136	Fan/LPC	305,000	73	209	116

may be a complete overhaul of all modules.

"The -7B18/20/22 will have a core refurbishment without LLP replacement, plus fan and booster refurbishment with LLP replacement," explains Crawford. This would be at a total accumulated time close to 30,000EFC.

The medium-rated -7B24 will have a similar second shop visit.

Higher rated -7B26 engines that did not have work done on the LPT at the first shop visit would have all major modules worked on during the second shop visit, as well as replacement of LPT and fan/LPC LLPs. This would be at a total accumulated time of 25,000EFC.

"The highest rated -7B27s would have another core refurbishment and workscope on the LPT, with LLPs being replaced in all these modules," says Crawford. This raises the issue of the fan/LPC module. Total accumulated time on-wing at this stage will be 17,000-20,000EFC, and so there would be up to 13,000EFC remaining until LLPs in the fan/LPC needed replacing. The fan/LPC module could thus be worked on at the third shop visit.

Engine management

These approximate on-wing intervals and LLP lives strongly influence engine management and shop visit workscopes. Total time to the second shop visit will be close to 30,000EFC for low-rated engines, which at an average EFC time of 2.0EFH will be near to 60,000EFH. This will be equal to about 20 years of operation for most airlines.

The higher-rated -7B26 will have a total accumulated time at the second shop visit of 25,000EFC, or about 45,000-50,000EFH. This will be equal to 15-17 years of operation for most airlines' operations. The highest thrust rated -7B27 will have accumulated about 20,000EFC and 38,000EFH at the second shop visit, after a total time of about 13-15 years' service.

This indicates that the second shop visits will not occur for about another seven years for the oldest and highest rated engines. It is therefore too early to estimate the intervals to the third shop visits and their subsequent workscopes.

Shop visit inputs

Inputs for shop visits in terms of man-hours (MH), materials and parts and cost of sub-contract repairs for the -7B, can be estimated on the basis of inputs for the -3 series.

"Man-hour inputs are expected to be similar to the -3 for similar shop visit workscopes, perhaps slightly lower," says Beale. "Material costs for a -7B are expected to be 20-35% more than a -3 and the -7B's cost of sub-contracted repairs will be 5-15% more than those experienced by the -3."

Sekinger estimates a core refurbishment plus some work on the LPT will use 2,700 man-hours (MH). Charged at a labour rate of $70 per MH this will take total cost to about $140,000. Cost of materials and parts will be about $700,000-800,000, on the basis of average part scrap rates. "If work is required on the LPT to repair rails on the inner wall another $200,000 can be added to the total cost of the shop visit. The cost of sub-contract repairs will be $300,000-350,000. This would take total cost for the shop visit to $1.15-1.30 million, not including the cost of replacing LLPs.

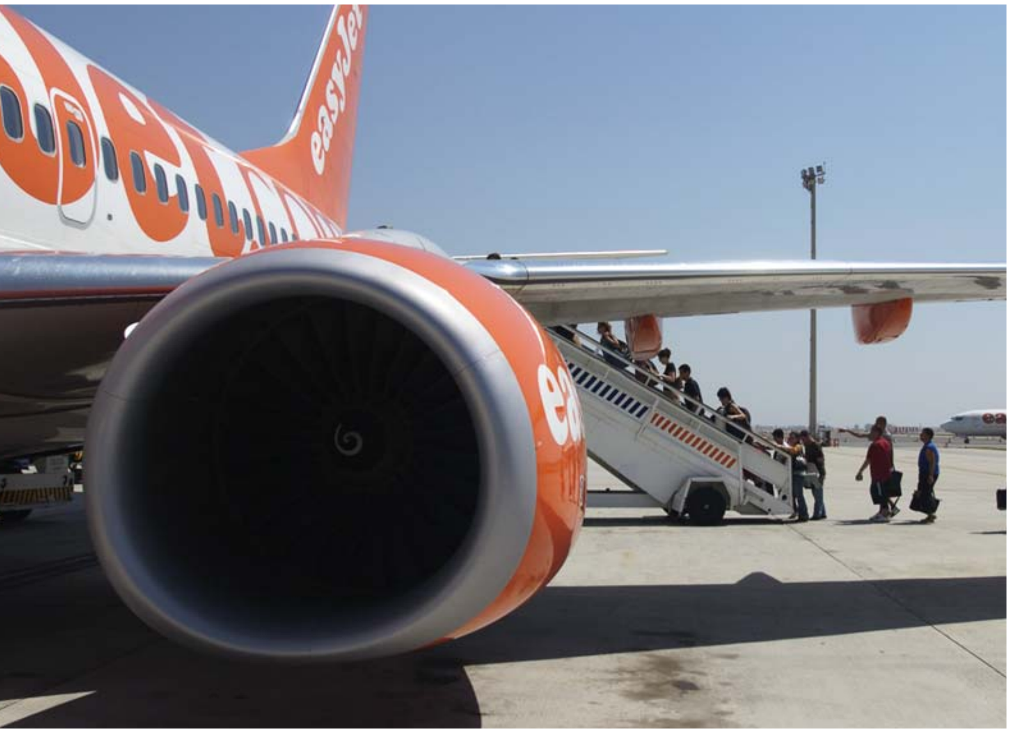
Crawford estimates that a heavier shop visit that included work on the LPT module would add up to another 500 MH, $200,000 for materials and parts and another $100,000 for sub-contract repairs. The same labour rate of $70 per MH would take the total cost for the shop visit to $1.5-1.6 million.

Crawford estimates that a complete overhaul would use about 3,000MH, up to $1.2 million in materials and parts, and about $500,000 for sub-contract repairs. This would take total cost for the shop visit to about $1.7 million. Some engine shops estimate that the MH inputs for these heavier shop visits may be as high as 4,000.

LLP amortisation

LLP amortisation has to consider probable intervals to the third shop visit. This is because LLPs replaced at the first shop visit will be replaced at the third shop visit. Their cost should thus be amortised over the combined second and third removal intervals. Although some modules have LLPs replaced together during the first or second shop visit, they may then get LLPs replaced for a second time at different shop visits. LLPs for the fan/LPC have a list price of $305,000, LLPs in the HP system a list price of $785,000 and LLPs in the LPT a list price of $426,000.

It has been assumed here that low rated -7B18/20/22 engines will have their core and LPT LLPs replaced at the first shop visit, after about 18,000EFC. A second interval of 11,000EFC and third possible interval of 9,000EFC means they will be replaced again after about 20,000EFC at the third shop visit. The



The most important feature of the CFM56-7B is that its shop visit intervals are equal to up to 10 years of operation. The implications of this are that each engine is likely to only have two or three shop visits over a 20 year period; the approximate time many operators use their narrowbody fleets before phasing them out.

combined cost of LLPs for the HP system and LPT is $1.211 million. The amortised cost of these parts is $67 per EFC up to the first shop visit and $61 per EFC between the first and second shop visits.

The fan and LPC LLPs will be replaced at the second shop visit at about 29,000EFC. The cost of $305,000 for these parts amortised over this interval is equal to $11 per EFC.

The combined cost for amortisation of all LLPs is $78 per EFC up to the first shop visit and about $73 per EFC between the first and third shop visits.

The -7B24 will have a similar pattern of LLP replacement up to the third shop visit, but at different shop visit intervals. The overall effect is for LLP amortisation to be $87 per EFC up to the first shop visit and then about $72 per EFC between the first and third shop visit.

The -7B26 will have a different pattern of HP LLPs being replaced at the first and then third shop visits. The LPT and fan/LPC parts will be replaced at the second and then probably fifth shop visit. Overall, amortisation of LLPs works out to be about $92 per EFC.

The -7B27 or -7B26 that achieves a relatively short first interval will have core and LPT parts replaced at the second shop visit after a total time of 18,000-20,000EFC. The fan and LPC parts will be replaced at the third shop visit. Overall, amortisation of LLPs will be about $79 per EFC.

Total costs per EFH

The combination of LLP amortisation and shop visit costs has to be considered in terms of cost per EFH. This analysis is made on the basis of an average EFC time of 1.8EFH.

Low-rated -7B18/20/22 engines are operated at shorter average cycle times in some operations, but engines powering the 737-700 have average EFC times in the region of 1.8EFH.

The cost of a core refurbishment and LPT workscope at the first removal will be in the region of $1.6 million. This will be after 18,000EFC or 32,500EFH, and is equal to $92 per EFC. When amortisation of LLPs is added, the total cost is $170 per EFC or $95 per EFH *(see table, page 48)*.

A heavier shop visit at the second removal will cost in the region of $1.7 million, equal to $136 per EFC. This is added to LLP amortisation of $73 per EFC, taking the total to $209 per EFC and $116 per EFH *(see table, page 48)*. This is similar to the CFM56-3 rated at 20,000lbs thrust and 18,500lbs thrust for the first and second removals *(see CFM56-3B1/B2/C1 maintenance cost analysis, Aircraft Commerce, February/March 2004, page 27)*.

The medium-rated -7B24 will have first shop visit reserve of about $97 per EFC and LLP amortisation of $87 per EFC totalling $184 per EFC up to the first removal, equal to about $102 per EFH *(see table, page 48)*. This increases to about $192 per EFC for the heavier shop visit workscope and LLP amortisation up to the second removal, equal to about $107 per EFH. This is similar or better than cost per EFH for the CFM56-3 rated at 22,000lbs thrust up to the second removal.

The higher rated -7B26 will have a lighter workscope at its first shop visit than lower rated engines, but after a shorter interval of about 13,000EFC. This will cost in the region of $1.25 million. Combined with LLP amortisation, total cost per EFC to the first removal is about $190, or $106 per EFH *(see table, page 48)*. The heavier second shop visit costing about $1.7 million after another 12,000EFC and LLP amortisation has a total cost per EFC rate of about $233 per EFC, equal to $130 per EFH. This is similar to the CFM56-3 rated at 22,000lbs thrust and better than the -3 rated at 23,500lbs thrust.

The highest rated -7B27 will have a higher total amortised cost per EFC because of shorter removal intervals. This will be about $120 per EFC for the first shop visit. Added to LLP amortisation this takes the total per EFC to about $200, equal to $111 per EFH. This will increase to $279 per EFC and $155 per EFH for the second interval *(see table, page 48)*.

This analysis has been made on the basis of an average EFC time of 1.8EFH. Shorter average cycles, that are similar to those operated by the CFM56-3, would result in removal intervals that were shorter in terms of EFH, but longer in terms of EFC. This would alter the management of the engines in terms of shop visit workscope patterns and LLP replacement timing. While low rated engines would still have first removal intervals forced by LLP expiry, more higher rated engines would also have their HP system LLPs replaced at the first shop visit. Fan/LPC and LPT LLPs would be replaced at the second shop visit in these engines.

The main effect would be reduced EFH intervals. Shop visit workscopes would be similar in content to those for engines operated at an average EFC time of 1.5EFH, but costs would be amortised over shorter EFH intervals and so costs per EFH would be higher.

Overall, the CFM56-7B has only a small advantage in costs per EFH over the CFM56-3 *(see CFM56-3B1/B2/C1 maintenance cost analysis, Aircraft Commerce, February/March 2004, page 27)*. The main reason for the -7B's advantage is the longer average cycle time that most of its operators utilise the engine at. Despite having long removal intervals, the CFM56-7B has higher shop visit costs and more expensive LLPs than the -3 engine. The -7B's higher shop visit costs are offset by its longer removal intervals, bringing costs per EFH close the -3's reserves per EFH. AC