The CFM56-5B series has eight variants. The whole life removal patterns and maintenance of the two main thrust rating groups are examined in detail. The engine's EGT margin and LLP lives permit a simplified planned shop visit management.

CFM56-5B maintenance management & reserves

The genesis of the CFM56-5B came from the limitations of the -5A, which did not have the capability to power the A321. The -5B was redesigned to incorporate a fourth low pressure compressor (LPC) stage. This increase in coreflow allowed the engine to safely and reliably produce up to 32,000lbs of thrust. The engine could then be de-rated to operate on the rest of the A320 family.

The -5B has eight different variants denoted by the suffix one to eight *(see table, page 28)*, with eight different thrust ratings from 21,500lbs to 32,000lbs of thrust *(see table, page 28)*. The highest thrust rating is that of the 5B3 at 32,000lb thrust, operated on the A321. The lowest is the -5B8 operated on the A319 with 21,500lbs thrust.

There are no differences in turbomachinery within the -5B family, just different thrust ratings set within the full authority digital engine control (FADEC). High-rated engines can be re-rated to lower thrusts if needed.

Utilisation

The A320 family are operated in most global regions. Most, however, are operated in Europe, followed by North America. This means the CFM56-5B operates in all kinds of environments and temperatures, including the harsh winters of North America, Russia and Northern Europe with their salt-gritted runways and temperatures from -20 to 25 degrees centigrade, and the hot-and-high climates of the Middle East where temperatures soar to more than 40 degrees centigrade.

The operating temperature is likely to be the largest factor that affects the maintenance costs of -5B engines, closely followed by the thrust rating. These combine to affect the rate of EGT margin and performance loss.

To a lesser extent the amount of take-off thrust de-rate, the engine flight hour (EFH) to engine flight cycle (EFC) ratio, and on-wing condition management will dictate the time on-wing (TOW).

The average EFH figure for a -5B fleet is 2.0. However, this figure is misleading because some operators have short EFC times of 0.7EFH, while the longest are upwards of 6.0EFH.

Variants

The CFM56-5B series can be split into three main groups that power the A319, A320 and A321. The majority of A319s are powered by the CFM56-5B5 and -5B6, rated at 22,000lbs and 23,500lbs thrust *(see table, page 28)*. They have high initial production EGT margins of 110-165 degrees centigrade.

Most A320s are powered by the CFM56-5B4 rated at 27,000lbs thrust, which has an initial production EGT margin of about 110 degrees centigrade.

Most A321s are powered by the CFM56-5B3 rated at 32,000lbs thrust, which has an initial production EGT margin of about 66 degrees centigrade.

Classics

The original -5B engines are known as the classic. From 1993 to 1996 fewer than 300 were produced As the engine matured, technical upgrades to the series were introduced.

/P series

The /P series was introduced in 1996 as a performance modification that reduced fuel consumption by as much as 3%. The /P incorporated a re-profiled high-pressure compressor (HPC) with more aerodynamically efficient blades. Re-designed HPT blades were introduced to increase cooling airflow and finally the low-pressure turbine (LPT) first stage nozzle was re-designed to reduce the thermodynamic losses transitioning between the high pressure turbine (HPT) and the LPT. The /P modification became standard across the production line, but was available as a mod kit that could be retrofitted at the next shop visit for the classic engines. A trade-off of the decrease in SFC of 3% was an EGT limit reduction of 10C from 950C to 940C, because of the redesigned turbo machinery.

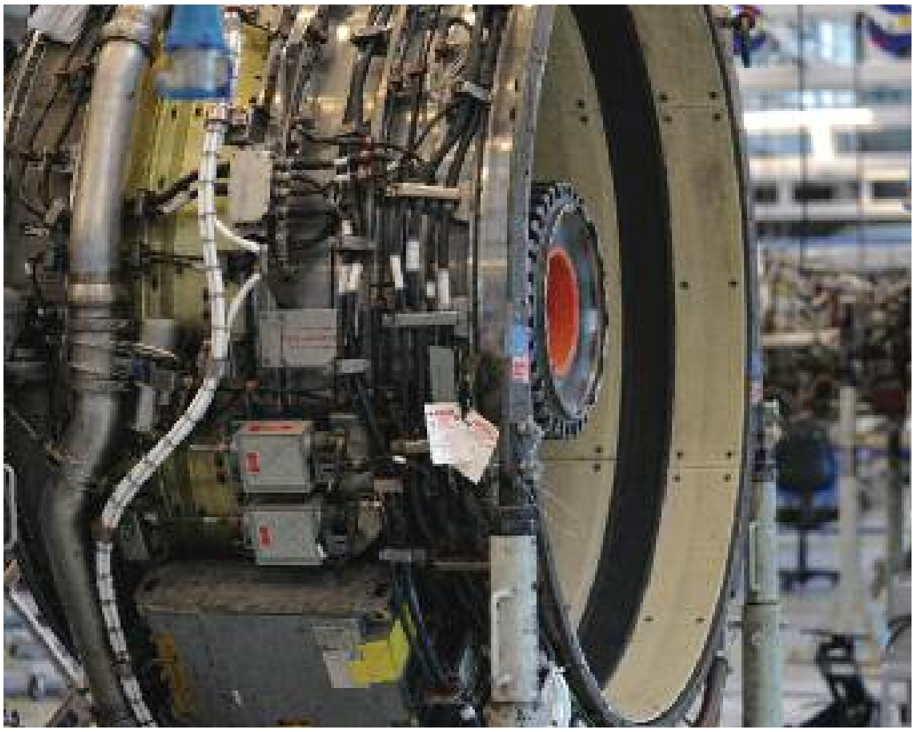
/2 (DAC) series

The /2 variant introduced a dual annular combustor (DAC) chamber, which was designed to reduce NOx emissions for airlines that operate out of areas that have specific penalties for emissions. Early adopters of the DAC, Swissair and Sabena, opted for the /2 model. The /2 model was a real step forward in emissions reduction thanks to its innovative design.

The DAC incorporated a second smaller inner annular combustion ring of fuel nozzles. Each nozzle had a secondary spray head serving the inner ring. At low power levels only the outer or pilot stage is used. The low volume and velocity of airflow through this stage promotes stable operation and near-complete combustion reducing NOx emissions by up to 40%. At high power both the stages are lit, but the combustion is split 75% inner:25% outer. The greater velocities induced by the DAC design greatly reduce combustion duration.

Early DAC engines experienced some severe problems in the hot section. The hot sections were reaching much higher core temperatures than the basic engine. This led to higher thermal stresses within the turbine sections, and several LPT blade failures during engine start.

Borescope inspections revealed early deterioration, and several engines had to



The large grey box in the lower left of the picture is the FADEC. Re-programming via a laptop adjusts the thrust rating for use on other airframes.

be removed due to cracking out of limits. CFMI introduced a revised chamber design with improved cooling and materials, and this improved on-wing life. In addition to these problems, the turbine rearframe cracked on a few examples that had experienced the higher temperatures. CFMI has confirmed that all the issues are now resolved.

Tim Walters, systems engineer at Lufthansa Technik, explains that the DAC engine overhaul is generally more cost-intensive, since the combustion chamber suffers more from cracking. Consequently the scrap rate is higher. In LHT's experience, many operators prefer to convert from the DAC to SAC combustion chamber, because the expected removal interval is longer.

The DAC's shop visit costs can be expected to be $250,000-350,000 higher than the SAC model. If the combustion chamber needs replacing, a new combustor could potentially drive the cost up by $1 million.

/3 Tech insertion

The /3 was launched in 2004 by CFMI as a major modification package aimed at improving fuel burn and EGT margin, while improving on-wing durability. The core of the engine was completely redesigned, with improvements to the HPC, combustion chamber, HPT and LPT. The /3 became standardised in production from 2008.

The HPC received an upgrade to stator bushings, and re-profiled blades with improved aerodynamics. The combustor is of totally new construction, designated the twin-annular pre-swirl (TAPS), originally developed for the GEnx. TAPS was designed to reduce combustion chamber temperatures through increased cooling, which reduced NOx emissions to CAEP 6 levels.

The HPT turbine blades get a new contour lowering the interaction loss between the HPT and LPT.

It was hoped the /3 tech insertion would increase the on-wing time by 10%, and reduce HPC deterioration to the equivalent of 10 degrees of EGT margin over the life of the engine.

The /3 in service is a more attractive lease asset than the DAC or /2, due to the interchangeability of the engine. An A320 can have a CFM56-5B/3 mounted on one side, and a regular CFM56-5B installed on the other, provided that the engine is properly primed through the FADEC.

EGT margin

EGT margin is the key indicator of the engine's performance and health.

New production -5B3 engines, rated at 32,000lbs thrust, have an installed EGT margin of 66 degrees. This increases to 95 degrees for the -5B2 rated at 31,000lbs thrust, and is 115 degrees centigrade for the -5B1 rated at 30,000lbs thrust.

EGT margins generally increase with reduced thrust ratings. The -5B4 and -5B7 rated at 27,000lbs have an initial margin of 109 degrees, while the -5B6 rated at 23,500lbs, has an EGT margin of 145 degrees. The -5B5 has a new margin of 163 degrees, and the -5B8 have margin of up to 180 degrees.

The lower thrust version of the CFM56-5/P will have the same initial EGT margin loss during the first 2,000EFC following entry into service. The deterioration rate will then reduce to 2.75-3.00 degrees C per 1,000 EFC.

The original EGT margin can never be fully restored after the first shop visit. The percentage of the original margin that can be regained depends on the shop visit workscope. Clearances between blade tips and engine casings, for example, will increase the EGT margin that is recovered, but the rate of initial EGT margin loss that is experienced following a shop visit is always high. Walters states that if a full workscope is carried out on both the hot section and the core, Lufthansa's engines post-overhaul have an average of an 80% recovered EGT margin compared to new build engines. It is typically 40% less than new build if only a hot section workscope is carried out.

The -5B4 and -5B7 specifically would have restored margins of 84 degrees, so second removal intervals could be 11,000-12,000EFC.

Corner point temperature

EGT margins are measured at different corner point ratings. Francis Tremblay, CFM56 programme manager at Lockheed Martin Commercial Engine Solutions (formerly Kelly Aviation) says that the corner point or flat rate temperature of the CFM56-5B/P high thrust versions is 30 degrees C, while that of the low thrust version is 44-45 degrees C. The EGT margins and their respective corner point, or flat rate, temperatures are summarised *(see table, page 28)*.

An engine with a high corner point temperature will be able to operate at maximum thrust in a higher OAT. This compares to an engine with a lower corner point temperature, which will have to operate at less than maximum thrust when experiencing the same OAT.

This is important, because the engine's EGT and EGT margin are protected by being kept constant at all outside air temperatures (OAT) above the applicable corner point temperature. This is achieved by reducing thrust with the FADEC unit. It reduces the throttle and thrust as OAT rises. Conversely, thrust is kept constant below the corner point temperature, with the EGT reducing and the EGT margin increasing as OAT declines. EGT increases by a ratio of 3.2:1 for every degree increase of OAT.

Because engine thrust reduces from its

CFM56-5B EGT MARGINS

Engine variant	-5B3	-5B2	-5B1	-5B7	-5B4	-5B6	-5B5	-5B8
Thrust lbs	32,000	31,000	30,000	27,000	27,000	23,500	22,000	21,600
Application	A321	A321	A321	A320	A320	A319	A319	A318
Corner point (deg C)	30	30	30	45	45	45	45	45
Initial EGT margin (deg C)	66	95	115	109	109	145	163	180
Restored EGT margin (deg C)	40-52	57-76	69-92	65-87	65-87	87-116	98-130	108-144

maximum level at OATs higher than the corner point, the aircraft's performance becomes more limited as OAT rises above the corner point. The aircraft may therefore suffer a take-off weight and payload limitation at high ambient temperatures. Engines with a higher corner point temperature may still be able to operate at maximum thrust, while engines with lower corner point temperatures will have to operate at less than maximum thrust.

Take-off de-rate

Engine thrust is often less than the maximum thrust rating at take-off.

Take-off thrust de-rate is applied for moderate and cold temperatures, and when the aircraft is operating at lower than maximum take-off weight from long runways. This prolongs on-wing life. The average EFC time of 1.8EFH for many operations means that most aircraft are being flown on routes that are a fraction of their maximum range, with a few extreme examples.

The effect of de-rate prolonging the on-wing life can be anticipated using a severity curve. This predicts the rate of deterioration in reference to the EFH:EFC ratio versus take-off de-rate. A severity curve would show that an engine operating with an EFC of 2.0EFH will have a 10% reduction in severity when increasing de-rate from 5% to 10%, and a further 7% reduction in severity when moving to 15% de-rate. With a longer EFC time of 2.6EFH, a 5% de-rate would yield a 10% reduction in the severity curve.

It is therefore desirable for operators rotate aircraft through long routes to ensure they maintain as high an EFH:EFC ratio as possible to maximise removal interval.

EGT margin deterioration

EGT margin loss is the prime removal reason for the high thrust variants. The rate of EGT margin deterioration is affected by the average EFC time. As with all engine types, the initial loss of EGT margin is highest in the first 500-1,000EFC on-wing following a shop visit. EGT margin decreases steadily after this initial high degradation phase. This is what is known as mature margin loss.

Tremblay comments that EGT margin deterioration is actually the main removal driver for the high thrust versions of the CFM56-5B, such as the -5B1/P, -5B3/P, -5B1/3 and -5B3/3.

All other -5B variants operating at low thrust level will be removed due to LLP or hardware condition. "Based on our experience in dealing with the high thrust version of the CFM56-5B/P powering the A321, it will lose 17 degrees C of EGT margin during the first 2,000EFC following service entry," says Tremblay, "The EGT margin deterioration rate will then reduce to 3.5 degrees C per 1,000EFC. The lower thrust version will have the same initial EGT margin loss during the first 2,000EFC following initialisation. The deterioration rate will then reduce to 2.75-3.0 degrees C per 1,000 EFC."

Unfortunately this means that the highest-rated -5B3 engine will lose all its margin before reaching the life limit of the LLPs with the shortest lives. The shortest LLP life on a -5B is now 20,000EFC. Previously the shortest lives were 15,000EFC, and it was expected that performance problems or total consumption of the EGT margin would occur before then.

Operators then face a dilemma. One choice is to remove the engine and have a performance restoration, with the aim of reaching the LLP life limit at the next removal interval. This takes into account the lower recovered EGT margin from a shop visit.

The second choice is re-rating the engine, if the fleet profile allows, and installing it on a A319 or A320 and potentially recovering 60 degrees of margin. Operating until it reaches its first LLP life limit at 20,000EFC.

Time on-wing is further reduced by the engine's operating environment and profile of the engine. "Engines operating in warm areas, where OAT is near the engine's flat rating temperature, will normally require removal for performance restoration when take-off EGT margin corrected to hot-day condition approaches zero degrees C," explains Tremblay. Engines operating in a colder region will have a higher EGT margin, and so a longer interval.

Life limited parts

The -5B series has 18 life-limiting parts (LLPs). It has three in the LPC module, five in the HPC module, four in the HPT, and six in the LPT. These 18 parts have a total list price of $2,554,910 *(see table, page 30)*.

This is split between $575,500 for fan/LPC parts, $632,360 for HPC parts, $635,360 for HPT parts and $711,690 for LPT parts. This is the 2013 CFMI list pricing for the /3 engines.

The LLPs are all now operating at the CFMI target life of 30,000EFC for LLPs in the LPC module, 20,000EFC in the HPC and HPT modules, and 25,000EFC in the LPT module.

Many of the LLPs of earlier-produced engines have lives restricted to less than the target lives. CFMI managed to get these restricted lives removed or gradually extended during operational experience, by testing LLPs removed from leading high-time engines. CFMI extended the lives of the LLPs in most cases before they reached their restricted life limits.

There is a wide range of life limits for each LLP, and the life limit for an individual engine will depend on the part number installed. The details of each LLP *(see table, page 30)* are not definitive. Earlier part numbers may still have restricted lives, so strict attention should be paid to the LLP lifing cards.

The eight variants of the original -5B engines mainly have part numbers in the fan/LPC, LPT modules and HPC modules that are close to their target lives. The likelihood of these engines still being in service with these original LLPs in situ, however, is small, but modules may exist in the used market place containing restricted LLPs.

There are parts in the HPC that are limited to 15,600EFC. Most HPT parts have lives close to the target of 20,000EFC, but some part numbers for the rear shaft are limited to 9,800EFC.

There are four sub-variants of the /P group of engines. Most part numbers for the fan disk have lives of 20,000-25,000EFC. All other part numbers in the fan/LPC module have lives of 30,000EFC. Similarly, all part numbers for LPT parts have lives of 25,000EFC. Most HPC part numbers have lives of 20,000EFC, but a few are limited to

CFM56-5B LLP LIST PRICES 2013

LLP	Cycle Limit	Cost-US$
Fan/Low Pressure Compressor		
Fan DisK	30,000	180,900
Booster Spool	30,000	263,600
Fan Shaft	30,000	131,000
High Pressure Compressor		
HPC Front Shaft	20,000	94,690
HPC Stage 1-2 Spool	20,000	135,600
HPC Stage 3 Disk	20,000	42,020
HPC Stage 4-9 Spoo	20,000	302,600l
Compressor Rear Air (CPD) Seal	20,000	57,450
High Pressure Turbine		
HPT Front Shaft	20,000	109,300
HPT Front Air Seal	20,000	228,400
HPT Disk	20,000	252,600
HPT Rear Shaft	20,000	45,268
Low Pressure Turbine		
LPT Stage 1 Disk	25,000	92,260
LPT Stage 2 Disk	25,000	106,900
LPT Stage 3 Disk	25,000	105,100
LPT Stage 4 Disk	25,000	93,430
LPT Shaft	25,000	189,600
Conical Support	25,000	124,400
Total cost for full LLP stack (USD)		**2,554,910**
Further high cost items		
HPT Blades /3 standard		800,000
LPT Blades /3 standard		870,540
1 Fan blade		30,849

17,200-18,200EFC. The HPT is the limiting module, with some part numbers having lives as short as 12,000-15,300EFC.

Removal intervals

The -5B series has not had to go through the same technical and material related trials as the -5A. The rapidly deployed technology developed for the GEnx in the /3 now means that the engine is truly mature.

CFM56-5B3/2/1

The highest-rated -5B3/3, with potentially 66 degrees of margin from new, operating in a benign environment could theoretically see the engine remain on-wing for 11,000-14,000EFC.

Recent OEM information estimates the first removal to be between 11,000EFC and 14,000EFC for the /P, and between 13,000EFC and 16,500EFC for the /3.

These estimates are based on typical take-off de-rate values and non-harsh environment operations. Conversely, a -5B3 operating in a high environmental OAT, typically accompanied with sandy conditions, can reduce the time on-wing. A freshly overhauled CFM56-5B3 operating in hot sandy regions may only achieve 2,500EFC before being EGT margin-limited.

Ricardo Correa, powerplant engineer at TAP Maintenance & Engineering, says that: “Since 2001 we have experienced a few problems with -5B3s, given TAP’s operation. The average flight ratio is about 2.0FH:FC, and average utilisation is about 1,800FC.

“Full performance loss is 11,000-14,000EFC with our utilisation, and this equates to 22,000-26,000EFH,” continues Correa. “At this point we typically remove these engines and re-rate them for use on the A320 and A319. This allows us to consume virtually all remaining LLP life.”

Re-rating increases the cost of the first shop visit, since the engine requires a full performance restoration after a longer interval. “The operator is left with an interesting choice,” says Tremblay. “LLP life variance between the core and LPT may drive an additional shop visit after the scheduled core restoration to perform LPT LLP replacement. Some operators, however, will replace the LPT’s LLPs, with 5,000-8,000EFC stub life remaining, at the core restoration shop visit to avoid this additional shop visit.

“LMCES offers different solutions to optimise the engine time on-wing and reduce the maintenance cost per EFH,” continues Tremblay. “Minimising LLP wastage is key when optimising engine maintenance management. Solutions may include module exchange to match core and remaining LPC/LPT life. LMCES may also replace modules on-wing to avoid costly engine lease and limit aircraft downtime.”

The elements of the cost of a shop-visit are labour man-hours (MH), new materials and parts, sub-contract repairs, and in house re-work and repairs. It can also include the repair of accessories.

There needs to be a fine balance between these elements for an engine to remain competitive.

Careful on-wing planning and re-rating allow the engine to run up to 15,000 EFC, where this removal is driven by EGT margin loss. The workscope for the shop visit will be to replace the core LLPs, so as not to limit the post shop visit time on wing to 5,000 EFC.

Labour for a core workscope is high at 3,000-3500MH, at a cost of $225,000-350,000.

The accessories for the engine are stripped and reconditioned or repaired as necessary. The accessories can form up to $250,000 of the shop visit cost.

The fan and LPT remain untouched, and little more than interface checks are required. Some light work may have to be carried out on the fan area if the blades have required any remedial FOD work in services such as blending.

HPC and HPT stacks are fully stripped and the LLPs removed. First run blades will need repair and re-coating as appropriate, but will be structurally suitable to be re-used for a second and possibly a third time. A 10% scrap rate of the blades accounts for a high portion of the $150,000-250,000 cost of new materials.

The balance of the shop visit cost of up to $1 million is divided between in-house repair, sub-contract repairs, new material handling fees for all externally-sourced new parts and LLPs, test cell fees, and miscellaneous items.

This takes the cost of the shop visit up to $1.6 million, and an additional allowance of $250,000 for materials *(see table, page 32)*.

The cost for HPC and HPT LLPs is $1,267,720 *(see table, page 32)*.

The second interval is limited to about 10,000EFC and a total time of 25,000EFC by the LPT’s LLPs. The second shop visit is heavier in terms of its workscope. This is because it calls for a performance restoration, and an overhaul of the LPT and fan/LPC modules to replace LLPs.

CFM56-5B SERIES SHOP VISIT MANAGEMENT & MAINTENANCE RESERVES

Removal	First	Second	Third
CFM56-5B3/2/1			
EFH:EFC ratio	1.8	1.8	1.8
Removal interval-EFC	15,000	10,000	10,000
Removal interval-EFH	27,000	18,000	18,000
Accumulated interval-EFC	15,000	25,000	35,000
Shop visit workscope	Core overhaul	Full overhaul	Performance restore
Shop visit cost-$	1,600,000	2,200,000	1,800,000
Material cost -$	250,000	600,000	1,600,000
Shop visit reserve-$/EFC	107	220	180
Material Reserves-$/EFC	16.67	60	160
LLP replacement	Core	LPT & Fan/booster	Core
LLP cost-$	1,267,720	1,286,690	1,267,720
LLP reserve-$/EFC	85	129	127
Total reserve-$/EFC	208	409	467
Total reserve-$/EFH	115	227	260
Average reserve -$/EFH, for three removals, including unscheduled shop visits	200	200	200
CFM56-5B4/7/6/5/8			
EFH:EFC ratio	1.8	1.8	1.8
Removal interval-EFC	20,000	10,000	10,000
Removal interval-EFH	36,000	18,000	18,000
Accumulated interval-EFC	20,000	30,000	40,000
Shop visit workscope	Core overhaul & LPT	Core restore & fan	Core overhaul
Shop visit cost-$	1,800,000	2,000,000	1,600,000
Material cost- $	250,000	1,300,000	600,000
Shop visit reserve-$/EFC	90	200	160
Material Reserves-$/EFC	13	130	60
LLP replacement	Core & LPT	Fan/booster	Core
LLP cost-$	1,979,400	575,500	921,000
LLP reserve-$/EFC	99	58	92
Total reserve-$/EFC	201	387	312
Total reserve-$/EFH	112	215	173
Average reserve-$/EFH, for three removals, including unscheduled shop visits	163	163	163

The core is still opened, because after 10,000EFC it will require a performance restoration to regain the tip clearances within the HPC and HPT that drive EGT margin recovery. The labour input for this shop visit is the highest at 3,600-4,000MH, equal to $270,000-400,000.

The HPC and HPT blades are repaired as necessary, although the number that require replacement due to condition is much higher after the second run. This explains the higher material cost associated of about $600,000 *(see table, this page)*.

Within the LPT, the scrap rate of blades and vanes is generally low. Corrosion and bearing deterioration are the main inspection findings. The majority of the repairs tend to be coatings and stationary seals.

The cost of materials in a fan/LPC workscope is heavily dependent on the number of fan blades that need to be replaced. Each one has a list price of $30,000-35,000. Other repairs and replacements can take the cost of materials in the fan/LPC up to $200,000. The fan case has been scrapped on occasion but most require some form of repair to the acoustic liners.

The shop visit's final cost depends on the combination of workscopes for the different modules once allowances have been made for sub-contract and in-house rework. Excluding LLPs, the expected cost of this shop visit is high at about $2.2 million, plus the $600,000 allowance for materials *(see table, this page)*.

The LLPs within the LPT are exhausted at 25,000EFC. These are replaced at a list price of $711,690.

The fan/LPC LLPs are replaced at a cost of $575,500. Total LLP replacement costs are $1,286,690 *(see table, this page)*.

The fan LLPs could possibly be retained for use in another engine within the fleet, or could be sold to offset the cost.

The third shop visit is almost identical to the first. The core is overhauled, and new LLPs are required.

After potentially 35,000EFC it is likely that the combustion chamber is going to require replacement or the cases of the HPC may suffer from the VSV aperture elongation. An allowance for this has been made within the materials costings which total at $1,600,000 *(see table, this page)*. This includes a full set of new /3 HPT blades at $800,000, the likelihood of a new combustion chamber, and HPC airfoils.

The other costs of labour, accessories, in-house and sub-house, and other costs can reach up to $1.8 million *(see table, this page)*.

All LLPs in the HPC and HPT are replaced. These have a 2013 list price of $1,267,720 *(see table, this page)*.

CFM56-5B4/7/6/5/8

The lower-rated -5B4, and other A320 and A319 engines, have high enough initial EGT margins to remain on-wing up to the limits of core LLP for the first removal interval at 20,000EFC.

Mechanical deterioration problems start to emerge, however, after about 15,000EFC. Contact between the rotors and stators in the HPC, due to VSV bushing attachment wear occurs.

This can wear through the interstage seal, releasing debris into the gas path. Borescope inspections can keep engines on-wing until shop visit.

CFMI has brought out workscopes and improvements that replace the plastic VSV bushings with metal ones. Glenford Marston, technical manager, at Aero Gulf SOLA engine facility says that in its experience it is better to continue using the plastic VSV inserts, and run the risk of potentially having to perform a top case repair in service. This is because when the cores were broken down for a shop visit, the metal inserts would fret, elongating the VSV apertures. The cost of replacing the compressor case is higher greater than top case repairing an engine to replace the plastic inserts.

Aircraft with a short EFH:EFC ratio of 1:1 in the low-rated engine variants have enough EGT margin to reach the planned removal interval of 20,000EFC. Engines operating at 2.0EFH:EFC have fewer problems reaching 20,000EFC.

The workscope for the first shop visit is to replace the core LLPs. It is also to replace the LPT LLPs so as not to limit the post shop visit time on-wing to 5,000EFC.

Once the core is removed, the HPC and HPT stacks are fully stripped and the LLPs removed.

The first run HPC and HPT blades will need repair and re-coating as appropriate, but will structurally be suitable to be re-used for a second and third time. This is because of the lower

CFM56-5 engines progressing through overhaul at Iberia Maintenance, in Madrid. Iberia has large in-house repair capability for the CFM56 family.

thermal stresses compared to the -5B3/2/1. It is prudent to allow for a 10% scrap rate of the blades in inspection and during repair, since they form a large proportion of the $150-250,000 of new materials for this shop visit *(see table, page 32)*.

The accessories for the engine are stripped and reconditioned or repaired as necessary. The accessories form up to $250,000 of the shop visit cost.

The remainder of the shop visit cost is divided between in-house repairs and subcontract repairs. The overall cost of this workscope is similar to the first shop visit for the -5B3/2/1 engine, except that this lower-rated engine will include a scope for the LPT. The total cost is therefore about $1.8 million *(see table, page 32)*.

HPC, HPT and LPT LLPs will all be replaced at a cost of $1,979,410 *(see table, page 32)*.

The fan/LPC LLPs limit the second interval to 10,000EFC *(see table, page 32)*. This will take total accumulated time at the second removal to 30,000EFC.

At this second shop visit, a workscope of a core performance recovery. An overhaul and LLP replacement of the fan/LPC is also needed.

No LLPs are replaced within the core, but the core is still opened. After a cumulative life of 30,000EFC the HPT blades are likely to require replacement on condition at a cost of $800,000.

The HPC blades are repaired as necessary, though the number that require replacement due to condition is much higher at this shop visit. The associated material cost is therefore potentially $1,300,000 *(see table, page 32)*.

The labour costs for this shop visit are the most expensive at 3,600-4,000MH, equal to $270,000-400,000.

The cost of materials in a fan/LPC workscope depends on the number of fan blades that need replacing. Each one has a list price of $30,000-35,000.

Other repairs and replacements, such as repairs to the acoustic liners, in the fan/LPC can take the cost of materials up to $200,000.

The shop visit's final cost depends on the combination of workscopes for the different modules once allowances have been made for subcontract and in-house rework. The expected cost of this shop visit, not including the material costs for the core, is about $2 million *(see table, page 32)*. The cost of fan/LPC LLPs is $575,500.

The interval to the third removal is driven by the life limits of the core LLPs installed at the first shop visit. This will be about 10,000EFC, but depends on the second removal interval.

The third shop visit is almost identical to the first, although because the engine is now about 20 years old. The operator is unlikely to replace the LPT's LLPs, unless required by a lessor.

After this shop visit, the fourth removal interval will be limited to 5,000EFC by the LPT's LLPs installed at the first shop visit. An airline has a choice at the third shop visit of including the LPT in the workscope, or later replacing it on-wing with a time-continued unit acquired from the aftermarket.

The core is overhauled in the third shop visit, and new LLPs are required throughout.

The HPC may suffer from the VSV aperture elongation an allowance for this has been made within the materials costing's which total at $600,000 *(see table, page 32)*.

The remaining total cost of the workscope, without the LPT change, is about $1.6 million *(see table, page 32)*.

The cost of HPC and HPT LLP replacement is in 2013/14 list price is $1,267,720 *(see table, page 32)*.

Unscheduled removals

Unscheduled removals fall into several categories. The first two main types are engine-related and non engine-related. Engine-related removals are forced by the failure of engine hardware, and are further sub-divided into light and heavy visits following removal.

Non-engine-related removals will be due to events such as foreign object damage (FOD) and birdstrikes. These will have a similar shop-visit workscope and cost to heavy removals.

Light visits do not interrupt planned removals and removal patterns, so they can be considered separately. Light visits will usually involve incidents such as oil leaks, and will incur a shop visit cost of up to $300,000.

Heavy and non-engine-related visits should be considered together because they incur shop-visit workscope costs, interrupt the schedule of planned removals and shop visits, and also reduce the average planned removal interval. Heavy visits can be the result of an event such as a bearing failure, which can incur some of the highest shop visit costs, and exceed more than $2 million.

All unscheduled removals occur at an average of once every 30,000EFH. An average cost of $250,000 would mean that a reserve of about $9 per EFH should be added to the reserve for planned removals.

Heavy and non-engine related events occur on average once every 70,000EFH. An engine, for example, with an average planned removal interval of 17,500EFH would therefore see an unplanned heavy shop visit once every four shop visits.

The randomness of these unplanned heavy events, however, means that they can occur shortly before a planned event or halfway between planned events, thereby reducing the average planned interval, rather than adding a full additional shop visit.

Summary of reserves

The reserves for the main shop-visit inputs and LLPs expressed in $ per EFC must be converted to equivalent rates in $ per EFH at the appropriate EFH:EFC

CFM-powered A320 TAP departing from a snowy airfield. Low OATS will help maximise TOW, allowing the highest de-rate to be applied.

ratio. These are shown as average reserves for all costs amortised over the three intervals, an allowance for quick engine change (QEC) line replaceable unit (LRU) component repairs, and an allowance for the engine having a low cost unplanned removal.

High-thrust variants have higher reserves at $200 per EFH, in comparison to the $163 per EFH for the lower-rated variants *(see table, page 32)*.

High-rated variants have higher reserves due to their overall shorter on-wing lives of about 5000EFC/9000EFH, and total costs over the interval being higher by about $864,000.

The reserves for the CFM56-5B3/2/1 accumulate a surplus of $728,000 over the three intervals and their associated costs. As described, this is to cover the cost of low-cost unplanned removals and LRU repairs.

Reserves for the low-rated variants are broken down in the same way. The time on-wing is longer. This increases the costs of the repairs, but this allows more reserves to be accumulated.

As with high-rated engines, the calculated reserve accrued over the three intervals leaves a surplus for several items. This is about $710,000.

It is critical to accrue reserves uniformly across the whole term. The temptation is for operators to collect reserves to cover just the upcoming shop visit. The problem is the second and third intervals are half as long so the cost per EHF doubles in comparison.

Reducing shop visit costs

The biggest removal driver for the high thrust CFM56-5B variants is loss of EGT margin and mechanical deterioration. With the introduction of the /3 tech insertion engines, the EGT margin deterioration has improved. This has had a trade-off against FOD resistance, however, according to Marston. He has seen a large proportion of engines come through from northern Europe where the low OATs really help to maximise the removal interval. His reasoning for this is that the engines are operated out of airports with salt gritting on runways during the long winters. Because of salt gritting, corrosion and FOD incidents are more likely to cause an engine removal, however. This has to be planned for with an extensive washing programme to ensure corrosion does not take hold.

In high pollutant environments compressor washing is just as critical, especially in places such as Italy and the emerging markets where air pollution is a problem. This is becoming a bigger challenge in Europe for example where there are strict rules on wastewater and effluent. Gone are the days of a line mechanic with a hose in front of an engine, while the engine is being turned over on the starter. Specialist companies which trap all the water and then dispose of it through the appropriate waste regulations have emerged, but their cost means that any benefits have to be carefully weighed up against the cost of the operation itself.

The use of PMAs

Shop visit inputs are largely dominated by the cost of parts and materials, and to a lesser extent by sub-contract repairs, which also include an element of material cost. OEM list prices generally increase at a rate higher than inflation.

The fan booster module in the LLP cost $375,000 in 2007, and was $575,000 in CFMI's 2013 list price, a 65% increase over seven years.

Some operators have sought to circumvent this cost by using parts manufacturing approval (PMA) components and materials. The main two PMA providers are HEICO and Chromalloy.

HEICO offers many types of PMAs, including the blades and vanes for the CFM56. In addition, HEICO offers PMA fan exit guide vanes and rotating airfoils. Capabilities cover both the hot and cold section blades in the turbine and compressor. Belac, a Chromalloy company, currently offers HPT airfoils at list prices up to 40% less than the equivalent OEM parts and on-wing performance reportedly exceeds the OEM offering in terms of scrap rates at in shop-visit inspection.

The reluctance to use PMAs largely comes from the asset value drop from the lease market perspective. While PMAs are attractive to large operators with total ownership, smaller operators, which may look to pass on the engines after only one overhaul cycle, are less likely to be interested in this cost saving.

Summary

The CFM56-5B's maintenance costs, in terms of LLP reserves and workshoping, have been examined. They have been equated to maintenance reserve rates per EFH and EFC.

Reserves are influenced by EFC removal intervals, which in turn are influenced by LLP lives and EGT margin. High-rated -5B engines therefore have reserves that are higher than lower-rated engines. This is because the intervals of lower-rated engines are compromised to a degree by the core engine LLPs with lives of 20,000EFC.

Mature CFM56-5Bs will continue to have removal intervals of 10,000EFC, due to LLP limits. The benefits of the /3 tech insertion engines are the much longer first intervals, where full LLP life can be truly realised on the low thrust -5Bs. Shop-visit data for the /3 confirms CFMI's claims for longer on-wing life.