CFM56-7B maintenance analysis & budget

Most CFM56-7B variants have high EGT margins and can achieve long on-wing intervals. The Tech56 modification will lower maintenance costs.

The CFM56-7B has become one of the most ubiquitous engines, with more than 2,550 737NGs in operation, and another 2,200 on order. The industry can therefore expect to see almost 10,000 CFM56-7Bs in service within five to seven years. The CFM56-7B is operated in many large fleets with airlines worldwide. Operations experience a wide range of ambient temperatures from minus 20 to more than 40 degrees centigrade. The maintenance costs of the -7B's six variants are analysed here at typical rates of utilisation and engine flight hour (EFH) to engine flight cycle (EFC) ratio.

CFM56-7B in operation

The 737NG's range gives it the flexibility to operate a mixture of short- and medium-haul operations economically. Average annual utilisation is 3,000-3,200 flight hours (FH). Average flight cycle (FC) time is 1.9FH, with most operations ranging from 1.8FH to 2.05FH. The oldest aircraft have now accumulated more than 36,000FH and 28,000FC. These rates of utilisation and FC times are typical of the 737NG's larger carriers. The majority of 737NGs are -700 and -800 variants, accounting for about 2,400 aircraft. There are only about 70 of the smallest -600 model, and 75 of the -900, in service.

The 737-700 is powered by the -7B20 rated at 20,600lbs thrust, the -7B22 rated at 22,700lbs thrust, the -7B24 rated at 24,200lbs thrust, and the -7B26 rated at 26,300lbs thrust. The 737-800 is powered by the -7B24, the -7B26, and the -7B27 rated at 27,300lbs thrust.

There are no -B18s in service. There are 90 -700s powered by the -7B20, 485 powered by the -7B22 and 344 by the -7B24. A small number are powered by the -7B26 and -7B27.

Of 1,400 -800s in service, 155 are powered by the -7B24, 906 are powered by the -7B26, and 337 by the -7B27.

The extremes of operation are engines operating at EFH:EFC ratios of 0.9EFH, and as high as 3.0EFH.

UK low-cost carrier easyJet operates the -7B20 on a fleet of 30 737-700s at an average EFC time of 1.57EFH. Southwest in the US has a large fleet of -7B24s powering more than 300 737-700s and has an EFH:EFC ratio of 1.71. More than 50 of these are powered by Tech56 Insertion engines. The operator also manages an average take-off de-rate of about 10%, despite operating in a hot environment.

KLM has a longer EFC time of 1.80EFH, and operates a mixed fleet of Tech Insertion -7B24 engines on six 737-800s and non-Tech Insertion -7B24 and -7B26 engines on 20 737-800s/-900s. The airline manages a de-rate of 12-14%.

UK charter operator XL Airways is an example of one of the longer EFC times. The airline has 18 aircraft, 15 of which are powered by -7B26 engines. The other three are Tech Insertion -7B26/27 engines. The airline has an average EFC time of 2.84EFH and an average de-rate across its operation of 10%.

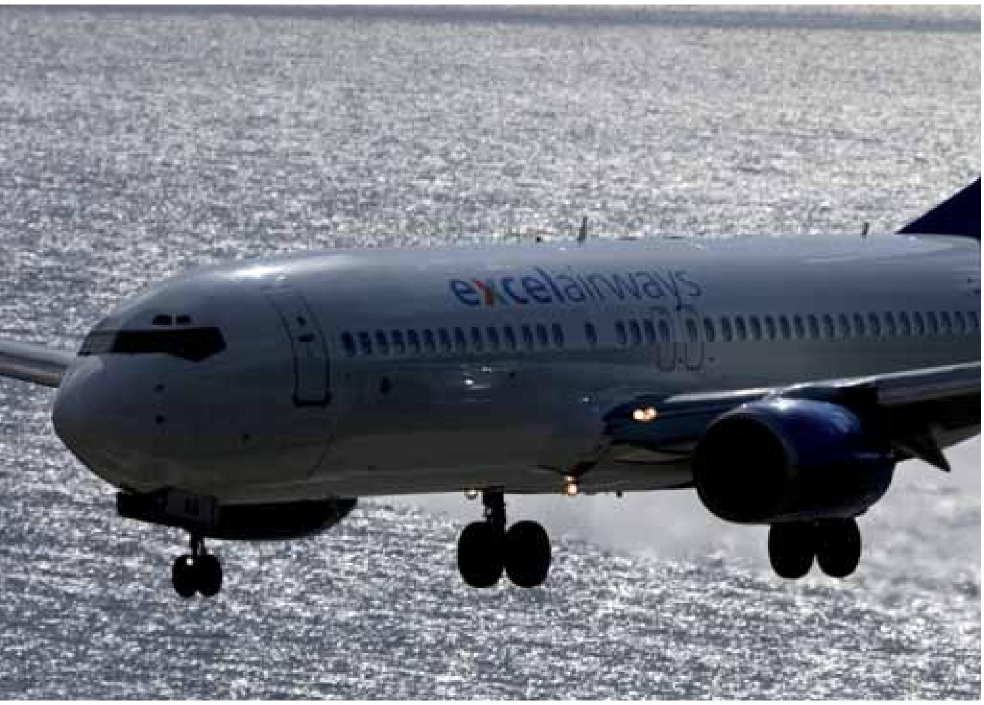
EGT margin

Exhaust gas temperature (EGT) margin is a main consideration for engine performance and maintenance. EGT margin erosion is generally the most influential factor in maintenance removal intervals for short-haul engines, while the effect of hardware deterioration is greater on engines used on medium-haul operations.

The -7B series has generally been designed with a high EGT margin capability, with the intention to limit the influence of EGT margin erosion as a main removal cause for maintenance shop visits.

Initial EGT margins are highest for the lowest rated -7B18 and -7B20 engines at 125-130 degrees for new engines *(see table, page 19)*. The medium-rated -7B22 has an initial EGT margin of 103 degrees, and the higher rated -7B24 has a margin of 100 degrees. The -7B26 and -7B27 have initial EGT margins of 80 and 55-60 degrees *(see table, page 19)*.

As with all engines, EGT margin deteriorates during operation. Rates of deterioration are highest in the first 1,000EFC of operation as blade tips and seals are worn and clearances increase. This leads to leakage around blade tips and causes EGT margin to erode. EGT margin deterioration rates slow down after the first 1,000-2,000EFC on-wing. The initial EGT margin and rate of EGT margin loss can be a leading factor in determining the length of time the engine can remain on-wing until EGT margin is fully eroded for some engines. Engines with higher initial EGT margins can



Operations of the CFM56-7B span a wide variety of EFC times, with some operators averaging close to 3.0EFH.

remain on-wing for longer intervals, and deterioration of hardware usually drives removals before all EGT margin is eroded.

Shop visit maintenance will restore hardware and clearances between blade tips and engine casings. Most of the original EGT margin will therefore be restored. The restored EGT margin will be lower than the original for a new engine, so EGT margin and its erosion will become a more important factor in driving engine removals when they are mature. "TAP Maintenance & Engineering guarantees to restore at least 75% of an engine's initial EGT margin following a shop visit," says Antonio Ferreira, CFM56 powerplant engineer at TAP Maintenance & Engineering. "Restored EGT margins are usually higher, and we can often achieve margins on the -7B26 and -7B27 that were higher than the initial margins."

Typical restored EGT margins are summarised *(see table, this page)*. They do not reflect the margins on engines which have had the Tech56 upgrade *(see CFM56-7B specifications, page 10)*. Ferreira comments that this adds about 10 degrees of EGT margin to new and restored engines. "The Tech 56 modification is only generally necessary for higher rated -7B engines which have lower EGT margins. All new production engines have the Tech 56 modification. The problem is that operators will end up with a mix of Tech 56 and non-modified engines in their fleets, which they will have to standardise to minimise the number of spare engines and inventories of parts."

CFM56-7B EGT MARGINS

Engine variant	-7B18	-7B20	-7B22	-7B24	-7B26	-7B27
Thrust lbs	19,500	20,600	22,700	24,200	26,300	27,300
Initial EGT margin (deg C)	125-130	125-130	105	100	60	55
Restored EGT margin (deg C)	88-104	88-104	74-84	70-80	42-48	39-44

EGT margin erosion

EGT margin loss rates are highest during the first 1,000EFC on-wing, then reduce to a mature level after 3,000EFC on-wing. No only does the -7B series have generally high levels of EGT margin, but its mature rates of EGT margin are lower and more stable than older generation engines. "It would be possible for some engines to remain on-wing for up to 25,000EFC given their EGT margins and rate of EGT margin erosion, if it were not for limitations placed by life limited parts (LLPs) and mechanical deterioration," says Ferreira.

Initial rates of EGT margin loss are less for lower-rated engines. These are 8-12 degrees centigrade in the first 1,000EFC for the -7B18, -7B20 and -7B22 engines. "The mature rates then slow to 2.5-4.0 degrees per 1,000EFC for these lower-rated variants," says Markus Kleinhans, propulsion systems engineer at Lufthansa Technik.

At these rates of loss, the -7B20, with an initial margin of 130 degrees, could remain on-wing for up to 40,000EFC if EGT margin and engine performance were the only limiting factor.

The -7B22 would have slightly higher rates of EGT margin loss, but could still remain on-wing for up to 36,000-38,000EFC if EGT margin were the only limiting factor.

"Initial rates of EGT margin loss for the higher rated -7B24, -7B26 and -7B27 variants will be 11-15 degrees in the first 1,000EFC on-wing. Rates will then drop to 4-6 degrees per 1,000EFC thereafter," says Ferreira. "On this basis, the -7B24 could remain on-wing for 17,000-18,000EFC from its initial EGT margin of 100 degrees. The -7B26 could remain on-wing for 12,000-14,000EFC, and the highest-rated -7B27 could stay on-wing for 10,000-12,000EFC from its initial EGT margin of 60 degrees."

Restored EGT margin

As described, the restored EGT margins following a shop visit will not be at the same levels as for new engines. Restored EGT margins vary from 70% to 80% of initial margins *(see table, this page)*. They are therefore 88-104 degrees for -7B18/20 engines, 74-84 degrees for -7B22 engines, 70-80 degrees for -7B24 engines, 42-48 degrees for -7B26 engines, and 40-45 degrees for -7B27 engines.

The initial and mature rates of EGT margin erosion are similar to new engines. As a result, -7B18 and -7B20 engines could remain on-wing for 27,000-30,000EFC for second and mature intervals if the EGT margin were not a limiting factor. The -7B22 would have intervals of 22,000-25,000EFC if EGT margin were the only limiting factor.

The higher-rated -7B24 can expect to have second and mature intervals of 12,000-13,000EFC, depending on actual EGT margin erosion rates and the nature of operation. The -7B26 could expect to have removal intervals of 9,000-12,000EFC, and the -7B27 intervals of 8,000-10,000EFC.

Life limited parts

The CFM560-7B series has 18 LLPs. There are three in the fan and low pressure compressor (LPC) module: the fan disk, the booster spool and the fan shaft. The current list price of these three parts is $356,000.

There are nine LLPs in the high pressure spool: the high pressure compressor (HPC) forward shaft; the HPC stage 1-2 spool; the HPC stage 3 disk; the HPC stage 4-9 spool; the HPC CDP air seal; the high pressure turbine (HPT) front shaft; the HPT disk; and the HPT rear shaft *(see table, page 20)*. The current list price of these nine parts is $921,000.

The LPT module has six LLPs: the four disks for the low pressure turbine (LPT) stages; the LPT shaft; and the LPT conical support. The current list price of these six parts is $499,000.

The total cost for a shipset of LLPs is $1.775 million.

There are another two parts which are sometimes classified as LLPs: the LPT frame and the LPT case.

CFMI has a policy of setting target lives for all its engines, and starting with certified lives that in some cases are lower than target lives. The certified lives are then extended as operational experience is gained with the engine. The target lives for the LLPs in the HP spool are 20,000EFC, 25,000EFC for the parts in the LPT module, and 30,000EFC in the fan and booster module.

There are several part numbers for each LLP, and the actual certified lives for each LLP vary. In the case of some part numbers lives are shorter for higher-thrust-rated variants than they are for lower-thrust variants. Lives of earlier manufactured part numbers are also generally shorter than for more recent part numbers.

The LLPs used in those engines with the Tech56 or Tech Insertion upgrade built from 2007 onwards all have the target lives of 20,000EFC, 25,000EFC and 30,000EFC for the three main groups.

The lives are also shortened for engines with thrust bump ratings or those used on the business-jet version of the 737NG.

The current life limits of each LLP for each rating for non-Tech56 or non-Tech

CFM56-7B LLP LIVES - NON-TECH INSERTION ENGINES

Engine variant	-7B18	-7B20	-7B22	-7B24	-7B26	-7B27
Fan disk	17,900	17,900	17,900	17,900	17,900	17,900
Booster spool	23,600	23,600	23,600	23,600	23,600	23,600
Fan shaft	30,000	30,000	30,000	30,000	30,000	30,000
Forward shaft	20,000	20,000	20,000	20,000	20,000	20,000
Stage 1-2 spool	20,000	20,000	20,000	20,000	20,000	20,000
Stage 3 disk	20,000	20,000	20,000	20,000	20,000	20,000
Stage 4-9 spool	20,000	20,000	20,000	20,000	20,000	20,000
CDP seal	20,000	20,000	20,000	20,000	20,000	20,000
Front shaft	20,000	20,000	20,000	20,000	17,300	17,300
Front Air Seal	20,000	20,000	20,000	20,000	17,300	17,300
Disk	20,000	20,000	20,000	20,000	20,000	19,200
Rear shaft	20,000	20,000	20,000	20,000	20,000	20,000
Stage 1 disk	25,000	25,000	25,000	25,000	25,000	25,000
Stage 2 disk	25,000	25,000	25,000	25,000	25,000	25,000
Stage 3 disk	25,000	25,000	25,000	25,000	25,000	25,000
Stage 4 disk	25,000	25,000	25,000	25,000	25,000	23,900
Shaft	25,000	25,000	25,000	25,000	25,000	25,000
Conical support	25,000	25,000	25,000	25,000	25,000	16,300

Insertion engines are summarised *(see table, this page)*.

The fan disk has a life of 17,900EFC for all six variants. "Although this limit is short compared to the other two LLPs in the fan/LPC module, the fan/LPC can be easily separated from the rest of the engine, and the disk removed and replaced after taking out the fan blades without having to disassemble the module. This avoids an early shop visit," says Ferreira.

The booster spool LLP has a limit of 23,600EFC for all variants, except the -7B27 which has a limit of 22,900EFC. "The life of this part can easily be extended to 30,000EFC after an inspection, and so prevents an early disassembly and shop visit of this module," explains Ferreira.

The fan shaft is the only LLP in this module to have a life of 30,000EFC, and this applies to all thrust variants. The overall result is that full disassemblies and workscopes on the fan/booster module are only required about once every 30,000EFC.

The five LLPs in the HPC all have lives of 20,000EFC for all six thrust ratings. The four LLPs in the HPT module have lives of 20,000EFC in the case of the four lower-thrust-rated variants. While the rear shaft has a life of 20,000EFC for all ratings, the other three parts have shorter lives of 17,300EFC for the two highest-rated variants.

The LPT has relatively few limitations: the stage 4 disk and conical support in the -7B27, which have lives of 23,900EFC and 16,300EFC *(see table, this page)*.

1st removal causes & intervals

These life limits have to be considered together with possible removal intervals that EGT margins would allow. "Low-thrust engines, which includes those up to the -7B24, can operate up to their first LLP life limiter," explains David Beale, customer programme engineer at MTU Maintenance Hannover. "High-thrust engines, the -7B26 and -7B27, might become EGT-margin-limited after 12,000-18,000EFC on-wing, depending on their average EFC length, their operating environment, and rate of EGT margin deterioration. Engines that fly at 1.5EFH per EFC or longer, which are relatively long cycle times, will accumulate a high number of EFH on-wing and so will experience relatively high deterioration. One main removal driver will be the need to replace variable stator vane (VSV) bushings in the HPC."

-7B18, -7B20 & -7B22

Lower-rated -7B18/20 and -7B22 engines have sufficient EGT margin to operate beyond the highest life limits of fan and LPC module LLPs on their first on-wing interval. Besides the fan module, which is easily removable, the LLPs in the engine that would actually limit the removal interval are those in the HP modules that have lives of 20,000EFC. First shop-visit removals for these lower-rated engines are likely to be forced by expiry of LLPs in the two HP modules.

easyJet's experience is an average first removal interval of 15,000-18,000EFC, but the airline has a relatively short EFC time of 1.57EFH. The main removal causes are mechanical deterioration, but it does also have some removals forced by LLP expiry, so some intervals are up to 20,000EFC.

After a removal interval of 20,000EFC, engines would then have stub lives of 5,000EFC for their LPT LLPs and stub lives of 10,000EFC for their fan/LPC LLPs.

-7B24

The medium-rated -7B24 has enough EGT margin to allow it to operate for to up 18,000EFC for the first on-wing removal. This compares to LLP life limits of 20,000EFC. In some cases the engines may be able to remain on-wing for 20,000EFC, so removals for shop visits will be forced both by performance loss and LLP expiry. Southwest's -7B24 fleet achieves first and mature intervals of 20,000EFC, and removals are forced by LLP expiry.

The LLPs in the LPT would therefore have stub lives of 5,000-7,000EFC at the first removal, and parts in the fan and booster would have stub lives of 12,000EFC.

-7B26 & -7B27

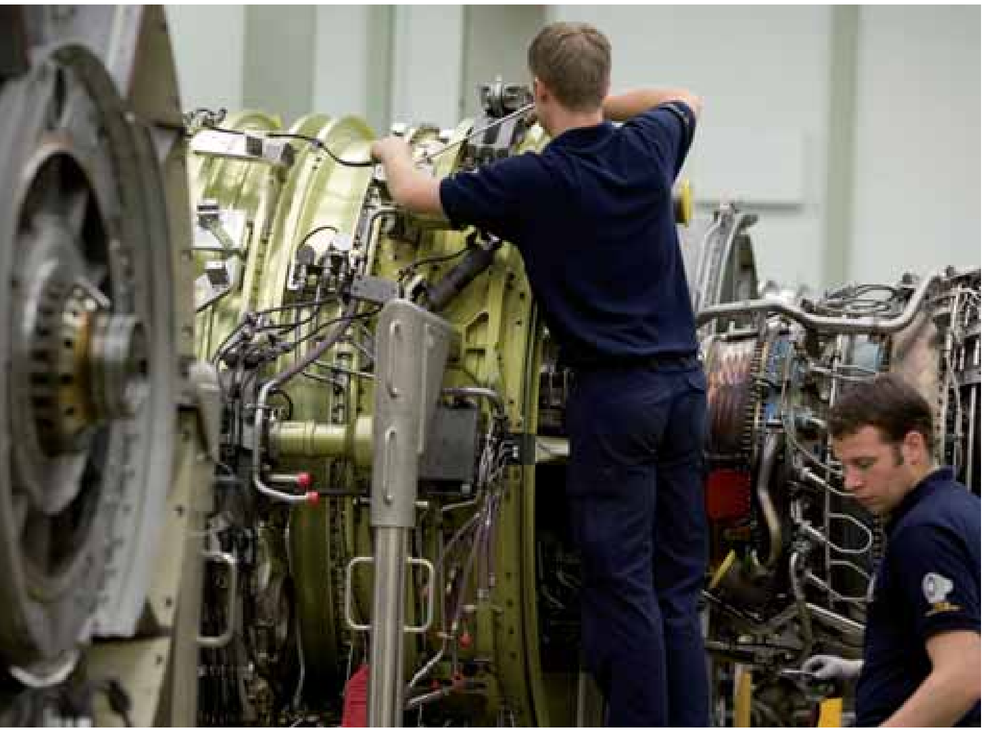
The high-rated -7B26 and -7B27 will use all their EGT margin after 10,000-14,000EFC by their first removal, and so be left with stub lives of 6,000-10,000EFC in their HP modules. Most parts in the LPT module will have stub lives of 11,000-15,000EFC, while parts in the fan and LPC will have stub lives of 16,000-20,000EFC.

XL Airways, which operates at 2.84EFH per EFC, has averaged 10,000EFC for its first removal intervals, equal to almost 30,000EFH. Main removal causes are EGT margin loss and the need to replace HPC bushings.

The Tech56 modified engines are expected to have EGT margins about 10 degrees higher than those of non-modified engines. "This would allow the higher-rated -7B24, -7B26 and -7B27 engines to remain on-wing for about another 2,000EFC and possibly another 3,000EFC," explains Kleinhans.

This suggests that after modification the -7B26's first removal interval could be up to 16,000EFC, and the -7B27's up to 14,000EFC. The engines would therefore have stub lives of 4,000-6,000EFC in their HP modules, 9,000-11,000EFC in the LPT, and 14,000-16,000EFC in the fan and LPC.

The lower-rated -7B18 and -7B20 engines would also have higher EGT margin if they had the Tech56 modification, but they would be unable to make use of this because of the limits imposed by LLP lives.



Shop visit removal intervals for lower rated -7B variants are rarely due to EGT margin erosion. Engines can usually remain on-wing to the first LLP life limit.

"The prime cause for the first removal for all non-Tech56 -7Bs is LLP life expiry, especially in low- and medium-rated engines," says Ferreira. "The second, third and fourth main removal causes all relate to hardware deterioration. Few engines are removed due to loss of EGT margin and performance.

"The first of these removal causes relates to HPC rotor-stator contacts, as a result of wear to the bushings in the HPC. The second removal cause is problems with the fuel nozzle, and the third involves deterioration of the HPT blade," continues Ferreira. "There have been six different part numbers and configurations for the HPT blade since the engine was introduced. The sixth configuration is used on the Tech Insertion build-standard engines. Earlier blades had a casting problem, which resulted in poor cooling, and led to deterioration. This was hard to detect with a borescope inspection, and could only be detected by x-ray. Soft removal times of 16,000EFC, or 20,000EFC were therefore established for older HPT blade configurations. In some cases repairs had to be completed by 14,000EFC on-wing time. These lives placed a limit on removal intervals."

Kleinhans explains that the main removal drivers on higher-cycle-length engines are HPC rotor-stator contact due to VSV inner bushing wear and problems with HPT blades. Performance and loss of EGT margin are a main removal driver for -7B26 and -7B27 engines. "Engines with shorter EFC times are mainly removed due to LLP expiry, while a larger proportion of engines with longer average EFC times are removed due to hardware," says Kleinhans.

2nd removal intervals

The second removal intervals will be a compromise between the stub lives of remaining LLPs, and the probable restored EGT margin after the first shop visit and the interval it could allow. "The length of the on-wing interval after the first shop visit will depend a lot on the remaining lives of LLPs," says Beale. "Low-rated engines are likely to reach the next LLP life limit in the engine. High-thrust engines can typically reach 65% of their first-run removal interval, unless they also reach an LLP life limit. Second shop-visit workscopes must be customised because of the large number of variables that have to be considered."

Removals of high-thrust engines will be driven by EGT margin loss and LLP expiry because restored EGT margins are lower than new-build engines.

-7B18, -7B20 & -7B22

The restored EGT margins will allow on-wing intervals of 27,000-30,000EFC for the lowest-rated -7B18 and -7B20 engines. Operators would not be limited by EGT margin for the second removal interval, so the interval would just depend on remaining LLP lives. "As the stub lives of LPT and fan/booster parts at the first removal would be 5,000-10,000EFC, it makes sense to replace all LLPs at the first removal so as not to limit the second removal limit. The engines would therefore be capable of intervals of 20,000EFC for every removal," explains Ferreira. "The second interval could then be 15,000-20,000EFC." The fan/booster LLPs with stub lives of up to 10,000EFC could be used in higher-rated -7B26 and -7B27 engines, which may only be capable of removal intervals of this length.

-7B24

Non-Tech56 modified engines would have stub lives of 5,000-7,000EFC in the LPT and 12,000EFC in the fan/booster at the first removal.

The engine would be capable of 12,000-13,000EFC for the second removal interval, based on its restored EGT margin. The best policy would be to replace HP module and LPT LLPs at the first removal and shop visit, and leave the parts in the fan/booster to be replaced at the second removal and shop visit. The remaining life of these parts and the probable time on-wing due to EGT margin would be similar at 12,000EFC.

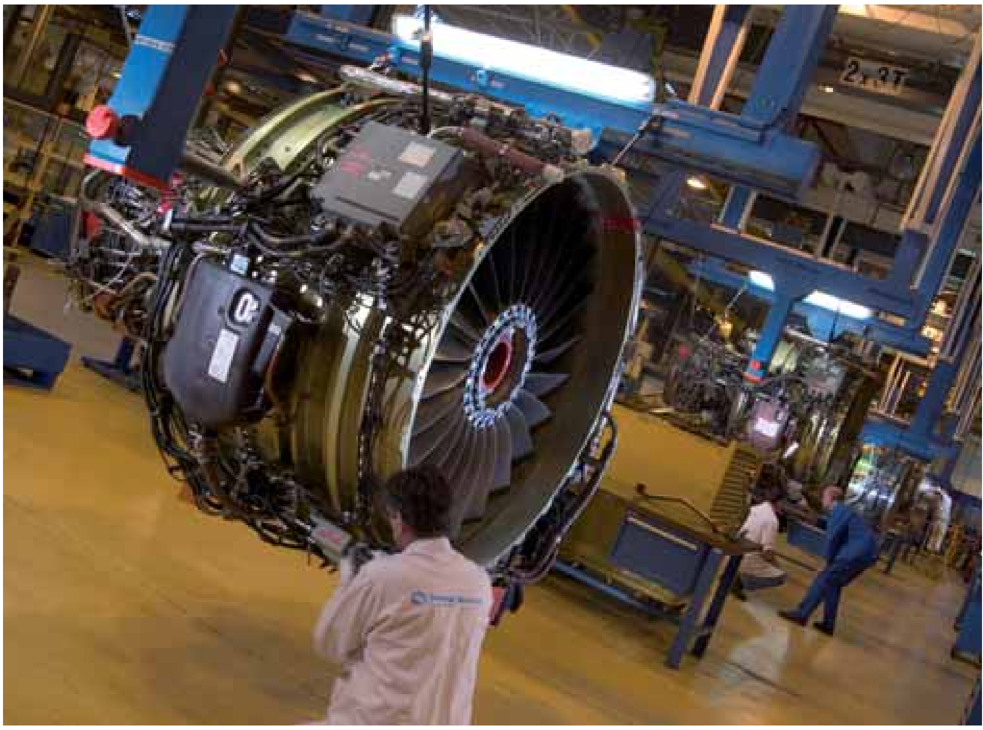
A probable scenario for non-Tech56 modified engines would be the replacement of HP and LPT parts at the first removal after 18,000-20,000EFC. The second removal would be limited to 10,000-12,000EFC by the stub lives of fan/booster LLPs. The fan/booster LLPs would be replaced at the second shop visit, at which stage the HP module LLPs would have stub lives of 8,000-10,000, and LPT LLPs would have stub lives of 13,000-15,000EFC.

The third removal interval would therefore be limited to 8,000-10,000EFC by the HP parts. The HP and LPT LLPs would be replaced at this shop visit, while the fan/booster LLPs would have a stub life of 20,000-22,000EFC at this stage.

The total accumulated time at the third shop visit would therefore be 38,000-40,000EFC.

There is a case for using the Tech56 modification on these medium-rated engines. The 10-degree higher EGT margin would allow another 2,000EFC on-wing time, and so a first interval of 20,000EFC. With a higher EGT margin, subsequent removal intervals could be as high as 15,000EFC. It may therefore be attractive to some operators to consider replacing all LLPs at the first shop visit, which would allow a second removal interval of 15,000EFC.

The HP and LPT module LLPs would therefore be replaced at the second shop visit, allowing a third removal interval of 15,000EFC, because of the remaining lives of parts in the fan/booster. The core and fan/booster LLPs would be replaced at this shop visit. The total of the three



There are three LLPs in the fan/LPC module with lives of 17,900-30,000EFC. The module can easily be separated from the rest of the engine, and have fan blades removed. The fan disk, lifed at 17,900EFC, can then be easily replaced. The booster spool, lifed at 23,600EFC, can have its life increased to 30,000EFC after an inspection.

intervals would be 50,000EFC, but a larger number of LLPs would have been replaced in the process. The LPT parts removed at the second shop visit would have stub lives of 10,000EFC, so they could be used in -7B26 and -7B27 engines that are only capable of intervals of similar lengths.

-7B26

Non-Tech56 -7B26s are capable of second and subsequent removal intervals of 9,000-10,000EFC, and -7B27 engines would be capable of 8,000-10,000EFC.

The -7B26 would be left with stub lives of 6,000EFC in its HP modules, 11,000EFC in its LPT, and 16,000EFC in its fan/booster at the first removal. The potential second run of 9,000-10,000EFC due to restored EGT margin means it would be best to replace HP LLPs at the first shop visit, but leave LPT and fan/booster LLPs.

After the second on-wing interval the LPT parts would be virtually used, and fan/booster parts would have a stub life of 5,000-7,000EFC. These two groups of parts would therefore be replaced at this stage. The HP LLPs would have a stub life of 9,000-11,000EFC, and so allow a third interval of the same length.

The Tech56 modification would allow a longer first interval of 16,000EFC, and a potential second interval of 12,000EFC. While the HP LLPs would clearly be replaced at the first shop visit, and the fan/booster LLPs could be left in to limit the second removal interval to 14,000EFC, the LPT parts would have a stub life of 9,000EFC at the first removal. Leaving them would limit the second removal to just 9,000EFC and a total accumulated time of 25,000EFC at the second removal. Replacing them at the first shop visit would allow a longer second interval of 12,000EFC, but this would then limit the third interval to 8,000EFC because of the remaining lives of the HP LLPs.

-7B27

The -7B27's first average removal interval of 11,000EFC will leave the engines with HP stub lives of 9,000EFC, LPT stub lives of 14,000EFC, and fan/booster stub lives of 19,000EFC. The second potential interval of 9,000EFC for non-Tech56 modified engines would mean all LLPs could be left at the first shop visit.

The second removal interval would be limited to 9,000EFC by the stub life of its HP LLPs, which coincides closely with the probable interval that would be allowed by its restored EGT margin. XL Airways, for example, expects its second removal interval to average about 7,000EFC, when operating at 2.85EFH per EFC. After 9,000EFC, the LPT LLPs would have a stub life of 5,000EFC, and so should be removed, while the fan/booster LLPs would have a stub life of 10,000EFC and so could be left in for the third interval. This would also be 9,000EFC, and be limited to 10,000EFC by LLP stub lives. The total accumulated time by the third interval would be 29,000EFC.

Tech56 modified engines would be capable of intervals that are 2,000-3,000EFC longer. First intervals could therefore be up to 13,000EFC, in which case LLPs in the HP modules would have a stub life of 7,000EFC and so be replaced. LPT and fan/booster LLPs would have stub lives of 12,000EFC and 17,000EFC, and so could be left for the second interval. The second interval, limited by HP module stub lives, would mean the core and LPT LLPs would have to be replaced at the second shop visit. The fan/LPC module LLPs would be left with a stub life of 10,000EFC, thereby limiting the third interval. The total accumulated time at the third interval would be 30,000EFC.

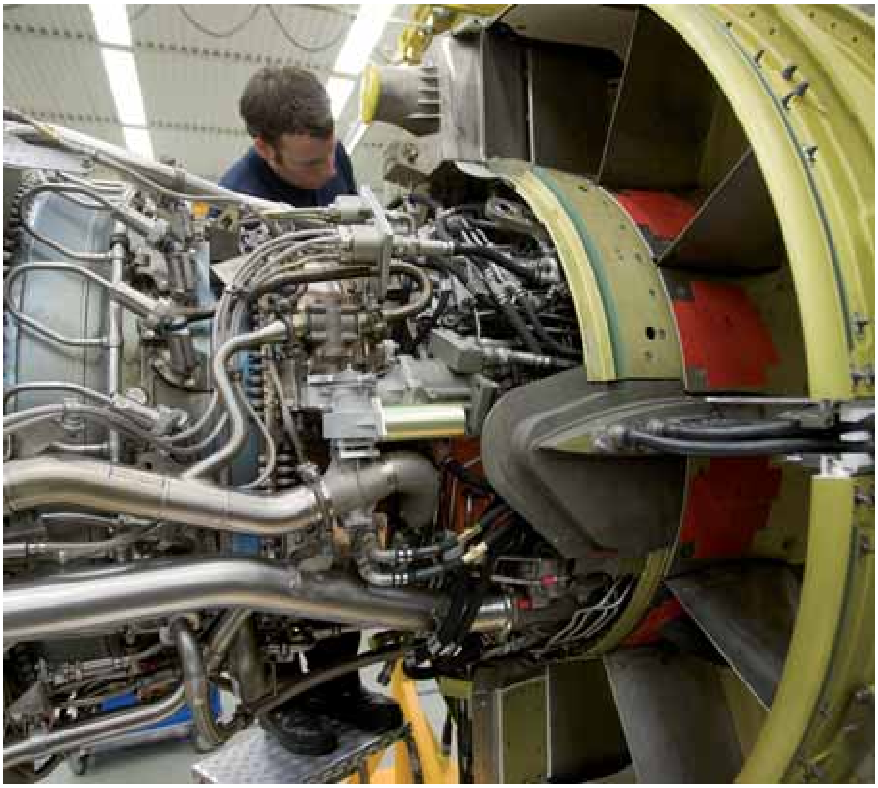
Shop visit workscopes

The workscopes required at each removal should fit the pattern of removals and LLP replacements as described. There are several levels of shop visit workscope, and the one used will depend on the time on-wing, the removal and the removal cause.

"If the engine is removed for loss of EGT margin or deterioration of the HPT or the fuel nozzles, then the engine can have a level 1 workscope. This is a repair without the need to carry out a full disassembly and any LLP replacement," says Ferreira. "This workscope would restore performance to allow it to reach LLP limits on the second interval. This would be a more likely scenario for high-rated engines.

"A level 2 workscope is a heavier visit for the core engine that involves full disassembly and LLP replacement. In some cases a level 2 workscope is required on the core without replacing LLPs. In the case of high-rated engines, 13,000-16,000EFC have been accumulated, and core LLPs need to be replaced. The stub life of 9,000-12,000EFC for LPT LLPs is the limit to the second interval," continues Ferreira. "In the case of low-rated engines the interval is likely to be 19,000-20,000EFC. Core LLPs should be replaced, and there is no sense in keeping LPT LLPs. The remaining life of fan/booster LLPs will determine if they are removed or left. If they are removed, the next interval will be limited by core LLPs to 20,000EFC. The fan/booster LLPs can be used on higher-rated engines for their later on-wing intervals.

"A level 3 workscope involves replacing LLPs for the whole engine," continues Ferreira. "In this case it is a full overhaul." This will be required for low-rated engines that have intervals of 20,000EFC.



Engine removals for shop visits will be a compromise between on-wing life that is possible with EGT margin and LLP limits. The workscope required on the HP modules, LPT and fan/LPC will depend on the utilisation of LLP lives and the subsequent removal interval that will be possible with the restored EGT margin.

-7B20/22

The workscope pattern for the first two removals for the -7B20 and -7B22 engines will involve a level 3 workscope, or an overhaul and full LLP replacement, at the first and second removals after intervals of up to 20,000EFC *(see table, page 26)*. While this includes the removal of fan/booster LLPs which have stub lives of up to 10,000EFC, these can be sold or used for other high-rated engines.

The lowest-rated -7B20 and -7B22 engines should continue with this relatively simple pattern of shop visits.

-7B24

The -7B24 will require a level 2 workscope on the core and LPT at the first removal after an interval of 18,000EFC *(see table, page 26)*. The core would require a full workscope to restore performance and replace LLPs, and the LPT would also require a full workscope to replace LLPs. The fan and booster module could be left until the second shop visit.

The second shop visit would require a level 1 workscope on the core engine, since LLPs would not require replacement, and a level 2 workscope on the fan/booster to replace their LLPs. The LPT could be left.

The third shop visit would be similar to the first.

In the case of Tech56 modified -7B24 engines, a level 3 workscope would be required at the first shop visit to completely disassemble the engine and replace all LLPs. A level 2 workscope would then be required at the second shop visit to completely disassemble the core and LPT, while the fan and LPC would be left. A level 2 workscope would again be required on the core and fan/booster modules at the third shop visit *(see table, page 26)*.

-7B26

The first run for the non-Tech56 -7B26 of 14,000EFC would require a level 2 workscope on the core for full disassembly and LLP replacement. The fan/booster and LPT would be left.

These two modules would then have level 2 workscopes at the second shop visit, while the core module would only require a level 2 workscope, without LLP replacement, to restore performance.

The core modules would require a level 2 workscope, with LLP replacement, at the third shop visit, while the fan/booster and LPT could again be left.

Tech56 modified -7B26 engines would follow the same basic shop visit workscope pattern as unmodified engines, although the modified engines would have longer shop visit intervals.

-7B27

The non-Tech56 modified -7B27 would only require a level 1 workscope on the core modules, and no other work on other modules after an interval of 11,000EFC. The second shop visit after another 9,000EFC on-wing would need level 2 workscopes on the core and LPT modules.

The third shop visit would require a level 1 workscope on the core to restore performance, and a level 2 workscope on the fan/LPC module.

The Tech56 modified -7B27 engines would still be limited by the HP LLP lives of 20,000EFC. The first two intervals would total 20,000EFC. The HP and LPT LLPs would be replaced at the second shop visit.

As the engine would be capable of mature intervals of up to 12,000EFC, it would be optimal to have a third interval of 10,000EFC and to replace fan/booster LLPs at this shop visit. The mature intervals would have to average 10,000EFC because of the lives of HP LLPs.

Workscope inputs

Workscope inputs comprise three main cost elements: labour; parts and materials; and sub-contract repairs. Different engine shops have different levels of hi-tech parts repair capability, and there is a trade between the cost of labour and materials versus the cost of repairs.

The total cost of a core performance restoration is $1.1-1.3 million. Total labour for such a shop visit will be 3,000MH for a level 1 workscope, and up to 3,500MH for a heavy shop visit. Using a standard labour rate of $70, this portion of the shop visit would cost $195,000-250,000.

The cost of materials for a core performance restoration is $650,000-900,000, depending on the level of workscope. The cost of sub-contract repairs can vary from $250,000 to $400,000, depending on the capability of the engine shop. The total cost for a level 1 core workscope will therefore be $1.2-1.3 million, and $1.5-1.6 million for a level 2 workscope.

A workscope for an LPT module will use 700-900MH, $200,000-250,000 for materials, and a further $50,000 for sub-contract repairs. The total cost for the workscope will therefore be $350,000-400,000 when using a standard labour rate of $70 per MH.

A fan/booster module workscope can use 400-450MH for labour. Materials will cost $100,000, and sub-contract repairs up to $40,000. The total cost of the workscope will be $170,000-180,000.

A full overhaul for the whole engine, or level 3 workscope, will use 5,000-5,500MH in labour. Materials will cost

CFM56-7B REMOVAL INTERVAL, SHOP VISIT WORKSCOPE & LLP REPLACEMENT PATTERN

Removal	Interval EFC	Accumulated EFC	Workscope content	Shop visit Cost-$	$/EFC	LLP replacement	LLP cost $	LLP $/EFC	Sub-total $/EFC	Unsched visits $/EFH	QEC $/EFH	Total $/EFH
-7B20/22												
1st	20,000	20,000	Full overhaul	1,950,000	98	All parts	1,775,000	89	186	20	10	127
2nd	20,000	40,000	Full overhaul	1,950,000	98	All parts	1,775,000	89	186	20	10	127
-7B24 Non-Tech56												
1st	18,000	18,000	Level 2 core & LPT	1,900,000	112	Core & LPT	1,420,000	91	202	20	10	136
2nd	12,000	30,000	level 1 core & level 2 Fan/LPC	1,425,000	128	Fan/LPC	356,000	83	211	20	10	141
3rd	8,000	38,000	Level 2 core & LPT	1,900,000	219	Core & LPT	1,420,000	83	302	20	10	189
-7B24 Tech56 modified												
1st	20,000	20,000	Full overhaul	2,000,000	100	All parts	1,775,000	89	189	20	10	130
2nd	15,000	35,000	Level 2 core & LPT	1,900,000	133	Core & LPT	1,420,000	106	221	20	10	146
3rd	15,000	50,000	Level 2 core& level 2 fan/LPC	1,725,000	127	Core & fan/LPC	1,277,000	93	221	20	10	146
-7B26												
1st	14,000	14,000	Level 2 core	1,550,000	134	Core	921,000	103	237	20	10	155
2nd	9,000	23,000	Level 2 core & LPT & fan/LPC	2,075,000	195	LPT & Fan/LPC	855,000	88	283	20	10	179
3rd	9,000	32,000	Level 2 core	1,550,000	197	Core	921,000	92	289	20	10	182
-7B26 Tech56 modified												
1st	16,000	16,000	Level 2 core	1,550,000	118	Core	921,000	92	209	20	10	140
2nd	9,000	25,000	Level 2 core, LPT & fan/LPC	1,775,000	160	LPT & fan/LPC	855,000	80	240	20	10	156
3rd	11,000	36,000	Level 2 core	1,550,000	166	Core	921,000	84	250	20	10	161
-7B27												
1st	11,000	11,000	Level 1 core	1,250,000	138	-	-	83	221	20	10	146
2nd	9,000	20,000	Level 2 core & LPT	1,900,000	196	Core & LPT	1,420,000	83	279	20	10	177
3rd	9,000	29,000	Level 1 core & level 2 fan/LPC	1,425,000	158	Fan/LPC	356,000	87	245	20	10	159
-7B27 Tech56 modified												
1st	12,000	12,000	Level 1 core	1,250,000	128	-	-	83	211	20	10	141
2nd	8,000	20,000	Level 2 core & LPT	1,900,000	217	Core & LPT	1,420,000	83	300	20	10	188
3rd	10,000	30,000	Level 1 core & level 2 fan/LPC	1,425,000	149	Fan/LPC	356,000	83	232	20	10	152

Planned shop visit engine maintenance reserves based on 1.9EFH per EFC.

$1.1-1.25 million, while the additional cost of sub-contract repairs will be $400,000-500,000. This will take the total cost of the shop visit to $1.85-2.1 million.

Unscheduled shop visits

Unscheduled shop visits fall into engine-related and non-engine-related events. Non-engine-related events are items such as birdstrikes and foreign object damage (FOD). Engine-related events are those where there is engine hardware failure. These can be further sub-divided into light and heavy events. Light events are issues such as oil leaks, hospital visits for damage on the HPC, and other minor incidents that do not require full engine disassembly.

Light engine-related events occur at a rate of once every 60,000FH/31,000EFC. They typically incur a cost of $250,000-300,000. A reserve of $5 per EFH should therefore be budgeted.

Heavy engine-related and non-engine-related events should be considered together because they require full engine disassembly. Heavy engine-related events are major issues that include bearing failures, which incur some of the highest shop visit costs of up to $2 million. Birdstrikes and FOD events can also incur similarly high shop visit costs. The two occur at a combined rate of once every 70,000-80,000EFH or 35,000-40,000EFC. This is equal to three or four times the interval of planned shop visits. One of these heavy events therefore replaces one of every three or four planned events. These heavy events usually have higher shop visit costs than planned events, so an allowance of half the cost of a heavy shop visit should be added for every three or four shop visits, equal to an additional $12-15 per EFH.

The total allowance for unscheduled shop visits should therefore be $20 per EFH.

Reducing shop visit costs

Shop visit costs can be mitigated to some degree by the use of parts manufacturer approval (PMA) parts. HEICO is one supplier of PMA parts for the CFM56-7B, and it manufactures all variety of parts for the engine. "We provide fasteners, washers, seals, as well as more expensive parts such as HPT and

Shop visit intervals mean LLPs cannot be fully utilised in all modules in the case of most engines. If managed, LLP reserves can be in the region of $90 per EFC.

LPT shrouds. We also provide parts for the engine's accessories, which include the starter motors, pneumatics and hydraulics," says Rick Stine, president of HEICO Parts Group. "We also have some blades and vanes available. Most of these are from the HPC, but we are also developing blades and vanes for the LPT. In total we manufacture more than 500 part numbers for the CFM56-7B, and are developing more. The possible savings we can provide for core engine parts are up to $100,000 per shop visit. Additional savings for parts used in engine accessories are about $8,000."

Maintenance reserves

Maintenance reserves per EFH are summarised for each engine variant *(see table, page 26)*. This includes engines which have had the Tech56 modification. The reserves are for engines operating at fleet average EFC lengths of 1.9EFH.

Basic reserves are a result of the planned shop visit intervals, shop visit workscopes and workscope patterns, and shop visit inputs. A common issue with all variants is that different modules have their LLPs replaced at different shop visits. Compromises have to be made with removal intervals that are possible with EGT margin and LLP life limits. This complicates the calculation of shop visit and LLP reserves.

An example is the -7B26 variant which has a level 2 core workscope and LLP replacement at the first shop visit, and a level 2 core workscope without LLP removal at the second shop visit.

The LPT and fan/LPC have level 2 workscope and LLP replacement at the second shop visit.

The reserves for the workscopes and LLP replacement for the LPT and fan/LPC are amortised over the first two intervals. The reserves for the core's two workscopes are amortised over the relevant intervals.

The need to compromise between possible removal intervals and LLP lives means that full LLP lives cannot be fully utilised, and parts are replaced early. This has the effect of raising LLP reserves.

An example of this is the -7B24 engine which has a first removal interval of 18,000EFC, and is capable of a second interval of up to 12,000EFC. The core LLPs are replaced slightly early at the first shop visit, and the fan/booster LLPs at the second visit after a total time of 30,000EFC. The LPT parts have to be replaced early at the first visit after 18,000EFC, therefore not utilising 7,000EFC of their life limit. This need to compromise also has the effect of making reserves increase and decrease between subsequent removals.

Average reserves for LLPs in all variants are $87-93 per EFC, suggesting that the average replacement interval for all parts is 19,000-20,000EFC.

A sub-total of reserves per EFC for shop visit inputs and LLP lives is calculated. These are then converted to rates per EFH at the EFC time of 1.9EFH. Additional costs for unscheduled visits of $20 per EFH, as described, and another $10 per EFH for quick engine change (QEC) repair and overhaul are added to get the total cost per EFH.

As expected, the -7B20/22 engines have the lowest overall reserves: $127 per EFH for the first two removals *(see table, page 26)*.

The -7B24 has reserves of $136-141 per EFH for the first two removals, but these rise to $189 per EFH as the engine matures and the third interval is limited to 8,000EFC by core LLP lives. Reserves for the fourth interval would be lower with just a workscope on the core at this shop visit.

The -7B24 with the Tech56 modification has more consistent first and mature shop visit removal intervals, and has lower overall reserves than unmodified -7B24 engines. Reserves for the modified -7B24 are $130-146 per EFH, which are $6-43 per EFH lower than non-Tech56 engines *(see table, page 26)*.

The -7B26 has reserves of $155-182 per EFH over its first three shop visits *(see table, page 26)*. This is up to $20 more per EFH more than the -7B24. The -7B26 benefits from the Tech56 modification by having longer removal intervals in some cases, and is overall able to achieve reserves that are $15-20 per EFH lower than those of unmodified engines.

The -7B27 has reserves of $146-159 per EFH, lower for some removal intervals than those of the -7B26 *(see table, page 26)*. This is explained by the -7B27 being able to better utilise its LLP lives, due to the effects of EGT margins on removal intervals. Reserves for the -7B27 modified with the Tech56 upgrade are $5-7 per EFH lower than those of non-modified engines.

Summary

The CFM56-7B has maintenance reserves in line with its -5B counterpart *(see CFM56-5A/5B maintenance analysis & budget, Aircraft Commerce, February/March, page 15)*. The possible planned removal intervals are long enough for just two or three removals to be experienced during its operating life on passenger jets. The engine has high EGT margins, but it also has good durability, and has experienced relatively few problems with degradation of hardware that previous generations have.

The engine clearly benefits from the Tech56 modification, since this lowers maintenance reserves by up to $40 per EFH, especially for mature engines which have lower restored EGT margins than their original EGT margins. AC